Virtual Reality Technologies for Health and Clinical Applications

Albert "Skip" Rizzo
Stéphane Bouchard *Editors*

Virtual Reality for Psychological and Neurocognitive Interventions

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Virtual Reality Technologies for Health and Clinical Applications

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Albert "Skip" Rizzo is a Clinical Psychologist and Director of Medical VR at the University of Southern California Institute for Creative Technologies. He is also a Research Professor with the USC Department of Psychiatry and School of Gerontology. Over the last 25 years, he has conducted research on the design, development, and evaluation of virtual reality systems, targeting the areas of clinical assessment, treatment, and rehabilitation across the domains of psychological, cognitive, and motor functioning in both healthy and clinical populations. This work has focused on PTSD, TBI, autism, ADHD, Alzheimer's disease, stroke, and other clinical conditions. He has also driven an extensive research program on the use of intelligent virtual human agents for clinical training, healthcare information support, and clinical assessment. In spite of the diversity of these clinical R&D areas, the common thread that drives all of his work with digital technologies involves the study of how virtual reality simulations can be usefully applied to human healthcare beyond what's possible with the traditional twentieth-century methods. To view some videos on his work, go to https://www.youtube.com/user/albertskiprizzo.

Stéphane Bouchard holds the Canada Research Chair in clinical cyberpsychology and teaches psychotherapy and cyberpsychology at the Université du Québec en Outaouais in Canada. As a Scientist-Practitioner, his current research projects involve developing virtual environments to treat complex anxiety disorders and pathological gambling, leading randomized control trials on the efficacy of in virtuo exposure for mental health disorders, and conducting experimental studies to understand why virtual reality is an effective treatment tool. Another prolific area of expertise is telepsychotherapy, where he conducts randomized control trials and processes studies on the efficacy of delivering cognitive behavioral therapy in videoconference. His research lab holds Psyche, the only six-sided total immersion virtual reality system dedicated to mental health research. He has received more than 12 million dollars in research funding, has published more than 150 scientific articles and book chapters, delivered hundreds of scientific communications around the world, and is actively collaborating with researchers from around the globe. He is also the President of Cliniques and Development In Virtuo, a company that distributes virtual environments to mental health professionals. To view some videos on his work, go to https://vimeo.com/videosvr.

Chapter 1
Applications of Virtual Reality in Clinical Psychology and Clinical Cognitive Neuroscience–An Introduction

Stéphane Bouchard and Albert "Skip" Rizzo

Simulation technology has a long history of adding value in aviation, military training, automotive/aircraft design, and surgical planning. In clinical psychology, Norcross et al. (2013) surveyed 70 therapy experts regarding interventions they predicted to increase in the next decade and virtual reality (VR) was ranked 4th out of 45 options, with other computer-supported methods occupying 4 out of the top 5 positions. The increased popularity of VR in the news, social media, conferences, and from innovative start-ups may give the impression that VR is something new. However, it is important to look back in time and recognize that as early as the 1960's, Heilig proposed a multisensory immersive experienced called the Sensorama, and Sutherland and Sproull had created a stereoscopic head mounted display (HMD) (Berryman 2012; Srivastava et al. 2014). The term VR was coined more than 30 years ago by Jaron Lanier and commercial games were distributed to the public as early as 1989 by Mattel (in the US, and by PAX in Japan) for its PowerGlove™ and Nintendo's failed Virtual Boy™ was released in 1995. Clinical VR applications were proposed as early as the mid 1990's by Lamson, Pugnetti, Rothbaum, Riva, Rizzo, Weiss, and Wiederhold (named in alphabetical order), among others. Moreover, several scientific journals, conferences, and handbooks dedicated to the subject have been reporting scientific findings for decades.

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In this recent age of affordable HMDs and software dedicated to building virtual environments, it is tempting to think that all this technology is brand new and anyone with a good idea can make and market clinical tools. However, the development of clinical tools without the guidance of both scientific knowledge and clinical expertise can, unfortunately, lead to the production of ineffective applications, or even worse (Rizzo et al. 2004). This book aims to provide readers with chapters written by longstanding experts in the field of Clinical VR that presents scientific evidence on what works for whom and under which conditions in the field of mental health and neuropsychological science. Therefore, the objectives of this chapter are threefold: contextualize the use of virtual reality within the broad scope of the current scientific literature, provide basic information and definitions that will be helpful when reading this book, and link the different chapters in this book to the general information presented.

VR applications can be conceptualized on a continuum (Milgram and Kishino 1994), from the physical to a virtual reality, passing by a series of mixed realities that include augmented reality and augmented virtuality (see Baus and Bouchard 2014 for visual illustrations). Fuchs et al. (2011) provided a definition of VR that is interesting because it is not based on, or limited by, a specific piece of technology. They define virtual reality as the use of computer and behavioral interfaces to simulate the behavior of 3D entities that interact in real time with each other and with a user immersed via sensorimotor channels (Chap. 2 will provide more elaborated examples). Mixed realities refer to the combination of physical and virtual stimuli that are integrated within a common sensorimotor channel. In augmented reality, the user perceives the virtual stimuli as combined realistically and interacting with the physical reality, often via some sort of visual display that allows 3D graphics to be overlaid onto the perception of the real world. By contrast, in augmented virtuality the user perceives the physical stimuli as realistically combined with what appears visually in the virtual reality, such that they can interact with physical objects that are tracked and rendered in the virtual world. These definitions become useful in several instances. For example, "virtual therapy" is a misnomer because treatment using virtual reality are *real* treatments. It is the stimuli used in therapy that are virtual, not the treatment. Visually, augmented reality is the opposite of augmented virtuality. In augmented reality, the majority of stimuli perceived by the user comes from the physical reality (e.g., in augmented reality, a virtual spider could be displayed on a smartphone screen while the camera is actually showing the user's real hand, with the combined image giving the impression the spider is actually on the user's hand). In augmented virtuality, the majority of the stimuli are virtual while the physical ones are added to enhance the elements of the experience (e.g., the user immersed in VR can see the physical table appearing in the virtual environment as he or she approaches this table before hitting it in the living room or similarly, a fan could be used to blow air on a user to match virtual wind effects).

Another interesting question concerns whether video games can be considered virtual realities? Since VR is not defined simply by the immersive properties of the system, video games can indeed meet the definition of VR. However, the person playing an interactive 3D game on a flat-screen computer monitor, or on a smartphone, may be much less immersed in the synthetic stimuli than when using a

HMD. Immersion is not a psychological state; it refers to the properties of the system. Similar to plunging a hand in water, immersion in VR refers to being surrounded by a flow of virtual stimuli. Thus, a HMD that occludes the view of the surrounding environment and updates the virtual perceptual content, contingent on user head movement, is more immersive than a flatscreen computer monitor. Moreover, by exposing the user to multisensory modalities (visual, auditory, haptic, olfactory), the system can also become more immersive. Note however that a user can be extremely focused and/or experience very strong emotions in conditions that are not very immersive, such as playing a competitive game on a smartphone. Conversely, users can become bored and detached in very immersive conditions if the VR content is poorly constructed or irrelevant to the user.

The coming of age of VR was not a simple and linear process. Several technologies have attracted the attention of researchers and clinicians over the years. The VR systems of the early 1990's were bulky, required very expensive computers and were not always user-friendly. For a while, very large immersive rooms were considered the future of VR. Distributed under the trademark CAVE (the acronym stands for Automated Virtual Environment, with a C added to create a "recursive acronym" referring to the Allegory of the Cave by the Greek philosopher Plato, Cruz-Neira et al. 1992), stereoscopic images were projected onto walls and motion trackers were used to adjust the image relative to the user's position and distance from walls. CAVEs and their variations were long considered the ideal technology for immersing people in VR as they could provide life size stereoscopic images visible from almost the full natural field of view. Within a CAVE, the seamless match between walls allowed objects to float in the air and, as the physical walls recede from perception, users could see their own body interacting with the virtual stimuli. Given sufficient physical space and budget, CAVE installations could include a rear projected floor and ceiling to induce complete immersion by providing images coming from every direction. However, while the technology is compelling for creating the illusion of presence or for representing/visualizing a very large mass of complex data, this technology is not without its drawbacks. CAVEs require a lot a physical space, are extremely costly to build and maintain, and remain relatively complex to operate. Moreover, many studies reported in this book illustrate that more affordable technology using a HMD or only one stereoscopic projector can lead to clinical improvements similar to or equivalent to CAVEs.

The affordable alternative to the CAVE was the HMD. Immersive VR produced by HMDs allow users to operate in a computer-generated simulated environment that changes in a natural or intuitive way with head and body motion. With HMD technology, the headset occludes the user's view of the outside world and the motion trackers sense the user's position and movement and sends that information to a computer that updates the sensory stimuli presented to the user in near real-time, contingent on user activity. Unlike HMDs available today, the visual quality of early systems was lacking (e.g., low resolution, slow framerate, limited field of view) and finding and integrating compatible hardware and software was a real concern. For a long time, HMDs were mostly built and sold separately from the motion trackers required to detect changes in head orientation and position. Interaction required the use of additional wearable tracking devices and this integration of various peripherals was far from user-friendly back in the early days of HMD implementation. Consequently, the public became disenchanted with the quality of a typical HMD VR experience around the mid-1990s. At that point, VR was generally viewed as a failed technology in part due to the wide gap between the promise or vision of VR and what the immature technology of the day could actually deliver. Despite these challenges, pioneers in the field continued to pursue the Clinical VR vision and laid the foundations for the majority of studies reported in this book. It has only been over the past 4–5 years that the technology for creating and delivering good VR has caught up with vision of creating compelling experiences for healthcare applications. For example, significant financial investment in HMD enabling technologies have occurred recently which has driven innovation and has led to the launch of many affordable HMDs dedicated to VR and augmented reality, many with built-in motion tracking, high fidelity visual displays, and large distributions outlets for the general public. While most HMDs are still tethered to computers, an emerging VR trend can be seen in the growing availability of "standalone" or wireless HMDs, using onboard computing or smartphones to process and render the virtual environment and the capability for delivering stored or streamed online content. These new developments are very exciting, but they are also a moving target, creating challenges for researchers and clinicians who now need to regularly update and adapt to rapidly evolving technological options.

Several lessons were learned from the transition in popularity from CAVEs to HMDs and other affordable technologies. One lesson involves the recognition of the difference between the needs of the entertainment industry and those of mental health professionals and patients. In the entertainment industry, it is important to powerfully engage audience attention and avoid factors that would reduce the quality of the user's experience. In this context, realism is very important. However, contrary to common expectations, realism is not always important in clinical VR. As well, a high level of realism comes at a price in terms of hardware capabilities and software development costs. Of course, high fidelity realistic virtual environments are more enticing, interesting to interact with, and have more credible face validity. But how much realism is necessary or enough to achieve a specific aim? Is the realism of the images more important than the realism of the context or interactive responsiveness of the virtual environment in which the user is immersed? For example, when training aircraft pilots in aviation simulators, having a beautifully rendered and realistic view when flying over a town is much less important than the realism and fidelity of the interaction with relevant indices that signal the plane is experiencing mechanical difficulties, fuel is running low, the airport is shrouded in fog, or another plane is on a direct collision course. Operating in such a VR training system under realistic parameters is crucial for skills acquisition while the pictorial realism of the sunset is secondary. By contrast, if a user immersed in VR is to experience and becomes emotionally touched by the breathtaking view of the Great Pyramids, high realism may be necessary. Such an immersive experience may require impressive graphics, spatialized sound, the feeling of temperature changes contingent on the position of the sun, and the olfactory cues that would come from smelling the ambient air, etc. If the same environment is used to teach children to learn the list of the Seven Wonders of the Ancient Word, the goal may be reached with more modest means. Similarly, if the same environment is used to help snakes phobics conquer their fear, even less details are required, and sometimes only the assumption that there *may* be snakes in the virtual environment is sufficient to produce a significant emotional impact (Bouchard et al. 2008). In the area of VR for pain management, if the virtual environment is used to distract the user from painful stimuli (as described in Chap. 8), the engagement of the user's attention with good interactive game content to provide distraction from nociceptive stimuli is more important than the realism of the experience. While current technology has given us the capability to create hyper-realistic VR content, developers need quality research to help guide decisions as to where resources should be distributed for other system components to make a stronger contribution to clinical effectiveness.

Spherical or 360 degree cameras are now commonplace, low cost, easy to use, and support the creation of highly realistic immersive images or videos of an actual physical environment that can be easily rendered in a HMD. This can be a very efficient solution for increasing pictorial realism by reducing the costs of creating 3D graphics to recreate that physical world in a virtual environment. However, this approach to content creation comes at the expense of user interaction, as users cannot explore the environment and interact with it at will, beyond basic head turning. The key question becomes whether interaction and user initiated control are important in the clinical application and a determination of the cost/benefit issues for the creation of highly realistic 3D graphic content. In sum, the question of how realistic and expensive a VR system should be must be addressed by first considering the specific and precise needs of clinicians and patients. The rest are extras.

VR has many specifiable properties that contribute to its value as a compelling tool for creating scientifically sound clinical applications (Rizzo and Koenig 2017) and the chapters in this book describe a wide spectrum of Clinical VR approaches. The added value of VR can be seen in the technology's capacity to create standardized (or customized) stimulus environments that can be used to produce emotionally evocative therapeutic experiences (as shown in Chaps. 3, 4, 5, 6 and 7 of this book). Such virtual experiences can replicate the physical reality under more controlled or affordable conditions (illustrations of this are found in Chaps. 10, 11 and 13, among others) and can reproduce complex interactions at will (consider the chapters on autism (Chap. 10) and on clinical training (Chap. 17) as relevant to this). Moreover, VR can provide multisensory opportunities useful for promoting learning and transfer of skills (as exemplified in Chaps. 13, 16 and 17), and which may appear more attractive to patients than traditional alternatives (as illustrated in the chapters on anxiety (Chaps. 3, 4 and 5) and related disorders). Physical activity can be precisely tracked, recorded, and analyzed to study human performance and behavior thanks to the real time interactions that define VR (see Chap. 10 on assessing sexual interests or Chaps. 11, 12, 13, 15 and 16 on neurocognitive assessment/interventions). Emotions can be evoked to help patients cope with them, as shown in Chap. 6. Cognitive challenges can be designed to test and exercise specific brain functions that need training to improve information-processing capabilities, as described at length in the four chapters dedicated to neuroscience and neuropsychology (see Chaps. 11, 12, 14, 15 and 16). Environmental factors can also be manipulated to practice skills at increasing levels of difficulty as performance improves (for examples, see Chaps. 3, 5, 12, 16). Artificial intelligence programs can further assist mental health professionals by way of the integration of a wealth of information that can guide interventions in real time, as described in the closing chapter of this book. Much like a manikin simulator serves to test and train doctors under a wide variety of controlled conditions, VR can be used to create relevant simulated environments where the testing, training, teaching, and treatment of cognitive, emotional, and sensorimotor processes can take place under stimulus conditions that are not easily deliverable and controllable in the physical world (as detailed in Chap. 9).

Regardless of the technologies used to create a virtual reality experience, one of the central aims is to create the illusion of being “in” the virtual environment, also referred to as the feeling or sense of *presence* (Heeter 1992; see also Chap. 2). The expression comes from the literature on teleoperation systems (Minsky 1980), where remote operators felt as if they were in the location of the remote robot. Many theories have been proposed to explain presence in VR and there is no simple consensus regarding its definition, how to measure it, its additive value, and its relevance to clinical applications. Slater (2009) proposed an interesting approach to presence. Users can feel the illusion of plausibility (i.e., the virtual stimuli are felt as if they were real) and the illusion of place (i.e., the users feels they are somewhere “in” the virtual environment other than in the physical space where the immersion is conducted). These two illusions are based on the integration of multiple sensorimotor channels that are contingent, coherent, and provide a sense of agency in the user. This approach allows one to consider the feeling of presence as a perceptional illusion, where the user is no longer aware that stimuli are produced by media technologies (Lombard and Ditton 1997; Riva et al. 2014). Again, in spite of the technical approach, the key aim of immersive systems is to perceptually replace the outside environment with the virtual environment in a way that psychologically engages users with simulated digital content designed to create a specific user experience.

Although inducing strong illusions of plausibility and place are laudable objectives, it is not always essential in clinical applications. In instances where the goal is to practice a skill (as described in Chaps. 10, 12 and 16), it is often more important to have an experience in the virtual environment that addresses the right targets and allows adequate training to occur. For example, in a cognitive remediation exercise where the user has to interact with or rotate objects to improve visuospatial skills, the illusion of being on a beach or a mountaintop or in an office wearing a funny pair of glasses is less relevant. What really matters is that the required skills are practiced and learned regardless of the context. Similarly, in a motor rehabilitation task where the user has to relearn walking skills, the perception of a treadmill or the graphic realism of the content projected on a widescreen display is less important than the method for getting a user to engage in the training activity. In this case, the primary aim is to create a system that supports and encourages practice of the correct skills for walking, maintaining gait, and avoiding obstacles. However, in either of the above examples, efforts to increase user presence may become relevant when the user must practice the skills in progressively challenging situations that represent everyday challenges in varied contexts (e.g., workplace or leisure environments or in emotionally stressful social interactions with virtual characters) (see Chaps. 11, 12, 14, 15 and 16 on cognitive neuroscience). In psychotherapy sessions where VR is used to treat anxiety disorders, as described in Chaps. 3, 4 and 5, what matters is that patients are exposed to and engage with emotionally charged experiences in order to develop new mental representations of the anxiety-evoking stimuli that eventually become associated with reduced threat (Bouchard et al. 2012). While the specific goal may not be for the user to feel present, the absence of presence may cause the user to *not* react with fear to the virtual stimuli. In this instance the intensity of the fear reaction is not a key factor in treatment success, it is an indicator that some conditions are met to allow inhibitory or extinction learning to take place. The key treatment mechanism for addressing anxiety disorders is to develop new associations with safety; presence, anxiety, and other psychological factors such as the therapeutic bond are unreliable predictors of treatment outcome, yet they remain necessary conditions (Tardif et al. 2019). Moreover, the relationship between anxiety and presence may not be linear (Bouchard et al. 2012). As illustrated in Fig. 1.1, it is possible that the relationship between anxiety and feeling present in VR follows a pattern where in the lower end of the presence continuum, a slight increase in presence may have a strong impact on the potential for VR to induce anxiety. However, after some point additional increases in presence have a very small incremental impact on anxiety. Because increasing presence in the higher end of the continuum comes at a significant cost, the investment may not be that important for clinicians.

The power of VR and augmented reality to create transformative experiences also applies to virtual characters, as documented in Chaps. 2, 13 and 17. First, let's specify the difference between *virtual humans*, which are synthetic representations of humans in VR; *avatars*, which are the representations of a physical person using it to interact within a digital environment (it can be a virtual human, but also a virtual animal or a fictional creature); and *autonomous agents*, which are virtual characters controlled by computer programs and algorithms. Users of immersive technologies have reported a sense of social presence when interacting with virtual humans. Numerous studies conducted by Blascovich, Bailenson and others have shown that principles of social psychology established in physical reality also apply to interactions with virtual humans and other virtual characters (see Chap. 2 for illustrations). Users engage in relations with virtual characters in ways that are very

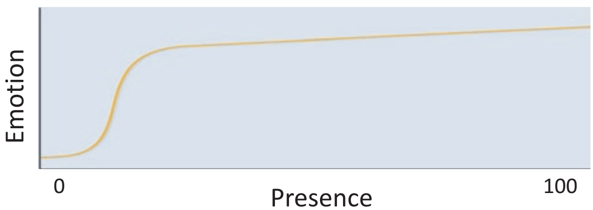

Fig. 1.1 Illustration of a hypothesized non-linear relationship between anxiety and presence

consistent with their usual behaviors (Chap. 9 provides an interesting illustration with the assessment of sexual preferences). Clinical applications involving social interactions, social neuroscience, social skills training, gender issues, sexual preferences, paranoia, and even empathy can thus put immersion in VR to good use. Researchers can now gather psychophysiological data such as eye-tracking, heart rate, and EEG to analyze the behavior of users engaged in long and complex social interactions. Some fascinating studies have gone as far as creating the illusions of being in the body of someone else (e.g., Blanke 2012), of having three arms (e.g., Stevenson Won et al. 2015), or of sharing the experience of being the victim of aggressive behaviors (e.g., Slater et al. 2010). The presence of autonomous agents can enhance the experience felt by users in VR. For example, not feeling alone in a virtual environment is reassuring for some users, and the credible occurrence of natural reactions by an autonomous agent to the presence of the user (e.g., eye-gaze pattern) can facilitate empathy. As well, being watched by virtual humans can elicit strong reactions in users that are dissatisfied with their body image (Chap. 7). Autonomous agents may even begin to take the place of clinicians in certain instances. Powered with strong artificial intelligence algorithms, and sometimes the additional input from emotion recognition software and psychophysiological measures, autonomous virtual humans have been tested that can coach patients when they engage in therapeutic exercises, provide limited counseling input, deliver psychotherapy sessions, or be used as virtual patients for the training of novice health professionals, as shown in Chap. 17. Using autonomous virtual humans as therapists should not threaten human clinicians. Automated clinical interventions provided by virtual characters can increase access to care in situations where human clinicians are not available (e.g., long duration spaceflight, war zone) or cannot provide specific evidence-based treatments (e.g., Freeman et al. 2018). Clinical work delivered by humans clinicians can also be combined with the use of autonomous virtual humans (e.g., when patients have to practice skills at home), or augmented by the input from the autonomous agents, their sensors, and their artificial intelligence algorithms (e.g., human therapists using augmented reality to receive suggestions from autonomous virtual co-therapists during a session with a patient). Finally, in some cases, what needs to be empirically documented is the added value of autonomous virtual therapists over being a fancier and more attractive version of bibliotherapy. For many mental disorders, reading self-help books (Gualano et al. 2017) or engaging in computer-based psychotherapy has been shown to be effective (e.g., Andrews et al. 2018). However, adding minimal human contact has been shown to improve treatment efficacy. Also, these treatments are effective for some patients but may not be for others due to several factors, including treatment complexity and motivation (e.g., Baumeister et al. 2014; Haug et al. 2012).

The clinical use of VR is not without potential drawbacks and should not be seen as a panacea for all patients and clinical targets. The most notorious are unwanted negative side effects induced by immersion in VR, commonly referred to as cybersickness. Several factors can contribute to these unwanted negative side effects (Sharples et al. 2014). Some causes are completely under the control of the health care professional using VR, such as a HMD strapped too tightly on the user's head or the conduct of immersive sessions that last long enough to cause oculomotor strain. Other side effects share many similarities with motion sickness and are induced by incongruent information from the visual sense, the inner ear, and proprioception, sometimes due of delays or lag in matching head movements with the corresponding visual scene. Most users will report minor and brief symptoms of cybersickness, very few will have intense reactions, and a few report no side effects at all. Cybersickness can be easily managed if professionals exclude users that are hypersensitive to motion sickness, pay attention to them during the immersion, and follow some simple post-immersion procedures. However, the literature on unwanted negative side effects induced by immersive VR is not without controversies. Studies have shown occurrences where users report *more* symptoms before than after the immersion in VR, or report the appearance of symptoms after a stressful task that involves no VR at all (Bouchard et al. 2011; Reger et al. 2018). Indeed many symptoms currently associated with cybersickness are also symptoms of anxiety, stress or cravings that come from the task performed in VR and not the VR per se. Another potential consequence of using VR is the risk of addiction. It is doubtful that phobic or schizophrenic patients immersed in VR to overcome their fears or delusions will develop an addiction to these stimuli. However, some users of VR may prefer to engage in intimate relationships with virtual humans compared to physical ones, especially with the increasing popularity of VR pornographic sites and teledildonic computer peripherals. As with any new technologic tool intended for use by humans, careful research is needed to document side effects and unintended consequences with an aim toward managing them to promote user safety.

Another lesson learned over the years is that VR and AR should not be used by clinicians "just because it can be done". There are recurrent cycles of interests in the use of technological innovations, and immersive VR technologies are currently in fashion. The design of technological tools worth using in clinical practice must be based on informed theoretical grounds (e.g., in the case of pain distraction, Chap. 8) and careful needs assessment requires user feedback from clinical scientists, practitioners, and patients (as shown in Chap. 16).

Currently, there is no regulatory systems or set of criteria to evaluate clinical VR applications. In medical research, for example, the development of a new treatment follows a broadly accepted sequence, starting with preclinical work on non-human subjects and Phase 0 studies for understanding the pharmacokinetics of a drug. Phase I studies usually follow, with testing on large samples of healthy volunteers to document the safety of the drug. The parallel with research on the clinical applications of VR may be studies documenting the effects of immersion in VR per se, such as using HMD or best-practice guidelines to improve health and safety issues (e.g., Fuchs 2017). The "real" clinical tests begin with Phase II, where the first signs of clinical efficacy are tested on large number of participants very well diagnosed with a specific disorder. Weaker research designs are tolerated at this stage. Then comes the Phases III studies, consisting of randomized control trials with hundreds of volunteer patients randomly assigned to the experimental treatment and to control conditions (such as, in increasing order of strength, remaining on a waiting list, receiving a placebo, receiving "the usual" treatment, or receiving the current gold standard treatment), with follow-up assessments, several controls of potential biases, reporting of side effects, etc. To claim efficacy, the findings have to be replicated in more than one independent trial of the exact same treatment. The trials are expected to adhere to the highest standards, such as the CONSORT guidelines for clinical trials, non-pharmacological interventions, of non-inferiority and equivalence trials, etc. (http://www.consort-statement.org). Finally, Phase IV could be conducted to document effectiveness, to better understand the treatment mechanisms and its predictors, or explore innovative ideas that are not addressed by Phase III trials. For assessment tools, the traditional psychometric properties are expected to be met, along with provision of information about sensitivity, specificity, construct and convergent validity, and relevant normative data. Although VR tests are often expected to provide greater ecological validity than traditional methods, researchers must rule out the possibility that the observed results could be explained by the use of VR itself (e.g., the poorer performance of older compared to younger adults on a VR memory task is not related to anxiety about technology or lack of experience in using new technologies). Regulatory agencies such as the Food and Drug Administration in the USA, the European Medicines Agency in Europe, the Health Products and Food Branch in Canada, or the Therapeutic Goods Administration in Australia, usually examine new clinical tools based on the above criteria. However, the development of clinical applications of VR did not follow traditional paths and these rules do not always apply. For example, drugs are based on formulas that are strict, cannot be changed at all, and protected against copies under copyright laws and regulations. The performance of VR applications may change with improvements in hardware technology, the visual content may be improved with software updates or the availability of new shaders (for example), and virtual environments can be copied or imitated without much legal implications. Finally, as opposed to drug indications that are disorder-specific, a VR environment developed for one disorder (e.g., a bar used for exposure to social interactions in the treatment of social phobia) can be used for another disorder that is slightly different but uses a similar treatment strategy (e.g., exposure with patients suffering from obsessive-compulsive disorder and fear of contamination by touching other customers' beer glasses in the bar), or for a disorder that is very different in terms of pathology and treatment rational (e.g., using the bar and its beer glasses for inducing cravings in people with substance abuse, or virtual characters in the bar to elicit social comparison in people suffering from an eating disorder).

Just as it is the case with smartphone apps, with the advent of affordable solutions to create and distribute VR content, clinicians are becoming confused when it comes to adopting Clinical VR in their practice. We propose a few guidelines to use when evaluating VR tools. We hope these suggestions will encourage and lead the research community in working on consensus statements that can be applied by professionals, researchers, corporations, and regulatory agencies. Eleven dimensions can be considered, in decreasing order of importance: (a) appropriateness of guiding knowledge or theories in the development of this specific environment/tool, (b) usefulness documented for this specific environment/tool (when unavailable, justifications can be based on a reference product but similarities and differences should be considered), (c) empirical results from Phase III or Phase II studies conducted with this specific environment/tool (when unavailable, justifications can be based on a reference product but similarities and differences should be considered), (d) relevance of the validation sample for the target population and culture, (e) safety and lack of side effects documented for this specific environment/tool, (f) usability of the specific environment/tool, (g) data protection while using the software (e.g., when connecting to remote servers) and after (e.g., corporations collecting or sharing information on users or their use of the software), (h) reliability and stability (e.g., lack of bugs), (i) accompanying support material (e.g., treatment manual), (j) aesthetic properties, and (k) impact of modifications and updates since the previous versions.

Once the clinical or research requirements are explicit, a careful review of the literature is essential to avoid "reinventing the wheel". What we see occurring more and more frequently is the appearance of "nouveau" experts in a public forum or conference, citing the great application developed by their friend Dr. X (typically accompanied by an image of a satisfied patient in the background as proof of success). By contrast, those familiar with, or exposed to the content presented in this book are likely to be aware that the same discovery was made more than a decade ago, dozens of independent controlled studies have been published on the subject, and researchers even had enough material to publish meta-analyses on the topic. The same can be seen with an enthusiastic CEO of a spin-off company citing their "soon to be published" study showing changes in "brainwaves" or self-report of patient satisfaction with their VR applications, when decades of research has shown this idea to be no more effective than placebo or has no long term effects. A significant literature has emerged in support of the positive impact of well-designed, theory-informed VR applications on mental health and physical functioning (Rizzo and Koenig 2017). The content in this book aims to present that background knowledge to both update old-timers *and* inspire passionate newcomers to the field in their efforts to create novel VR applications informed by the extant R&D literature.

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Chapter 2
Virtual Reality: Whence, How and What For

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Virtual Reality: Whence, How and What for

In the 1990s, the term "virtual reality" brought to mind futuristic scenarios based on sci-fi fantasies popularized in books such as Gibson's (1984) *Neuromancer* and movies such as the Wachowski brothers' *The Matrix.* These media classics pointed to and perhaps raised expectations for digital three-dimensional sensory displays rendered by some complex yet to be invented or at least not-quite-ready for prime time hardware.

Since then, key innovations and inventions have occurred. Today, viable digital immersive virtual environment technologies are commercially available including hardware, software and design expertise based on the scientific understanding of the nature of human behavior and social interaction within digital virtual environments. The "virtual reality" work of computer and behavioral scientists in the scientific and engineering fields is not only widely published in academic journals but also widely disseminated via traditional and online press pieces (see Oh et al. 2018 for a review of research of social interaction in VR).

While digital media technologies capable of creating virtual reality experiences are available now, it is important to understand that the concept of virtual reality should not be limited to digital technological advances that characterize its current popular referent (see Blascovich and Bailenson 2011 for a history and a review). Indeed, virtual environments need not be rendered digitally or even graphically at all. Written and spoken word can be used to create synthetic worlds with the impact

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of the best in three-dimensional digital renderings and cinematography. Hence, digital virtual reality is a relatively recently honed technology but neither the concept of virtual reality nor virtual reality technology is limited to inventions of the late 20th and early twenty-first centuries. Rather, the concept is applicable to natural and augmented human perceptual experiences elicited by the mind internally via dreams and daydreams and externally via storytelling and cave drawings.

Since the beginning of human history, a progression of media technologies has enabled people to travel psychologically to places other than the natural environments in which they are situated. Aptly, the original referent of the word "media" is "middle." Media provide the interfaces between people and externally implemented virtual worlds. Today, video and audio displays of one sort or another engender the majority of our digital virtual experiences. However, older media forms persist: oral storytelling, paintings, sculptures, theater, music, books, photography, cinematography, radio, and television are hardly in danger of extinction despite the proliferation of digital platforms, affirming that humans have a natural and normal desire to engage ourselves socially and otherwise somewhere other than where we are physically.

Generally, as we become more immersed in digital virtual realities, we act as if they are natural. Our representations; that is, "avatars," on a social networking sites such as networked Social VR platforms or in MMO (Massive Multiplayer Online) games such as Fortnite, depict us as we and/or others have designed them. They can be quite convincing whether they are veridical in terms of how we or others see ourselves or not.

Consider the digitally rendered version of our own and our parent's voice on a cell phone. We assume that we are talking directly to our parent and she or he to us, not the digitized rendering of her voice and ours that are embodying the interaction. Furthermore, we are hardly aware of the mediating role of telephonic technology, including the filtering out of much of the sound spectrum by the phone provider, due to the sufficient fidelity of the ultimately rendered voice. Indeed, when digital renditions of sounds are of sufficient fidelity, participants are unable to distinguish them from naturally occurring ones in the physical environment (Zahorik et al. 1996).

With the continual advance of digital technologies, we are not far from similar levels of fidelity across other sensory modalities, especially visual. Such advances not only invariably change the ways in which humans interact with one another, but also how we study such interactions.

What is Reality Anyway?

As mentioned above, humans have created and enjoyed virtual environments via a plethora of media since prehistoric times. Humans have also long been questioning what constitutes "reality" in the first place. What we label reality is typically based on what we consider and experience as the natural or physical world. But, because no two individuals necessarily experience any given stimuli in exactly the same way, their realities can differ, as can be demonstrated via many visual illusions.

To many, asking what is "real" seems a silly question. That there is a real or genuine reality is readily assumed, but difficult to define or agree upon even by those whose job involves doing so, such as philosophers, physicists, and digital media experts. Furthermore, humans can't be sure that any given color, sound, or smell is experienced identically by different people or even by the same person at different times. Cilantro spices up a meal nicely for some, but tastes like soap to others. Red-Green color blindness exemplifies differing perceptions of visual fields. Synesthesia, a neurological condition in which the stimulation of one sensory pathway leads to the automatic stimulation of another such that affected individuals perceive numbers and/or letters as having an inherent color or eliciting a specific location in space, further complicates the picture.

Not only do we perceive and process stimuli somewhat idiosyncratically, but we do not have the sensory bandwidth to perceive much of the stimulus fields in which we find ourselves at all. Does such perceptual blindness make these stimuli any less "real"? Certainly the fact that the unaided ear cannot hear sounds in the high frequency range that bats can does not render such sounds non-existent. Indeed, humans can perceive only a relatively small fraction of the broad spectrum of auditory, visual, olfactory and other stimuli in our environments. Even though we cannot readily perceive them, dog whistles, UV light, and carbon monoxide are certainly "real."

Blascovich and Bailenson (2011) maintain that the distinction between "What is real and what is virtual?" is arbitrary for humans and involves a principle of "psychological relativity," the operation of which can explain differences in the perceptions of the same stimuli by different people as well as differences in one person's perceptions at different times. Accordingly, when humans often make the distinction between the real and the virtual, they do so relatively (and often arbitrarily) similarly to the ways which physicists accept that time and motion are relative.

In sum, encountering "virtual reality" is nothing new. It is an experience with which humans are intimately familiar, so familiar that we often fail to distinguish between what is "real" and "virtual," sometimes accepting the latter as "real" and the former as "virtual." This point is not trivial for many fields of scholarship and research. Indeed, in the behavioral and related sciences; for example, it provides a robust "technology" for the empirical examination of perceptual, cognitive, clinical communicative and social psychological processes among others within traditional behavioral laboratory contexts. Today, such efforts are and can be facilitated by impressive new digital technologies but in essence are psychologically very similar to the compelling non-digital experimental virtual worlds built by social psychologists such as the Stanford prison experiment (Haney et al. 1973) and Milgram's (1965) obedience environment.

Virtual Reality Defined

One of the best explications of the term "Virtual Reality" can been found in Jaron Lanier's book, The Dawn of the New Everything (2018), where he offers over 50 distinct definitions of the term. In this chapter, we take a relativistic approach and use the term *grounded reality* to refer to the perceptual integration of stimuli, that people judge as natural or real and *virtual reality* to refer to the externally mediated presentation of sensory stimuli that enables the person to perceive an artificial environment as non-synthetic to a greater or lesser extent. As noted above, virtual environments can be perceived via any sensory modality (and any combination of them) and need not be merely visual. Musical recordings are an example of aurally rendered virtual environments. Stimulating touch, smell, and taste can also be augmented virtually, albeit relatively complex technologically. We use the term *Immersive Virtual Environment* to refer to those in which the sensory information is compelling enough to create perceptions of being physically present within the virtual environment

Importantly, the term "virtual reality" or "virtual environment" need not refer to digitally rendered three-dimensional displays and can be accomplished via "hammer and nail" techniques in the same fashion that one would create a haunted house. Nevertheless, here, we use the term *immersive virtual environment technology* to refer to the digital technology used to render an immersive virtual environment. This technology is powerful and ever evolving. In the section below we discuss design and operation of the system used in the majority of our research and in many other laboratories.

Creating a Sense of Immersion

When participants and visitors to our lab enter an immersive virtual environment they don a head mounted display (HMD) that renders the virtual world stereoscopically. This three-dimensional view is accomplished by presenting two different, binocularly offset images to each of the eyes, just as we are accustomed to when we use our eyes naturally. Various form of hardware tracks participant's position and rotation of participants' head, hands, and sometimes feet. This information is sent to the rendering computer so that the user's view can be updated to reflect his or her current position. Eye tracking within the headset can also be done, but generally given the narrower than natural field of view within HMDs, it is sometimes redundant as participants typically gaze where their noses are pointed.

Each of these systems communicates with the computer digitizing the virtual environment. This computer contains the software and the program script with all the necessary information to visually render the virtual environment and to control the flow of events in the digital IVE. With current "standalone" systems, the trackers, rendering hardware, and display are all worn on the head in the HMD.

Creating a convincing virtual environment depends heavily on the integration of hardware and software that enables the system to track the individuals' location in the world and update the view accordingly. It is essential that this occur very quickly but smoothly. Typical systems update about at least 90 times per second in order for the view to appear natural. If the virtual environment is too graphically complex and the system cannot update quickly, perceptual lag occurs. The disconnect between the individuals'physical movements and visual information can lead to cyber sickness. Thus, sometimes there is a tradeoff between rendering a graphically complex, detailed environment and one in which the user can move freely and naturalistically. However, as processing speed continues to increase the threshold of this tradeoff is changing such that worlds can be created that are both richly visually textured and allow for naturalistically quick movements.

Applications and Benefit to Psychological Science

Psychologists, as well as other behavioral scientists, have long relied on the creation of virtual environments to immerse participants in situations relevant to the constructs and hypotheses in question. Indeed, many of the most well-known psychological experimental paradigms relied on the construction of "hammer and nails" virtual environments in the lab. Notable examples include Milgram's obedience studies and the Stanford Prison Experiment referenced above. In the latter, Zimbardo and his colleagues literally built a "physical" virtual prison in the basement of the psychology building.

Accurately assessing the psychological variables in question and their relation to one another is predicated on the assumption that participants are immersed in the experimental world or paradigm and respond in naturalistic ways. The results of any given study are only generalizable to the extent that the paradigm they were found within is representative of "real" experiences and interactions outside the laboratory.

The added complexity and cost of using immersive virtual environment technology (IVET) in psychological research is more than paid for by its benefits. This technology offers researchers the ability to increase ecological realism without compromising experimental control. Thus, IVEs support much more realistic, engaging, and interactive paradigms than more traditional paper and pencil or desktop experimental manipulations. Rather than asking participants to imagine the scenario of interest, the researcher can immerse them in it. Though traditional human confederate-driven experimental manipulations also increase ecological realism, there is a cost of reduced experimental control over the human confederate. It is impossible to ensure that human confederates treat each participant in exactly the same manner. With a well-programmed digital human appearing agent described as an avatar of an actual person, the researcher gains the desired experimental realism without introducing additional sources of error.

Finally, experimental social psychologists and other researchers benefit from the necessary tracking and rendering technology because it preserves much in the way of precise information including temporal, movement, proxemics and gaze data. Hence, there is a wealth of implicit data added to the researchers' efforts. Researchers can look to reaction times and durations of gaze, gaze avoidance, spatial relations, etc. as dependent variables thereby adding quite a bit of power to their experimental endeavors.

The Threshold Model of Social Influence in Digital Virtual Environments

In the tradition of social and cognitive psychology, our research using immersive virtual environment technology to explore human social behavior is theory driven. Two categories of general social influence theories evolved during the twentieth century in social psychology; one targeted at understanding and explaining intra-individual social psychological processes such as beliefs, attitudes, and values, and one targeted to understanding and explaining inter-individual social psychological, that is, social influence processes. Regarding the latter, explanatory approaches to understanding human social interaction and influence changed during the last half of the twentieth century from relatively "grand" or general theories of interpersonal relations to theories constrained to more specific aspects of social interaction and influence such as interpersonal attraction, stereotypes, etc.

In much of our initial virtual reality work, we ran experiments testing specific inter-individual theories and hypotheses ranging from proxemics theory (e.g., interpersonal distance and personal space) to theories of group interaction. However, so many possibilities and compelling reasons (see Blascovich et al. 2002) for using immersive virtual environment technology to conduct social psychological research became clear to us early on to follow Kurt Lewin's maxim, "There is nothing so practical as a good theory" (Morrow 1977). This course of action has facilitated our efforts and helped broaden our understanding of social influence not only in digital immersive virtual environments in particular but more generally as well.

Consequently, we developed a theory to guide us. It started out as a general two-factor model (Blascovich et al. 2002), was expanded to a five-factor model (Blascovich 2013), and most recently to a mixed model of three independent factors and two moderating factors (debuting for the first time in print here).

As described above, humans psychologically or mentally leave grounded reality to enter some form of virtual reality endogenously and exogenously with great frequency. Even without technology, people dream and daydream. Although it is well known that the former happens 4–6 times per night, not so well know is the fact that peoples' minds wander approximately 2000 times during the waking hours of the day (Smallwood and Schooler 2006). Some of those waking wanderings are unintentional ("zoning out") and some intentional ("tuning out").

Furthermore, we humans not only travel virtually to imaginary or "unreal" places endogenously, we can also use exogenous tools to do so also, including those based on digital virtual environment technologies.

Our work has focused on humans' digital travels to virtual worlds that include the apparent presence of other humans who may or may not exist in grounded reality but in either case with whom digital social interaction is possible at both conscious (i.e., explicit) and unconscious (i.e., implicit or automatic) levels. Hence, humans' virtual experiences often involve multiple levels of social influence by, and interactions with apparently animate digital human representations some of which may be actual representations of other humans in real time and some of which may be visual and auditory manifestations of computer algorithms.

As stated above, the current incarnation of our "Threshold Model of Social Influence in Virtual Environments" (TMSI) involves interactions among three independent factors and at two moderating factors. The former include *Agency, Communicative Realism,* and *Response System Level*. The latter includes *Self-Relevance* and *Context*, though undoubtedly there are other candidate moderators to be explored in the future. For simplicity, our description is based on the purview of a single user.

Independent Factors

Agency refers to a user's theory of mind regarding other possible human representations within immersive digital virtual environments. In other words, agency is the degree to which the user perceives the sentience (e.g., consciousness, free will, motivation) of the representation(s) of apparent other(s) in the digital immersive virtual world. Perceptions of agency vary from non-sentient to fully sentient on the human scale. A user may base their sentience attributions to a digital representation explicitly either on prior information or infer it implicitly from observations of the actions and appearance of the representation.

Illustrated in the figures below, agency or theory of mind is represented on the abscissa and varies from "Agent" to "Avatar," with the latter referring at the extreme to an online representation of another actual person in real time and the former at the opposite extreme to an online representation of an artificially intelligent computer algorithm and in the middle of the dimension some combination of human and computer; that is, a "Cyborg" (see Bailenson and Blascovich 2004 for an explication of this concept, and Fox et al. 2015, for a meta-analysis showing the benefits of human agency in social interaction).

Communicative Realism, depicted on the ordinate in the graph refers to the human-like quality of a digital representation's communicative signals and varies from high to low within digital immersive virtual environments. Communicative realism is less critical for representations that users assume are avatars, but much more critical for representations that users don't know are avatars or that they assume are agents (i.e., computer algorithms). Whether exhibited by an assumed avatar or agent, communicative realism heavily influences automatic and unconscious processing. That is, even though an immersive virtual environment user may believe that a representation is an agent, his or her automatic or unconscious processes can attenuate the impact of that conscious knowledge, much like a fear response can be evoked by a monster in a scary movie despite conscious awareness that the monster is not real.

Furthermore, in our model, communicative realism is a latent variable that itself incorporates three manifest variables that are hierarchically organized. Surprisingly to many, the most important communicative realism variable is neither photographic nor anthropometric realism but movement realism (i.e., does the representation of the virtual other move at least in somewhat human like ways in terms of body and head orientation, vocalizations (implying vocal cord activity even if there are no digital vocal cords), gestures, maintaining appropriate interpersonal distance, etc., as cartoonists have long known.

In our model, we regard anthropometric realism as second in communication impact because the presence of certain body parts is necessary for certain communication signals. For example, a human digital representation must have an arm and a hand to wave to a user, lips to air kiss another, or eyes to attempt mutual gaze. Finally, photographic realism can be important but only in the sense of connoting the representation's individual identity, and it need not be very high in fidelity as illustrated by caricatures. Indeed, the higher the photographic realism, the more communicative realism is likely to be attenuated because the composite humanity of the representation is thrown off (i.e., the "uncanny valley" problem).

Our argument regarding communicative movement realism is bolstered by the fact that bodily movements of others elicit neural processes in observers that stimulate mirror neurons that project to areas of the brain that predispose people to treat "others", even robots and pets, as sentient at some level, mostly unknowingly (Rizzolatti and Sinigaglia 2010). In our view, agents' and avatars' movement realism trumps anthropometric realism and photorealism, something that animators and cartoon aficionados have recognized for decades.

Response System Level, represented on the z-dimension in our graphs, varies from automatic to deliberate. Social influence channels include automatic or unconscious ones that affect uncontrolled or automatic behaviors as well as controlled or deliberate ones. As previously reviewed, social psychologists have noted the ubiquity and strength of "implicit" or automatic social influence effects. This is true for social influences whether they occur in physical or virtual reality. We argue that unconscious social influence processes are similar within or outside of immersive virtual environments. If a digital agent mimics a user, he or she responds positively to that mimicry, as they would in grounded reality (e.g., Bailenson and Yee 2005). If a digital agent makes a sudden loud noise, users exhibit a startle response, just as they would in grounded reality.

Moderating Factors

Self-relevance is a major moderating factor in the model denoting the importance of a social interaction within a specific virtual environment. It ranges from low to high and represents the personal value or meaningfulness of any social interaction in the virtual world. Of course, this is true in grounded or physical reality as well. Virtual interactions range from casual or relatively unimportant ones to very important ones, especially those that invite others' evaluations of one's character or performance. Contrast playing a simple game with another versus possibly falling in love with another in a virtual environment.

Context Important factors underlying context in virtual environments include ecological complexity and action options. Together these factors determine the level of communicative realism necessary given the nature and complexity of any social interaction within a virtual environment. To illustrate, when one plays certain games in a digital virtual environment, lower levels of communicative realism, at least in terms of anthropometric and photographic realism, suffice as players can become quite immersed because the interaction is quite delimited.

To illustrate, imagine that a person enters an immersive digital virtual room with six sides (four walls, a floor, and a ceiling) furnished like a recreation room to play the game generally known as "hot and cold." A digital human representation instructs the person to find an object in the room that "she" is thinking about and explains the rule that the player cannot talk or ask questions. The player moves about trying to find the object being "thought of" by the digital human representation. At short intervals, the digital representation tells the player that he is getting "warm," "warmer," "hot," or "cold," "colder," "freezing." Eventually the player finds the object the digital human representation if thinking about and is told so by the digital human representation.

In the above context, the nature of the digital representation (i.e., avatar compared to an agent) giving the vocal verbal feedback would be impossible to determine by the player definitively because both the context and the feedback options are limited. On the other hand, if the immersive virtual context is more important and complex, say an oral defense of a dissertation or a high level job interview, it is unlikely given current artificial intelligence technology that an agent would be indistinguishable from an avatar.

The surfaces in the figures below depict theoretical relationships among agency, communicative realism, and response system level, in high, moderate, and low self-relevant context within digital immersive virtual environments. The depicted surfaces are the theoretical "thresholds of social influence." This threshold predicts the likely occurrence of social influence effects as a function of the three factors discussed above. At or above the surfaces, social influence effects are more likely to occur. Below the surfaces, they are not.

To illustrate, if agency is high (i.e., the representation is believed to be an avatar), then neither high communicative realism nor deliberate response system level are

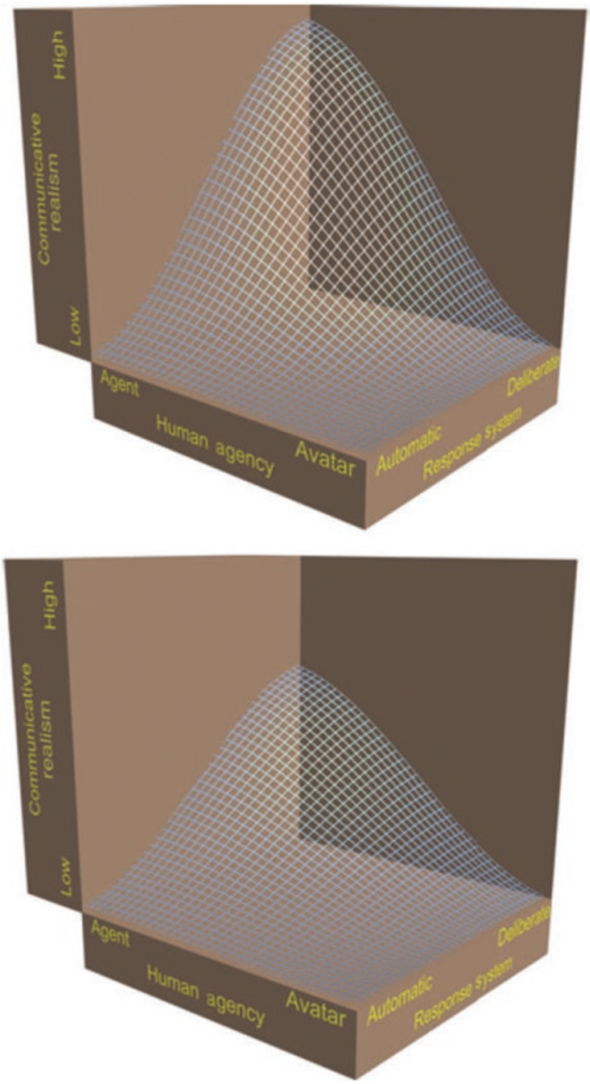


Fig. 2.1 The model of social influence in virtual environments

necessary for social influence effects to occur. Hence, an avatar representation that is merely a "frowning face" can elicit negative affect as evidenced by automatic user behaviors such as a returned frown or in terms of a consciously delivered user response such as a "Thank you!" On the other hand, if agency is low (i.e., the user believes the representation is an agent), then social influence will occur as a function of communicative realism (e.g., high movement realism) for deliberate user responses such as occur during conversation. High levels of communicative realism are not necessary for automatic or unconscious user responses even to an agent (see Fig. 2.1). A meta-analysis (Fox et al. 2015) provides a review of research on these effects.

Applications

In line with the threshold model of social influence described above, digital immersive virtual environment technology provides a tool that can create and assess one-on-one social influence effects involving human-to-human and human-to-agent interactions or interactions involving groups of agents and avatars. Not surprisingly digital virtual environment technology has become more and more prominent in behavioral science research facilities around the world providing advanced technology to study psychological, social psychological, and other behavioral phenomena in fields such as communication, social psychology, education, medicine, clinical psychology and health among others in ways that improves both internal and external validity while sparking new lines of research.

For example, researchers can utilize immersive virtual environments to control or constrain potentially contaminating variables that can occur in traditional field and laboratory settings (Blascovich et al. 2002) as well as to create environments that are too difficult, costly, or dangerous to produce in physical or “grounded” reality (Fox et al. 2009; Lanier 1992; Biocca and Delaney 1995).

As IVE related hardware, namely HMDs such as the Oculus Rift and tracking systems (such as the Microsoft XBOX Kinect), have become inexpensive, digital immersive virtual environment related research is on the increase (cf. Blascovich and Bailenson 2011). As noted by Fox et al. (2009), there are three ways that immersive virtual environments have been incorporated in the scientific research process. First, immersive virtual environments themselves have been objects of inquiry allowing investigators to explore and understand how they can be used to evoke psychological and social psychological reactions and how similar or dissimilar the human experience within virtual reality is to parallel experiences in grounded reality. Second, they have been used for applications outside of the laboratory in applied settings; for example, by medical students to practice medical procedures before employing them on live patients (Burdea and Coiffet 2003). Finally, immersive virtual environments have been used as a method for studying various social psychological phenomena such as studying reactions to and successes of members of minority members when interacting with out-group members (Groom et al. 2009; Dotsch and Wigboldus 2008; Eastwick and Gardner 2009; Peck et al. 2013). Given the multi-faceted nature of digital immersive environments, their potential uses, applications continue to expand with the needs of researchers in multiple fields of scientific inquiry.

It is important to note two common types of digital immersive virtual environments; “True to Life Simulations” (TLFs) and “Transformed Social Interactions” (TSIs). The former attempt to replicate grounded reality environments that “follow” natural laws and, consequently, everyday behaviors therein (Bailenson et al. 2004). In contrast, the latter allows researchers to manipulate or remove constraints that exist in grounded reality; for example, changing the way a person’s avatar appears and/or behaves via computer algorithms (Bailenson and Segovia 2010; Bailenson and Yee 2005) and, in no small measure, distracting individuals from natural environments full of personally negative cues.

Until recently, the bulk of behavior and communication research conducted using digital immersive environments has employed agents; i.e., computer controlled representations, instead of avatars; i.e., human controlled representations (Bailenson and Blascovich 2004). The necessary computing power to track and render research participants in real-time data improved steadily over the last two decades making the use of actual avatars more prevalent in digital virtual environment-related research. Hence, improvements in computing power and speed has proven to be a catalyst for the impressive but not totally inclusive archive of virtual reality based research that is discussed in the next two sections.

True-To-Life Simulations

Given their nature, digital immersive virtual environments are well suited to simulate grounded reality and the situations and challenges that people encounter daily. Five illustrative domains in which true-to-life simulations have been employed for such research include: mental health, physical health, social norm development and management, personnel training, and information delivery. The vast situational differences among these domains demonstrate how far reaching the impact of immersive environment technology has and can be.

Mental and Physical Health

The use of digital virtual technology has significantly expanded the abilities of practitioners and researchers to improve patients' mental health. More specifically the capability for creating controllable, multisensory, interactive immersive environments in which dysfunctional behaviors can be elicited, observed and recorded allows researchers and clinicians to employ and explore person-situation interactions that are largely unavailable to them in grounded reality.

As in other domains, immersive digital environments are particularly well suited for studying or treating psychological disorders because the experimenter or clinician, has complete control over a multitude of factors in the appropriate digital setting, including the gaze of other "people" (i.e., agents) who might be present, their verbal comments; their number, gender and age, level of attentiveness, etc. By manipulating any of these factors, the experimenter or clinician can design, create and/or test a variety of environments appropriate to study or treat people with specific diagnoses.

Phobias

Virtual worlds have been created to elicit phobias while patients are in the relative safety of the laboratory or clinician's office. Using immersive virtual environment technology for such therapy is particularly powerful because clinicians can hold parameters constant that otherwise would be impossible to control in grounded reality. It is also possible to control the intensity of phobia stimuli that patients encounter. In this respect, the researcher or clinician is able to create digital virtual environments in which phobia stimuli can be increased or decreased in intensity to match the progress and needs of the patient. Immersive virtual environment technology has been used to study phobias including (Côté and Bouchard 2008): acrophobia (Coelho et al. 2006), agoraphobia (Botella et al. 2007), arachnophobia (Coté and Bouchard 2005); aviophobia (Rothbaum et al. 2000); public speaking anxiety (Harris et al. 2002; Safir et al. 2012), panic disorder (Botella et al. 2007) and social phobia (Roy et al. 2003).

Anxiety

Immersive virtual environments have also been used to assess and treat other forms of anxiety and fear disorders such as fear of public speaking. For example, Slater et al. (2006) studied confident and phobic people in an immersive virtual environment by requiring them to deliver a speech to either an empty room or an audience of digital human agents. Phobic speakers demonstrated significantly more anxiety in the populated room. With repeated exposure to audiences that were nonverbally negative or disinterested, phobic speakers acquired coping tools to deal with their anxiety (North et al. 1998; Slater et al. 1999).

Post-Traumatic Stress Disorder (PTSD)

Using digital environments is also helpful in addressing symptoms of post-traumatic stress disorder (PTSD). Following a pattern of psychotherapy involving desensitization, or slow reduction of anxious reactions through repeated exposures, patients can begin to deal with anxiety inducing stimuli (Wople 1968). The clinician can gradually add features to the digital environment (such as behaviors, objects and sounds) to more closely approximate the actual environments that patients fear. In this way, clinicians can help patients identify trigger points, or aspects of naturalistic environments that evoke the most critical patient responses.

As Rizzo and colleagues note (2011), cognitive behavioral treatment with prolonged exposure appears to have the best documented therapeutic effect for PTSD treatment. Perhaps the most widely studied application of IVEs and PTSD involves active and veteran military personnel (Ready et al. 2010; Riva et al. 2010; Kramer et al. 2010; Reger et al. 2011; McLay et al. 2011; Baños et al. 2011).

Eating Disorders

More recently, immersive virtual environments have been employed to address dietary health concerns such as eating disorders. By immersing such individuals and exposing them to high-anxiety environments (e.g., social gatherings with food, buffets, etc.), their gaze directions can be closely monitored, thereby allowing assessment of the objects of their attention and related emotional reactions facilitating development of individually targeted treatments (Gutiérrez-Maldonado et al. 2006; Aimé et al. 2009; Gorini et al. 2010). Virtual cafeterias and grocery stores have been created and proven useful for educating diabetes' patients about proper diet and exercise (Johnson et al. 2014; Vorderstrasse et al. 2014). Such IVEs are particularly well suited for studying food-related behaviors because participants' gaze can be tracked. This allows the clinician to analyze how long they spend attending to any particular food item in the IVE. With this information, the clinician can then address specific trigger points that may cause poor patient choices.

Addiction

Similarly, digital virtual environments have been applied to problems of addiction. Cho et al. (2008) used digital cues to stimulate alcohol cravings. Baumann and Sayette (2006) used a similar technique to stimulate nicotine cravings in cigarette smokers. By assessing reactivity to cues and subjective craving ratings over an extended time period, efficacy of proposed treatment plans can be assessed and then individually tailored to meet patient needs (Kaganoff et al. 2012; Traylor et al. 2011).

Pain

Digital virtual environments have also been shown to have significant impact on subjective perceptions of pain stimuli while immersed; regardless of whether the participant is wearing a head-mounted display or in a virtual world projected onto a wall creating a two-dimensional image (Gordon et al. 2011). This finding resulted from acquiring patients' pain ratings while their hands were immersed in ice water (Law et al. 2011). Since then, it has been employed for patients experiencing severe pain such as burns and broken bones (Teeley et al. 2012). In addition to subjective ratings of pain, research has also found that areas of the brain responsible for identifying and signaling pain have a decrease in activity while the patient is in an immersive virtual environment (Hoffman et al. 2011). It is believed that the reduction in reported pain as well as decreased brain activation in pain sensitive areas stems from distraction in the virtual environment attenuating cognitive resources impeding the processing of neural signals from pain receptors.

Physical Therapy

Distraction tasks have also been remarkably beneficial in encouraging the elderly and infirm to continue and complete physical rehabilitation exercises. Anecdotal and case study analyses have been conducted to understand the physical, mental and emotional benefits of using interactive exercise based video games (Wollersheim et al. 2010; Pigford 2010; Jung et al. 2009). These studies report that participants felt more connected with their social groups while enjoying an activity that allowed them to keep physically active even with physical limitations and ailments.

Stroke

Other work has explored the use of video game consoles as a rehabilitation tool for patients with neurological injuries. The Nintendo Wii is particularly well suited for rehabilitation exercises because it provides bio-visual feedback from force plate systems embedded in the Wii Fit Board. The researchers adapted software that targeted weight shifting and balance movements. Patients "play" by transferring weight onto their impaired limb to improve weight shift ability while standing and walking. This technique has been shown to improve balance, mobility, and gait following neurological injury (Lange et al. 2010). Similar work has been conducted by de Silva Cameirao et al. (2011) on rehabilitation gaming systems (RGS) for patients recovering from acute strokes. The RGS software uses the number of successful patient trials to individualize training goals. In their experiment, the group of patients utilizing the RGS displayed significantly improved performance of specific body motions when compared with control groups. In addition, the RGS group improved significantly faster than the control group.

Clinical Training

Health care providers also have benefitted, using digital virtual environments to learn and hone their own practice skills, thereby increasing their success and efficacy rates (Spicer and Apuzzo 2003; Seymour et al. 2002). For example, physicians and first responder personnel have been immersed in virtual environments including busy emergency rooms, natural disaster areas, and emergency situations to learn how to triage and prioritize needs of the patients as well as to learn to be aware of how to assess danger to themselves and others. Surgeons have also been immersed in virtual environments to practice diagnosing virtual patients and conducting virtual surgeries, such that they are able to gain valuable experience and practice in situations that may very rarely occur in grounded reality. Having virtual exposure to them provides resources with which to address rare medical situations in the future (Andreatta et al. 2010).

Education

Along with training situations, many researchers and educators have long realized the value of using digital immersive environments for education. Markowitz et al. (2018) provide an up to date review on the empirical work in VR and learning. Learners feel more psychologically present in such digital environments than is possible in more traditional settings (Kafai 2006; Kafai et al. 1998). Additionally using immersive virtual environments for didactic purposes removes traditional time and location constraints making learning possible anywhere, anytime. Arguably, however, it may possibly isolate students potentially depriving them of the social experiences of a grounded multi-student classroom (Wegner 1998). For example, researchers (Johnson et al. 1979; Wood et al. 1995) have found that such "grounded" students outperform isolated students and students in pairs tend to remember more factual material than solitary students. However, with advances in computing capabilities, rendering avatars of multiple learners in a virtual world has become more common (Kim and Baylor 2006; Bailenson et al. 2008a).

While some may argue that virtual renderings of fellow students may not provide the same sense of classroom community found in grounded classrooms, research suggests that people respond to a virtual co-learner similarly to how they respond to human co-learners (Reeves and Nass 1996; Blascovich et al. 2002). Research in low achieving schools has found that digital immersive virtual environments and other virtual simulations help narrow the achievement gap between high and low performing students, especially on performance based measures (Dede 2009).

Virtual worlds such as River City (Dede 2009), Quest Atlantis (Barab et al. 2007) and Whyville (Neulight et al. 2007) are educational multiuser virtual environments for adolescents that increase engagement and learning by including frequent opportunities for reflection and synthesis of information. The most powerful feature of these IVEs is that users are required to take multiple perspectives within one session. For example, in River City, students work together to determine why people in a small town are becoming ill. To solve the mystery, they have to think both like a resident of River City and as a visitor to the city.

Researchers contend that digital immersive virtual environments provide a successful teaching tool because they can enhance learning transfer via simulation of the physical world (Schank 2005; Zyda 2005). Transfer occurs when knowledge learned in one situation is applied to another situation, such that there is improved performance on the subsequent task (Mestre 2002). With increased opportunities to practice in digital virtual environments, students arguably can learn and retain more information than without such practice.

Although traditionally education takes place primarily in a school setting during childhood and is likely to continue in that kind of setting, learning is a lifelong process in which knowledge is augmented and adjusted by individuals' novel experiences encoded by the brain. Rogers et al. (1977) concluded that self-reference encoding (SRE) results in better recall than other types of encoding, suggesting that individuals learn and remember information better when it is related to the self. This finding has significant implications for digital virtual environments because researchers can render a participant's avatar in infinitely different ways. Hence, similarity between a participant and his or her avatar can be based on physical traits, personality variables, or shared beliefs and attitudes, or all of the above (Stotland 1969).

To illustrate, the likelihood of learning increases when teachers are of the same sex (Andsager et al. 2006), race (Ito et al. 2008; Baylor and Kim 2003), skill level (Meichengaum 1971), opinions (Hilmert et al. 2006) and/or behaviors (Andsager et al. 2006; Baylor 2009) of the people they represent. However, participants must perceive that their avatar is similar to themselves to vicariously experience the same outcomes; more specifically, they must identify with it. Traditional non-immersive virtual environment studies have shown that, identification with others increases the likelihood of performing learned behaviors (Bandura 2001; Bandura and Huston 1961). For example, increasing the similarity between a participant and their avatar in a smoking cessation IVE would increase the likelihood that the participant would quit. Similarly, immersing gang members in digital virtual environments with avatars of members of rival gangs who all work together on a common task could impact outcomes in grounded reality positively. The ideas in this vein that could be generated are seemingly endless.

Social Influence

According to the threshold model of social influence model discussed above, social influence takes many forms and its effects can be just as powerful in virtual reality as in grounded reality. In fact, Reeves and Nass (1996) have shown that people tend to socialize with virtual agents the way they do with other people. With repeated digital immersion, influence can be exerted and social norms and roles can be manipulated and measured implicitly such as with gaze and proxemics analysis. Proxemics refers to the physical distance that people maintain among themselves based on appropriate interpersonal distance norms that vary by culture (Blascovich and Bailenson 2011; Hall 1963). Dotsch and Wigboldus (2008) placed Dutch participants in a digital immersive environment in which they encountered a White or a Moroccan agent (Moroccans are highly stigmatized in the Netherlands). They were instructed to walk around each agent to identify a number on their back, a proxemics task described as necessary for equipment calibration purposes (Bailenson et al. 2003).

When the resulting proxemics data were analyzed, it was found that Dutch participants maintained greater interpersonal distance from the Moroccan agent. This finding also matched the participants' scores on the Implicit Association Test indicating that they maintained personal distance as a reflection of unconscious beliefs about the Moroccan outgroup. Similarly, Eastwick and Gardner (2009) found that previously held beliefs about race carried over to digital virtual environments. In their experiment, Black avatars were less successful using the door-in-the face compliance technique than White avatars.

However, biases in digital immersive virtual environments are not limited to racial contexts. Hoyt and Blascovich (2007) used one to activate norms about sex stereotypes and leadership abilities and found that women with high levels of leadership efficacy experienced positively motivating reactance responses and outperformed women with low leadership efficacy. Along a similar line, Fox and Bailenson (2009a) found that participants who interacted with a stereotype-confirming virtual female later expressed more sexism and anti-female attitudes than participants who interacted with a non-stereotypical virtual female.

True to life digital immersive environments have also been used to document pro-social tendencies. Gilliath et al. (2008) studied prosocial behavior using a digital immersive virtual environment and found that approximately the same proportion of people provided aid or expressed concern for a virtual needy person as has been observed in grounded reality assessments. Slater et al. (2000) compared grounded reality groups and virtual groups and found that leadership emergence and embarrassment occurred in both environments. Hoyt and Blascovich (2003) examined leadership styles of virtual groups and found that participants' group performance and cohesiveness were equivalent to those who engaged in the same activity in the physical world.

Finally, Jabon and colleagues used a virtual driving game to study facial features that would predict driving accidents. Their findings suggest that important signals for accident prediction show on a driver's face up to 4 s before the accident (Jabon et al. 2011). This information may be particularly useful in decreasing rates of teenage driving accidents or creating auto-correcting vehicle safety algorithms for new car models.

The aforementioned studies demonstrate only a small proportion of the amazing collection of work conducted using digital immersive virtual environment technology. Although these applications are topically diverse, they show how truly versatile and impactful such digital environments can be. Additionally, as more studies using true-to-life immersive virtual environments are conducted, more potential applications will become apparent.

Transformed Social Interaction

Although there are many practical uses for true-to-life digital simulations of grounded reality, researchers are often interested in manipulating variables to create or measure an effect that ordinarily could not happen in grounded reality. In this case, instead of merely using true-to-life simulations, researchers can avail themselves of "transformed social interactions" (TSIs). As the label suggests, in TSIs some aspects of grounded reality have been removed, or transformed, to allow for situations that may not be possible in grounded reality, essentially creating a new reality. Via digital immersive virtual environment technology, there are three factors that researchers commonly manipulate to create transformed social interactions: self-representation, sensory abilities, and situational contexts. Each can be combined with the other factors or used independently to produce digital environments that focus on the outcome of interest (Bailenson et al. 2008b).

According to Goffman's explanation of identity, the presentation of the self must be understood as a constant performance in the midst of a social audience. People often choose their gestures, mannerisms, and actions to elicit a desired impression of the self to others (Goffman 1959). This behavior is instrumental; specifically, people manipulate their presentation in order to make a positive impression (Cooley 1902), such as appearing pleasant or likeable, to gain social advantage (Jones 1964; Jones and Pitman 1982). It is important to carefully balance favorability and believability while presenting oneself in a positive manner (Schlenker 1980).

Over 50 years before Goffman, Cooley (1902) described the "looking glass self" as a metaphor for how people imagine their appearance will be judged by an observer and what observer feelings will be associated with that judgment. While Cooley used the analogy of mirror to describe this presented self, today's digital virtual reality technology allows individuals to interact with virtual human representations (avatars or agents) three-dimensionally and in real time. What is typically of most interest to participants is what their virtual representation of self looks like. In most cases, their avatars have been created to look or behave at least on some dimensions like the participant that the participant identifies with. In some ways, interacting with one's digital representation can be like looking in a mirror, particularly if the digital self exhibits physical characteristics that match the individual's (Bailenson et al. 2001; Biocca 1997; Nass et al. 1998).

However, it is important to note that the virtually represented self can vary significantly from a mirror image based on the transformations made by the researcher (Bailenson et al. 2004). For example, the virtual self can be rendered to move independently of, look physically different from, or stay in position of the participant while the latter obtains novel views of their virtual self representation (e.g., looking at it from directly above or behind). These changes can be subtle so that the individual hardly notices any difference, or so obvious such that the individual would not recognize their own avatar unless specifically directed towards it (Bailenson et al. 2008b). In fact, the focus of many "transformed social interaction" studies is how participants behave as a consequence of altering their view of their own avatars.

Bem's (1972) self-perception theory states that individuals develop attitudes by observing their own behavior and concluding what attitudes must have caused them. Several studies have shown that emotions can be derived from observing such behaviors (Bailenson and Segovia 2010). Emotions such as liking, disliking, happiness, and anger have been induced by overt behaviors that had been manipulated by research assistants (Larid 2007).

One classic study illustrated this effect very clearly. Cacioppo and colleagues asked students to hold a pen sticking straight out of their mouths but held in place either by their lips or by their teeth. The teeth condition more closely mimics the muscles used during actual smiling and, as predicted, students in the teeth condition later reported a cartoon they saw as funnier than the participants in the lip condition (Cacioppo et al. 1986). Self-perception theory has had enormous impact on immersive virtual environment technology-based research because researchers have the ability to control any aspect of a virtual representation's behavior, speech, and appearance.

Self-Representation Transformations

Transforming the appearance of an individual's digital representation in an immersive virtual environment is easily accomplished. Based on self-perception theory, a so-called "Proteus Effect" occurs when people infer their expected behaviors and attitudes from observing their avatars' appearance and behavior (Yee and Bailenson 2007). In immersive virtual environments, an object called a "virtual mirror" is used to enable participants to "see" what their embodied avatar looks like (Blascovich et al. 2002). It is interesting to note that because the digital environment can be rendered uniquely for each co-actor in the virtual world, a participant's avatar may look one way to the participant and quite another to other co-actors. Although the researcher does not always exercise the ability to option to present different views of avatars for each co-actor, it is one of the many advantages of conducting research in digital virtual environments.

According to Bem, as noted above, individuals can develop attitudes by observing their own behavior and appearance and concluding what attitudes they hold that would have caused those actions. In foundational virtual environment work, participants were placed in a digital virtual environment in which they viewed themselves in a virtual mirror. Subsequently, they interacted with other co-actors (both avatars and agents). The resulting data indicated that the interpersonal distance participants maintained between themselves and others was normative—as it would have been in in grounded reality (Bailenson et al. 2003). This finding reinforces the notion that participants react to virtual others the same way they would have with others in grounded reality (Reeves and Nass 1996).

Building on this idea, researchers have manipulated an individual's avatar and observed that individuals' interactions with other agents or avatars in an immersive virtual environment. They were able to document changes in behavior and attitudes both implicitly, for example, via proxemics and gaze data, as well as via participants' self-reports. Many studies along these lines have manipulated various features of individuals' avatars and documented resulting changes in behavior and attitudes.

For example, in a study involving a money splitting task, participants who had been given a taller avatar than the negotiation partner's avatar (by 15 cm) were more willing to make unfair money splits in their own favor, while participants who were given avatars shorter than the confederate's avatar (by 15 cm) were more willing to accept unfair splits made by the confederate (Yee et al. 2009). This finding supports established literature indicating that physical height positively correlates with self-esteem (Judge and Cable 2004).

In a similar study, participants were randomly assigned an attractive or unattractive avatar of the same gender. They were then instructed to interact with a virtual other and the results were quite striking. For those individuals given an attractive avatar, they tended to disclose more personal information and maintained less interpersonal distance than those individuals who were assigned an unattractive avatar (Yee et al. 2009). It has also been found that, regardless of gender of the participant, if the participant knowingly or unknowingly embodies a male avatar, they exhibited more masculine gestures than participants who were embodied by female avatar (Jung and McLaughlin 2008).

Transforming self-representation has been shown to affect other behaviors as well. Merola and colleagues found that participants given avatars dressed in a black robe expressed a greater desire to commit antisocial behaviors than participants given avatars dressed in white robes (Merola et al. 2006). Documented behavior changes have also been identified in the domain of exercise. When participants saw their digital virtual representation either gain or lose weight while they themselves exercised, participants performed more exercise during a subsequent voluntary phase of the experiment. Similarly, when participants were assigned a digital representation that was running on a treadmill, versus loitering, they exercised more during the next 24 h (Fox and Bailenson 2009b). Taken together, these studies (and others like tbem) indicate that participants can truly identify with their virtual self representation and become immersed with other co-actors as though they were interacting with them in grounded reality.

An important extension of the "Proteus Effect" is the influence that digital virtual environments can exert on participants who are prejudiced against members of an outgroup. Regardless of their own race, participants who embodied a Black avatar demonstrated levels of implicit racial bias favoring Whites that was higher than participants who embodied a White avatar (Groom et al. 2009) indicating that implicit bias is heightened by exposure to outgroup (e.g., Black) avatars even it is one's one avatar. However, exploration using digital immersive virtual environments to increase contact with others who are embodied as members of stigmatized groups may reduce such bias according to Allport's (1954) theory of interpersonal contact (Peck et al. 2013).

While increasing liking between members of differing outgroups is undoubtedly a positive application of self-representation transformations, the technology afforded by digital virtual environments to manipulate features of an individual's virtual self representation can potentially be used as a tool for persuasion that is so subtle that the individual may not even know they are being manipulated. Using digital transformations, researchers (and potential advertisers) could capitalize on human beings' disposition to prefer faces similar to their own (Bailenson et al. 2006). Physical similarity between two people encourages altruism (Gaertner and Dovidio 1977), trust (DeBruine 2002) and may be used as a gauge for determining compatible interests and values (Zajonc et al. 1987). In a study by Bailenson and colleagues (Bailenson et al. 2006), participants faces were surreptitiously morphed with a face of a candidate for a fictitious election. Male participants evaluated the candidate as more attractive, warm, and were more likely to vote for the candidate when their face was morphed, but unrecognizably so, with the candidate's face. This seems to indicate that when voters have little substantive knowledge of candidates, visual affective cues may provide the dominant basis for their vote.

Researchers have also used transformed self-representations to increase retirement saving behavior in participants. When participants were given direct exposure to digitally aged version of themselves, they later allocated more money to their savings account and showed an increased tendency to opt for delayed monetary rewards (Hershfield et al. 2011). In a similar vein, deciding which product to buy at the grocery store may also be open to influence via use of transformed self-representations. Ahn and Bailenson (2011) completed multiple experiments in which participants were assigned a digital virtual self representation and interacted with it. They determined that when avatars looked like the participant, purchase intention and positive feelings for the brand the endorsed by the similar looking representation was increased. As companies create more sophisticated ways to track users activities via the internet, more targeted, personal advertising can be created that incorporates the user's physical features, making it a more persuasive message. Of course, the ethics of such manipulation are highly debatable.

The limits of the persuasiveness manipulated immersive virtual environments were tested in a study by Segovia and Bailenson (2009) in which they explored the feasibility of immersive virtual environments to instill false memories in young children. Pre-school and elementary school children were told a story about swimming with two orca whales. Next, the children were placed in one of four conditions: sitting idly, mentally imagining themselves swimming with the whales, in an immersive virtual environment with an avatar of another child swimming with two orca whales, or in one swimming with two orca whales. When interviewed, all pre-school children had made their story condition into a false memory. However, in elementary school aged children, the mental imagery and the virtual self swimming with the whales conditions resulted in more false memories than the other conditions. This is potentially due to the increase in media richness of these conditions when compared to the idle and other avatar condition.

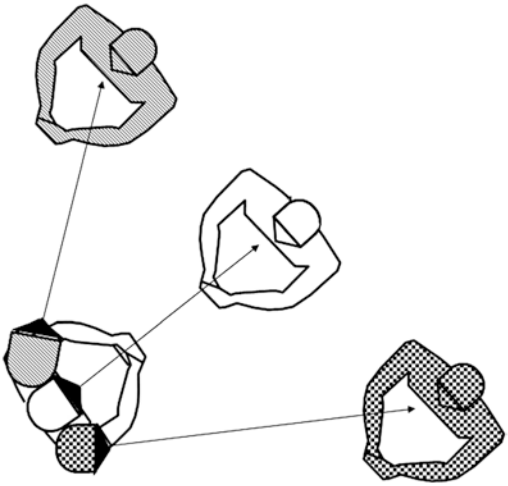
It is perhaps concerning enough to know that increasing the physical similarity of participants' digital avatars to themselves can have a significant impact on those individuals thoughts and behaviors, but it is also important to note that researchers can increase the similarity of others' avatars to oneself. Specifically, researchers can control the non-verbal behaviors of a virtual representation of self such that it mimics the non-verbal behaviors of another user thereby creating what is known as a "digital chameleon" (Bailenson and Yee 2005). Automatic (unintentional) and intentional mimicry of facets such as posture, speech patterns, language, gestures and mood, are mechanisms that increases social rapport and affiliation in face-to-face interactions (Lakin et al. 2003; van Baaren et al. 2003; Chartrand and Bargh 1999; Lakin and Chartrand 2003).

In a study by Bailenson and Yee (2005), half of the participants heard a persuasive speech by an avatar whose head movements were a playback of another subject's head movements while the other half of the participants interacted with an avatar whose head movements were an exact mimic of their own head movements but at a 4 s delay (the digital chameleon). Participants who interacted with the digital chameleon were more persuaded by the speech, liked the avatar more, and maintained more eye gaze. Most surprisingly, participants rarely detected the mimicry, suggesting that this powerful tool for increasing affiliation may be highly automatic.

Another facet of non-verbal behavior that affects ratings of persuasion and liking is length of eye gaze. In grounded reality, gaze is described as "zero sum." If participant B is looking at participant A, it is not possible for him to be simultaneously looking at participant C. However, in an IVE, the apparatus worn by the participant tracks and records the roll, pitch and yaw of a participant's head multiple times per second so consequently, determining where and how often a participant is looking is easily calculated.

Additionally, in an immersive virtual environment with multiple co-actors, it is possible for the researcher to override a speaker's actual head movements and render the virtual self-representation's movements so that it looks as though it is in eye contact with the each listener 100% of the time (or any other percentage; See Fig. 2.2). This is known as "non-zero sum gaze". This effect is possible because the digital environment is rendered uniquely for each co-actor present. Therefore, for Participant B, the information rendered on HMD about Participants A and C has already gone through a transformation to fix their gaze solely on Participant B

Fig. 2.2 Depiction of "non-zero sum gaze" in an immersive virtual environment with multiple co-actors



before it ever reaches Participant B's HMD. Non-zero sum gaze can also be reversed so that all listeners in the immersive environment (in this example, participants A and C) believe they are receiving 100% of the eye contact from the speaker (participant B).

Eye gaze is an extremely powerful tool for communicators seeking to garner attention, be persuasive and provide instruction (Segrin 1993). Multiple studies have confirmed that when a persuasive speech delivering avatar uses non-zero sum gaze to give unwavering direct eye contact to *each* co-actor simultaneously, participants are more likely to return the eye contact. Furthermore, listeners rarely detect that the gaze was unnatural, and female participants (more so than males) were more persuaded by the speaker (Bailenson et al. 2005). These findings have enormous implications, particularly in the realm of education. With online and distance learning become more prevalent, more students are interacting with instructors via online platforms. If students meet with the instructors in digital immersive environments and feel as though they have the instructor's complete attention, it could increase attention levels and increase learning (Blascovich and Bailenson 2011).

Sensory Abilities Transformations

Although manipulating self-representation factors may be the most apparent transformation to users, additions to a user's sensory abilities within digital virtual environments can have an enormous impact. Sensory ability transformations provide enhancements to human perceptual abilities. One example that has become prevalent even outside of digital environments is multilateral perspective taking abilities. In an immersive digital virtual environment, a participant views not only their perspective of the environment but the perspective from any other co-actor or position

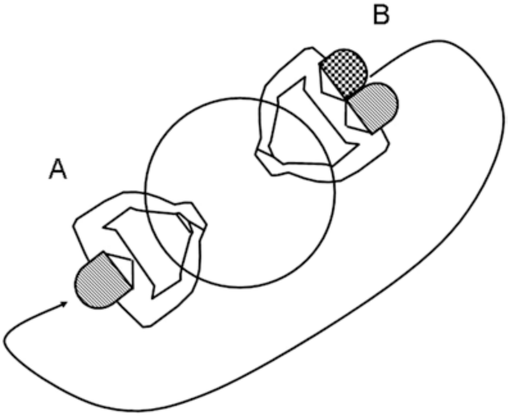


Fig. 2.3 Depiction of multiple perspective taking in an immersive digital virtual environment

in the environment (see Fig. 2.3). This additional perspective can either be a "pop-up" window or completely dominate the screen (Bailenson et al. 2004). This sensory ability is currently available in many video games across many platforms as well as some online networking software such as SKYPE.

Another type of sensory enhancement provides the participant with aggregated information they would have not have been able to assemble on their own. This transformation is known as "invisible consultants." Either algorithms or human avatars, who are only visible (i.e. rendered) to particular individuals in the immersive environment, can receive all sensory information from all co-actors in it. These consultants can use the tracking information already collected for each co-actor to provide real-time summary information about the attentions and movements of other co-actors or can scrutinize the actions of the user herself. The invisible consultant then aggregates this data and can use (or be programmed to use) behavioral flags, a flag/banner that pops up above the avatar with summative information about verbal and non-verbal behavior. These behaviors can, for example, include: head nods/shakes, facial expressions, gaze (the participant's fixation point in the IVE), and speaking frequency (Bailenson et al. 2008a).

As the number of online classes and social platforms increases, more time will be spent interacting via virtual environments. Teachers could utilize these invisible consultants and behavioral flags to ensure that all students are looking in their direction (a proxy for paying attention) to a sufficient degree during a lesson (Bailenson et al. 2008a). This transformation has also been suggested as a method of therapy for children with autism. One of the behavioral concerns with children on the autism spectrum is that they struggle to make eye contact. Researchers created an immersive virtual environment that included an audience with the autistic child who was immersed. As the child spoke, if they went too long without making eye contact with one of the audience members, that audience member's avatar would slowly fade. Throughout this study, they found that the fading was a significant cue to autistic children and when the avatars began to fade, they would increase amounts of eye contact to levels consistent with unaffected children (Bailenson et al. 2008a; Jarrold et al. 2013).

Situational Context Transformation

The last of the three types of manipulated factors is "situational context transformations." These transformations alter the spatial or temporal structure of an immersive virtual environment. This type of transformation has found many applications in education. Instructors teaching can change the flow of rendered "real time," in a sense using a "rewind" and "fast forward" button, to increase comprehension of the topic by their students. Teachers could also implement a spatial transformation by which they control the visual angle of an object as it moves, allowing students to analyze size, distance and motion without being concerned with the angle. The digital virtual world can also be spatially enhanced to be optimally configured. In this altered environment, each student would feel as though they are sitting directly in front of the teacher while the rest of the students are sitting further away (Bailenson et al. 2008a; Blascovich et al. 2002). Again, this is possible because the digital environment is rendered uniquely for each individual so changing the seating location is a relatively simple command.

Summary

Using digital immersive virtual environments to study behavior provides researchers with more experimental control than they may otherwise have been able to obtain. By manipulating three factors: self-representation, sensory abilities, and situational contexts, researchers can create an experience seemingly unlike anything that could be obtained in grounded reality. However, it may be argued that transformed social interactions skew the social influence model by reducing realism as it compares with grounded reality. But it is important to note that because transformed social interactions are hyper-personal, they result in more persuasion than natural movements or settings would. The personalized avatar and settings have become idealized to become more real than would be possible in a face-to-face setting (Walther 1996). As people spend more time online and upload more personal information, it will become even more likely that hyper-customized user experiences can be created that far exceed the boundaries of grounded reality. The question will then become, where should the new boundaries lie?

Conclusion

Although digital immersive virtual environment research took firm root in the 1990s, decreases in computing cost, coupled with increases in computing power has created an opportunity for more researchers in more laboratories to conduct research using three-dimensional tracking and real time rendering. While medicine, surgery and psychiatry represent the areas with most virtual reality based publications, the social sciences are not far behind (Oh et al. 2018). In fact, researchers are continuing to find new and innovative research questions using immersive virtual environment technology.

In particular, digital immersive virtual environment technology provides behavioral and social scientists with a new tool to study previously documented, but perhaps poorly understood, social psychological phenomenon. In addition, the technology provides a new paradigmatic approach to analyzing social interactions. Generally, researchers build theories based on testable hypotheses. However, using digital virtual technology, researchers could begin to slowly remove one component of a social interaction at a time until only the truly key pieces to the social interaction are left. In this way, they operate more like engineers determining what makes the machine "go." Although logical positivism has been the paradigm that has dominated the field of social psychology for the last few decades, perhaps immersive virtual environments will provide a new paradigmatic approach that will revolutionize the field.

Notes

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Chapter 3
Virtual Reality and Anxiety Disorders Treatment: Evolution and Future Perspectives

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Introduction

Anxiety is a natural response and a necessary warning adaptation in people. Anxiety can become a pathologic disorder when it is excessive and uncontrollable, requires no specific external stimulus, and manifests with a wide range of physical and affective symptoms as well as changes in behavior and cognition. The last version of the DSM (American Psychiatric Association 2013) introduced several changes in the classification and diagnostic criteria for anxiety disorders, specifically on specific phobias, social anxiety disorder, and agoraphobia. APA defines anxiety disorders as *"Disorders that share features of excessive fear and anxiety and related behavioral disturbances. The anxiety disorders differ from one another in the types of objects or situations that induce fear, anxiety, or avoidance behavior, and the associated cognitive ideation."* The new classification of DSM-5 for anxiety disorders includes separation anxiety disorder, selective mutism, specific phobias (animal, natural environment, blood-injection-injury, situational), social anxiety disorder (SAD),

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panic disorder, agoraphobia, generalized anxiety disorder (GAD), anxiety disorder due to another medical condition, other specified anxiety disorder, and unspecified anxiety disorder. In this chapter, we will focus on anxiety disorders in which there is empirical evidence regarding the use of VR-EBT in its treatment. This new classification for anxiety disorders no longer includes obsessive-compulsive disorder or posttraumatic stress disorder and acute stress disorder, and for this reason, they are not included in this chapter.

Virtual Reality in the Treatment of Anxiety Disorders

Virtual Reality (VR) is a technology that allows the simulation of different real-life situations in a tridimensional computer-generated environment where the user can interact with the environment as if he/she were in the real world. VR has potential as an exposure technique for treating anxiety disorders because VR and real objects have similar characteristics, which creates the illusion that the user is immersed and engaged with objects in the real world. Since its emergence, several studies have proved the usefulness of virtual reality exposure-based therapy (VR-EBT) for treating several psychological disorders, many of them focusing on anxiety disorders. These studies highlight the usefulness of VR-EBT in particular because it allows the patient to confront the different stimuli and significant elements associated with the anxiety disorder (Botella et al. 2004b). Since the first VR systems emerged in the 90s, these have now become less costly, more widely available, and generally more usable; however, it is necessary that future researches report uniform and detailed information regarding presence, immersion, anxiety duration, and demographics (Parsons and Rizzo 2008).

Another technology, which has also started to be explored for treating specific phobias, is augmented reality (AR). Which is considered as a variant of VR technology because it combines real world objects with virtual objects, using computer graphics that are blended into the real world and in real time. The user sees the real world "augmented" by virtual objects, that is, AR tries to complement or improve the reality, not to replace it. A core aspect of AR is that virtual objects add relevant and helpful information to the physical details of the real world (Azuma 1997). Milgram and Kishino (1994) analyze the qualities of VR and AR systems along a continuum from real to virtual environments. In VR systems, the user is completely immersed in synthetic contexts, whereas in AR the user sees an image comprising both the real world and virtual objects. The review of Baus and Bouchard (2014) emphasizes that augmented reality exposure-based therapy (AR-EBT) has proven itself to be a tool where people suffering from specific phobias can be exposed safely to the fear objects, without the costs associated with programming complete VR environments.

Regarding the use of VR-EBT and AR-EBT in treating anxiety disorders, to date several studies have made important contributions to guide the study of the application of VR-EBT for treating anxiety disorders. These studies have shown promising results for generalizing the effectiveness of VR-EBT in the treatment of anxiety disorders.

A meta-analysis (Powers and Emmelkamp 2008) compared controlled studies using VR-EBT with in vivo exposure therapy and a control group. This work was focused on the study of VR-EBT as a stand-alone treatment and excluded other studies combining VR-EBT with cognitive behavior therapy (CBT). The authors concluded that compared with in vivo exposure, VR-EBT was equally effective, however the small number of controlled studies based on a stand-alone VR-EBT, does not allow the generalization of these results to all anxiety disorders.

The results of a later meta-analysis (Opriş et al. 2012) which compared VR-EBT with evidence-based interventions, revealed several interesting conclusions regarding the use of VR-EBT on the treatment of anxiety disorders: (1) VR-EBT does far better than a waiting-list group. (2) The post-treatment results showed similar efficacy between the behavioral and the cognitive behavioral interventions incorporating a VR-EBT and evidence-based intervention with non-VR-EBT. (3) VR-EBT has a powerful real-life impact, similar to that of the classical evidence-based treatments. (4) VR-EBT has good stability of results over time, similar to that of the evidence-based treatments. (5) There is a dose–response relationship for VR-EBT. (6) There is no difference in the dropout rate between VR-EBT and in vivo exposure.

Likewise, literature reports VR-EBT presents several advantages in the treatment of anxiety disorders, for example:

- The main advantage of using VR-EBT is the *high degree of control* that the therapist has over the anxiogenic objects or situations; this control may encourage patients to begin exposure treatment, as it can prevent the occurrence of unpredictable events, which sometimes happens with in vivo exposure. The highest rated benefit was the ability to expose the patient to stimuli and places that would otherwise be difficult to access (e.g. an airplane, a high building, etc.).
- VR-EBT is an *effective treatment* for anxiety disorders.
- VR-EBT can be used to *maximize the benefits* of in vivo exposure.
- VR-EBT provides an *alternative* for those persons who consider that in vivo exposure is aversive.
- VR-EBT offers a more *confidential* setting than in vivo exposure; the patient's exposure task takes place within the discreet confines of the therapist's office.
- Using VR-EBT is *attractive* because of the cost-efficiency and simplicity relative to in vivo exposure.
- VR-EBT is a *flexible tool* that has allowed replicating different physical environments for treating several anxiety disorders.

VR-EBT research is *expanding* in different parts of the world with research carried out in the United States, Spain, Canada, Italy, Netherlands, United Kingdom, Germany, Australia, France, Belgium, South Korea, Switzerland, Israel, Luxembourg, Austria, Brazil, Mexico, South Africa, Chile, Sweden, Hungary, India, Portugal, Romania, Singapore among others. Although it has demonstrated its efficacy and numerous advantages, the use of VR-EBT in psychological treatments still has some limitations, years ago, was mainly noted the high costs or the limited accessibility to VR-EBT to therapists. However, as stated before (Parsons and Rizzo 2008) in the last decade the costs have been reduced significantly, and therapists have access to more specific training regarding the application of VR-EBT in psychological treatments; this has facilitated its implementation throughout the world.

Virtual Reality Software Developments

Several universities around the world have been studying for almost two decades, the possible insertion of VR-EBT in psychological treatments. Today this is a reality, and several mental health centers offer treatments based on VR-EBT to the general population. Some VR environments are commercially available for use in the treatment of several psychological disorders. These VR environments have demonstrated efficacy in the evidence-based treatment of different anxiety disorders. PreviSL (http://www.previsl.com) has available VR environments validated in the Hispanic population for treating claustrophobia, fear of flying, agoraphobia, and acrophobia. VRMC: Virtual Reality Medical Center (http://www.vrphobia.com) and Virtual Reality Medical Institute (http://www.vrphobia.eu) have available VR environments validated in English-speaking, Spanish-speaking, and German-speaking populations for treating posttraumatic stress disorder (PTSD), chronic and acute pain, fear of flying, fear of heights, fear of spiders, and other specific phobias. Virtually Better (http://www.virtuallybetter.com) has available VR environments validated in English-speaking population for treating acrophobia, storm phobia, social anxiety disorder (SAD), fear of public speaking, and fear of flying. These centers also provide support services for installation, training, and problem solving. CleVR (http://clevr.net) offers VR environments for treating fear of flying and fear of heights. Cliniques and Development in Virtuo (www.invirtuo.com) provides VR environments for treating specific phobias, GAD, SAD, obsessive compulsive disorder (OCD) and PTSD.

A few VR environments are also freely available on the condition of having a legal license of the programs necessary for its proper functioning, and these do not have support services for installation, training, or problem solving. The Cyberpsychology Lab at Université du Québec en Outaouais (http://w3.uqo.ca/cyberpsy/en/index_en.htm), freely shares three VR environments designed for treating arachnophobia, acrophobia, and claustrophobia. NeuroVR (http://www.neurovr.org), is a cost-free VR platform based on open-source software that offers a number of VR scenes which are configurable (office, class, apartment, scale, swimming pool, restaurant, lake, campfire, mountain, park, valley, waterfall, beach, desert, gazebo, island, waves, supermarket, auditorium, cinema, square, campfire, beach, lake and desert with oasis, hospital, station).

However, most VR environments remain commercially unavailable; this aspect continues limiting its imminent implementation in public and private mental health services, both industrialized and developing countries. Despite the limitations, more and more mental healthcare providers are approaching the empirically validated treatments using VR-EBT to the general population in different places in the world. Table 3.1 contains the main mental health centers that offer VR-EBT.

Table 3.1 Main private mental health centers that offer VR-EBT or AR-EBT treatments

Spain	http://www.previsl.com	-Specific phobias (travel by plane, heights, enclosed spaces, spiders, cockroaches).
	http://www.labpsitec.es	-Agoraphobia
		-Panic disorder.
		-Fear of public speaking.
		-Post-traumatic stress disorder.
		-Adjustment disorder.
		-Pathological gambling.
		-Fibromyalgia
		-Eating disorders.
United States	http://www.virtuallybetter.com	-Specific phobias (heights, storms, travel by plane, school).
		-Social anxiety and fear of public speaking.
		-Post-traumatic stress disorder.
		-Pain distraction.
		-Drug and alcohol addictions.
	http://www.vrphobia.com	-Specific phobias (enclosed spaces, driving, travel by plane, heights, needles and blood, spiders, storms, school).
		-Agoraphobia
		-Panic disorder.
		-Social anxiety and fear of public speaking.
		-Attention deficit hyperactivity disorder.
		-Chronic pain
		-Post-traumatic Stress Disorder
Belgium	http://www.vrphobia.eu	-Specific phobias (enclosed spaces, driving, travel by plane, heights, needles and blood, spiders, storms, school).
		-Agoraphobia
		-Panic disorder.
		-Social anxiety and fear of public speaking.
		-Attention deficit hyperactivity disorder.
		-Chronic pain.
		-Post-traumatic Stress Disorder.
Canada	http://invirtuo.com	-Specific phobias (travel by plane, heights, enclosed spaces, dogs, cats, insects).
		-Agoraphobia
		-Panic disorder.
		-Social anxiety and fear of public speaking.
		-Generalized anxiety disorder.
		-Obsessive-compulsive disorder.
		-Post-traumatic stress disorder.
Mexico	http://www.solucionesvirtuales.com.mx	-Fear or flying
		-Agoraphobia
		-Panic disorder.
		-Obsessive-compulsive disorder.
		-Post-traumatic Stress Disorder.
		-Social anxiety and fear of public speaking.

Virtual Reality and Specific Phobias

According to the DSM-5, individuals with specific phobias are fearful or anxious, or avoidant of circumscribed objects or situations. A specific cognitive ideation is not featured in this disorder, as it is in other anxiety disorders. The fear, anxiety, or avoidance is almost always immediately induced by the phobic situation, to a degree that is persistent and out of proportion to the actual risk posed. There are various types of specific phobias: animal; natural environment; blood-injection-injury; situational; and other situations. It is common for individuals to have multiple specific phobias. The average individual with specific phobia fears three objects or situations, and approximately 75% of individuals with specific phobia fear more than one situation or object. In the United States, the 12 month community prevalence estimate for specific phobia is approximately 7–9%. Prevalence rates in European countries are largely similar to those in the United States (e.g., about 6%), but rates are generally lower in Asian, African, and Latin American countries (2–4%). Prevalence rates are approximately 5% in children and are approximately 16% in 13–17 year-olds. Prevalence rates are lower in older individuals (about 3–5%), possibly reflecting diminishing severity to subclinical levels (American Psychiatric Association 2013).

Efficacy of Virtual Reality in Specific Phobias Treatment

The use of VR environments for treating specific phobias has been the field most studied with regard to psychological treatments. Literature reports since the year 1995–2017 more of 80 studies that demonstrate its effectiveness, advantages, and limitations. The variety of specific phobias in which the usefulness and effectiveness of VR-EBT has been studied are numerous, among which are the fear of flying, arachnophobia, claustrophobia, acrophobia, driving phobia, storm phobia, school phobia, cockroaches phobia, blood-injection phobia and small-animal phobia. Treatments have been carried out from a single session to an average of 12 sessions.

The first case study, which explored the utility of VR-EBT for specific phobias in acrophobia, was carried out by Rothbaum et al. (1995). This study was one of the starting points to perform other studies and thus to study the usefulness and effectiveness of VR-EBT in the treatment of specific phobias. Most studies have found positive results, demonstrating the effectiveness of VR-EBT for treating specific phobias.

Acrophobia Treatment using VR-EBT

Acrophobia is characterized by a marked anxiety upon exposure to heights, avoidance of heights, and a resulting interference in functioning of the individual. VR-EBT technology has been used in the psychological treatment of acrophobia since the first randomized clinical trial (RCT) published in 1995 (Rothbaum et al. 1995) which evaluated the *efficacy* of a VR-EBT in a sample of 20 participants. The only treatment condition was carried out on 8 weekly sessions, demonstrating its effectiveness. It was found significant differences between the VR-EBT and a waiting-list group. The authors conclude that treatment with VR-EBT was successful in reducing fear of heights.

The *efficacy* of another RCT with two treatment conditions (VR-EBT and in vivo exposure treatment) has been proved with a sample of 33 acrophobic participants (Emmelkamp et al. 2002). The treatment conditions were carried out on three sessions. Results showed that VR-EBT was as effective as in vivo exposure treatment, reducing the acrophobia symptoms; in addition, the results were maintained up to 6 month follow-up.

These positive results were also found in another study conducted by Coelho et al. (2008) showing significant progress on anxiety and avoidance behavior when participants were confronted with real height circumstances, participants keep these results in the 1 year follow-up.

The *role of cognitive self-statements* on VR-EBT has been explored in a study with a sample of 26 participants (Krijn et al. 2007b). The authors hypothesized that coping self-statements would enhance the effectiveness of VR-EBT. Results showed improvements regardless of the addition of coping self-statements. Specifically, VR-EBT with coping self-statements decreased anxiety of heights, decreased avoidance of height situations, and improved attitudes towards heights. However, these positive results were not maintained in the 6 month follow-up.

Many research groups have realized the importance of including objective physiological measures in VR treatment protocols. Wilhelm et al. (2005) immersed 20 non-phobic participants in a virtual elevator while monitoring heart rate and skin conductance to determine if VR was able to activate both the behavioral activation (BA) and the behavioral inhibition (BI) systems. Analysis of high-anxiety and low-anxiety groups revealed no statistically significant difference in heart rate (BA) but did reveal a difference in skin conductance (BI). When individuals are exposed in vivo, both systems are activated. As VR systems progress in power and believability, the activation of both systems could leader to more powerful VR-EBT.

In addition to peripheral physiology, it is important to begin to understand the neurophysiological processes involved in VR-EBT. A group of researchers studied the impact of glucocorticoids in 40 patients suffering from acrophobia (De Quervain et al. 2011). Subjects were given either cortisol or a placebo 1 h prior to each of three sessions of VR-EBT. Among other measures, the Acrophobia Questionnaire was administered pre- and post-treatment (3–5 days after the last exposure) and at 1 month follow-up. Results showed that acrophobics receiving VR-EBT combined with cortisol showed greater fear reduction at post-treatment and follow-up compared to subjects in the placebo condition.

In literature are also described different VR-EBT and AR-EBT systems, with different immersion levels and characteristics. These systems have demonstrated its ability to generate sense of presence and immersion; they also showed its potential usefulness in the treatment of acrophobia (Ibrahim et al. 2008; Jang et al. 2002;

Juan et al. 2006). A study evaluated *differences in sense of presence using an HMD or a CAVE system* (Krijn et al. 2004). VR-EBT for treating acrophobia showed to be effective in the post-treatment and at 6 month follow-up, but no differences were found in effectiveness between VR-EBT outcomes using an HMD or a CAVE.

Subsequent studies have been able to replicate the mentioned results, thus revealing the effectiveness of the use of VR in the treatment of this specific phobia (Coelho et al. 2014; Levy et al. 2015).

Beyond these studies, it is also important to point out that VR has been transitioned successfully from the laboratory to the private clinical setting. As an example, at the Virtual Reality Medical Centers in California, Belgium and China, the success rate of VR-EBT for specific phobias is estimated at 92%. At these clinics, the treatment is set up much like many of the studies above however; the VR-EBT can be combined with other forms of therapy to create a more individualized approach for clients to improve the chance of a successful treatment outcome.

Arachnophobia Treatment using VR-EBT

Arachnophobia is a persistent fear of spiders, an immediate anxiety response on exposure to spiders, and avoids spiders. These symptoms can interfere with the patient normal social routines, activities, and interpersonal relationships and can produce distress about having the fear. The person typically recognizes that his or her fear is excessive or unreasonable.

The first case study regarding the use of a VR-EBT for arachnophobia treatment (Carlin et al. 1997) demonstrated the *efficacy of a VR-EBT combined with mixed reality* (touching real objects which participant also saw on VR-EBT). Treatment was conducted in 12 sessions. The authors described that each session consisted of five, 5 min trials with a 2 or 3 min break between trials. The participant was sometimes encouraged to pick up the spider and/or web with her cyber-hand and place it in orientations that were most anxiety provoking. Spiders were placed in a cupboard with a web, made to jump unpredictably upon being touched, made to climb or drop in incremental jumps between the ceiling and the virtual kitchen floor, and they were touched, held and manipulated by the participant. Results suggest that VR-EBT was effective in reducing anxiety and avoidance of real spiders. A RCT with one treatment condition compared the *efficacy of a VR-EBT* versus a waiting-list group (García-Palacios et al. 2002) with a sample of 23 participants, who received four sessions of treatment. The authors report that to have completed treatment participants must be able to achieve a final exposure goal, holding a big virtual spider with tactile feedback while reporting low levels of anxiety. Then as the participants reached out with their cyber-hand to explore the virtual spider, their real hand explored a toy spider. Results showed that VR-EBT was effective for treating arachnophobia; the authors suggest that using VR-EBT with tactile augmentation significantly reduced fear and avoidance of spiders. A later RCT confirmed the hypothesis that *tactile augmentation improves the outcome of immersive VR-EBT* because it adds a physical texture and force feedback cues to VR-EBT (Hoffman et al. 2003).

Tactile augmentation is defined as a simple, safe, and inexpensive interaction technique for adding physical texture and force-feedback cues to virtual objects. The purpose of this study was to give participants the illusion of physically touching a virtual spider and evaluated that this increases treatment effectiveness. Eight participants with arachnophobia were assigned to a no treatment group, a VR-EBT, or a VR-EBT with tactile augmentation group; in this last, a physically "touchable" virtual spider (a toy spider) was used. Treatment was carried out in three sessions. Results showed that the VR-EBT with tactile augmentation had the greatest progress on behavioral avoidance and subjective fear ratings.

A *less expensive alternative VR-EBT system* for treating arachnophobia has been tested in an open trial conducted by Bouchard et al. (2006). The VR-EBT system was developed using modified 3D games to offer graduals hierarchies of fearful stimuli. It was tested in 10 participants who received a five session of treatment. Results showed significant improvement in avoidance, beliefs, and perceived self-efficacy after the treatment. The authors suggest that this results using VR-EBT by a modified computer game are promising and useful in the treatment of arachnophobia. A later RCT with two treatment conditions and 3 month follow-up (Michaliszyn et al. 2010) compared the efficacy of VR-EBT and in vivo exposure with a waiting-list group. A total of 32 participants took part in the study; participants received eight treatment sessions. Clinical and statistically significant improvements were found both VR-EBT and in vivo exposure groups; no significant differences between both groups were found. The authors suggest that both in vivo exposure and VR-EBT are efficient methods of treating arachnophobia.

Kleim et al. (2013) have studied the *enhancement of memory consolidation with sleep*: eighty subjects were recruited and fifty (who met inclusion criteria) were given one-session of VR-EBT. The protocol was similar to that used for an acrophobia study done by this group (De Quervain et al. 2011). After exposure, participants were randomly assigned to a wake condition (watching a neutral movie) or were allowed to nap. All participants then completed a behavior avoidance test (BAT) and after 1 week returned for a second BAT. Those in the sleep condition had a greater reduction in anxiety. This approach could allow for a more effective VR-EBT for those patients who do not initially receive benefit from exposure or who suffer from relapse (Craske and Mystkowski 2006).

Claustrophobia Treatment using VR-EBT

Botella's team (Botella et al. 1998) has developed and validated the first VR-EBT for treating claustrophobia. This first case study involving this VR-EBT showed improvement in claustrophobia symptoms and these were maintained at 1 month follow-up. A later case study (Botella et al. 1999) suggested that this same VR-EBT had an effect over other specific symptoms which were not treated. The authors concluded that VR-EBT was effective in reducing fear in closed spaces, in increasing self-efficacy in claustrophobic situations, and in improving other problems not specifically treated. Moreover, changes in participants were maintained at 3 month follow-up. A later open trial with a 3 month follow-up has proved the *effectiveness of this VR-EBT in* the treatment of claustrophobia (Botella et al. 2000). Four participants took part in the study. Treatment consisted of eight sessions. VR-EBT lasted approximately 35–45 mins each session; the therapist's instructions in the VR-EBT sessions were similar to those used in regular in vivo exposures. The therapist encouraged the participant to interact with the VR-EBT environments long enough for his or her anxiety to decrease. Results supported the effectiveness of the VR-EBT for treating claustrophobia; moreover, changes were maintained at 3 month follow-up. The authors suggest that VR-EBT was effective in reducing fear and avoidance in closed spaces and for increasing self-efficacy in claustrophobic situations. A later case study (Botella et al. 2002) again found these positive findings.

Fear of Flying Treatment using VR-EBT

Fear of flying is a specific situational phobia. It is characterized by an excessive, irrational fear of airplanes or any related situations, which are avoided or endured with great anxiety. Several studies using VR-EBT have demonstrated its effectiveness for treating this specific phobia.

Wiederhold and cols., carried out the first RCT to explore the *efficacy of VR-EBT and physiological monitoring* for treating people with specific phobia (Wiederhold et al. 1998). A case study was first done to evaluated the physiological symptoms that a person with fear of flying versus a person without fear of flying manifest. Heart rate, peripheral skin temperature, respiration rate, sweat gland activity, and brain wave activity were measured during a 5 min eyes closed baseline period, a 20 min virtual flight, and a 5 min eyes closed recovery period. Differences were found between the two participants' physiological responses. The authors suggest that physiological monitoring appears to be helpful when working with persons in VR-EBT environments and provides objective data that desensitization is occurring. A later RCT (Wiederhold et al. 2002) evaluated *the efficacy of a VR-EBT compared with an imagination exposure treatment.* A sample of 30 participants was randomized into three groups (VR-EBT with or without physiological feedback, and imagination exposure); treatment was carried out in 6 exposure sessions done once per week. Each group showed improvements in self-report measures, and participants in the VR-EBT groups were able to fly without medication during a post-treatment follow-up period (VR-EBT with physiological feedback, 100%; VR-EBT alone 80%). Moreover, the analysis of physiological responses showed that both VR-EBT groups became much more physiologically aroused than did the exposure with imagination group. The authors suggest that VR-EBT may help in the habituation process. One-year later, the authors presented the data of the 3 year follow-up treatment (Wiederhold and Wiederhold 2003). Results showed all participants in the VR-EBT with physiological feedback maintained their ability to fly after 3 years post-treatment whereas there was some relapse in those receiving only VR-EBT. The authors suggest that the addition of teaching self-control via visual feedback of physiological signals may serve to enhance treatment success initially and may help to maintain treatment gains in long-term follow-up.

Rothbaum and cols., have also studied the *efficacy of VR-EBT* for treating this specific phobia. In their first work (Rothbaum et al. 2000) conducted a RCT with a 6 month follow-up using a VR-EBT environment described in a previous study (Hodges et al. 1996). A sample of 49 participants was randomly assigned to VR-EBT, traditional in vivo exposure therapy, or to a waiting-list group. Treatment was completed in eight sessions. Results indicated that VR-EBT and traditional exposure therapy were both superior to waiting list group, with no differences between VR-EBT and traditional in vivo exposure therapy; in addition, the gains observed in the treatment were maintained *at 6 month follow-up.* A later study (Rothbaum et al. 2002) reported the *12 month follow-up data.* At 12 month follow-up participants maintained their treatment gains, and 92% of VR-EBT participants and 91% of traditional in vivo exposure therapy participants had traveled by airplane. A later RCT (Rothbaum et al. 2006) with a larger sample (83 participants) tested a VR-EBT with a six and 12 month follow-up and compared it with a traditional in vivo exposure therapy and a waiting-list group. The treatment consisted of eight sessions of anxiety management training followed either by exposure to a virtual airplane or a real airplane at the airport. Results indicated that VR-EBT was superior to waiting-list group. Nevertheless, they found no significant differences between VR-EBT and in vivo exposure therapy. Follow-up assessments at six and 12 months indicated that treatment gains were maintained.

Another RCT (Tortella-Feliu et al. 2011) analyzed the efficacy of *three computer-based exposure treatments* for fear of flying: a VR-EBT, a computer-aided exposure with a therapist's assistance, and a self-administered computer-aided exposure (without therapist's assistance). A sample of 60 participants with fear of flying was randomly assigned to each group. Results showed that the three treatments were effective in reducing fear of flying at post-treatment and at 1 year follow-up. Large within-group effect sizes were found for all three treatments conditions at both post-treatment and at follow-up. The authors suggest that therapist involvement might be minimized during computer-based treatments, and that a self-administered computer-aided exposure with or without therapist's assistance can be as effective as VR-EBT in reducing fear of flying.

The RCT conducted by Rus-Calafell et al. (2013) compared the effectiveness of a *VR-EBT with an exposure treatment with imagination*; a sample of 15 participants with fear of flying were randomly assigned to either VR-EBT or exposure treatment with imagination; treatments consisted of six exposure sessions. Results showed no differences between the two treatments in relation to reduced clinical symptomatology associated with fear of flying, although participants in the VR-EBT experienced less anxiety during the real flight after the treatment. Furthermore, at 6 month follow-up, danger expectations and flight anxiety continued to decrease in participants who had received the VR-EBT, and some participants took at least one more flight. Results were consistent with those found by Wiederhold et al. (2002) who also evaluated the effectiveness of a VR-EBT compared to a treatment with imaginal exposure.

Botella and cols., have also carried out several studies which have demonstrated the efficacy of VR-EBT in the treatment of this specific phobia. First, a case study (Baños et al. 2001) and a case series study with four participants (Baños et al. 2002) demonstrated its effectiveness. In a later open trial with 1 year follow-up (Botella et al. 2004a) the short and long term efficacy of VR-EBT was evaluated. The study was carried out with a sample of nine participants using a multiple baseline design (1–3 weeks). The treatment included one session of education about anxiety, flying, and exposure, and six sessions of VR-EBT. Results obtained, at post-treatment and 1 year follow-up, support the efficacy of VR-EBT in the treatment of fear of flying; after the treatment, all participants flew. This study supported the hypothesis that VR-EBT can be considered as a unique therapeutic component for fear of flying treatment. A *cross-cultural validation* of this VR-EBT was carried out in a Mexican population (Cárdenas et al. 2009). Five participants took part in the study. Results showed that VR-EBT was effective for treating fear of flying in Mexican population. Participants achieved improvement regarding their avoidance and fear; they were able to control their anxiety levels; and all were able to fly into the 3 months after the treatment. In addition, results offer evidence regarding the convenience to cross-cultural validation for treatment protocols, it showed a high percentage average of agreement between judges in the dimensions of cultural pertinence, language, and theoretical validity, in the dimension of wording the average scores above 90%. The authors suggest that the emotional perception of the problems as well as the idiomatic expressions have to be adapted to the cultural and social context of the target population.

Another open trial was carried out in a collaborative effort between Bouchard's clinic in Québec (Canada) and Wiederhold's clinics in California (USA) (Robillard et al. 2004). A total of 53 aviophobics received 8–10 VR-EBT sessions with therapists who varied in their experience with VR. Results showed a statistically significant reduction in the scores on two questionnaires: Fear of Flying and Attitudes towards Flying, with large effect sizes (>.60).

Other aspects such as the *treatment time and efficacy of treatment components* have also been studied. The efficacy of a 1-session of VR-EBT with a 6 month follow-up was evaluated in a sample of 45 participants (Mühlberger et al. 2003). The VR-EBT environment was validated in a previous study (Mühlberger et al. 2001) demonstrating its effectiveness as a tool for treating fear of flying. Participants were randomly assigned to a VR-EBT with motion simulation, a VR-EBT, or a cognitive treatment alone. Results revealed reduced fear of flying only in the VR groups' treatment. Regarding the dismantling of treatment components in VR-EBT with motion simulation, results also revealed that visual and acoustic stimuli were the main active components of VR-EBT; motion simulation as part of VR-EBT exposure does not seem to further enhance treatment effects.

The comparative efficacy of *VR-EBT with CBT and bibliotherapy* (without therapist contact) has been evaluated in an open trial (Krijn et al. 2007a) with a sample of 86 participants who took part in the study. VR-EBT was carried out in 4 weekly sessions. Results showed that the treatment with VR-EBT or CBT was more effective than bibliotherapy; statistically significant differences were not found between VR-EBT and traditional CBT. Regarding effectiveness, VR-EBT as a sole treatment component was not sufficiently effective in reducing phobic symptoms. The authors suggest that VR-EBT or CBT hold promise as treatment for fear of flying; in this

Table 3.2 Comparative of components for fear of flying included in some VR-EBT protocol treatments

	Psycho-education	Cognitive restructuring	Breathing training	VR exposure	Interoceptive exposure	Relaxation training
Wiederhold et al. (2002)			X	X		
Rothbaum et al. (2000, 2002, 2006)	X	X	X	X	X	
Botella et al. (2004a)	X			X		
Mühlberger et al. (2001)	X	X		X		
Maltby et al. (2002)	X	X		X		X

study it was the addition of cognitive training with an in vivo exposure component that showed the largest decrease in participants' anxiety, therefore, they suggest the combination of CBT with exposure techniques.

Since 1998, studies support the efficacy of VR-EBT in the treatment of fear of flying. Table 3.2 shows a comparative of the components for fear of flying treatments included in some VR-EBT protocol treatments. Recent studies have replicated the mentioned results, thus revealing the effectiveness of the use of VR in the treatment of this phobia (Boyd and Hart 2016; Czerniak et al. 2016; Ferrand et al. 2015).

Driving Phobia Treatment using VR-EBT

Driving phobia is defined as a specific phobia. It is considered as a situational phobia, and is one of five types of specific phobias that also include animal, natural environment, blood-injection-injury, and others. Driving phobia has been less studied compared to other specific phobias (e.g., fear of flying, spider phobia, or claustrophobia). In literature there are few preliminary results regarding the efficacy of VR-EBT for treating driving phobia. A case study (Wald and Taylor 2000) evaluated its efficacy in a long-standing driving phobia; the participant was treated with a VR-EBT with a design including a 7 day baseline phase followed by three treatment sessions using a standardized treatment protocol. Results showed that phobic symptoms decreased from the pre-treatment assessment, and gains were maintained at 1 and 7 month follow-up assessments.

The effectiveness of the *combination of two technologies involving computer-generated environments* (a driving game and a VR-EBT) for treating driving phobia has been evaluated (Walshe et al. 2003). The open trial was carried out with a sample of 14 participants diagnosed with driving phobia after a motor vehicle accident. The treatment was carried out a maximum of 12 sessions. In addition to the exposure component, the treatment included self-monitoring, cognitive reappraisal, physiological feedback, and diaphragmatic breathing. Measures included physiological response, subjective ratings of distress, and severity of driving phobia, post-traumatic stress, depression, and achievement of target behaviors. Findings at post-treatment supported the utility of VR-EBT and computer games in the treatment of driving phobia even when co-morbid conditions such as post-traumatic stress disorder and depression were present.

The *efficacy of VR-EBT* in the treatment of driving phobia has also been demonstrated in another open trial with one-year follow-up (Wald 2004). The VR-EBT was applied during 8 weekly sessions in a sample of five participants. Results showed significant reductions in fear and avoidance symptoms in three of five participants that were maintained at 1 year follow-up. However, VR-EBT did not result in an increase in driving frequency for any of the participants. The author suggests that VR-EBT might be most useful as a preparatory intervention or as an adjunct for in vivo exposure rather than as a stand-alone intervention.

These studies regarding the use of VR-EBT for treating driving phobia are preliminary but they offer promising findings; however, we need studies for exploring the efficacy of VR-EBT in this specific phobia. The main potential advantages of VR-EBT for treating driving phobia lie in its ability to provide safe, controlled, and standardized driving practice. It may be a more acceptable and less-threatening treatment medium than in vivo exposure for some people. However, there is relatively little controlled treatment outcome research on driving phobia and no controlled studies to date have examined the efficacy of VR-EBT for this type of phobia (Wald 2004).

Additionally, the systematic environments offered by VR can also be used for testing driving abilities. A study conducted at VRMC in San Diego in 2002 tested the effects of antihistamines (fexofenadine, loratidine, and cetirizine) on cognitive abilities (Wiederhold and Wiederhold 2013).

Cockroaches Phobia and Arachnophobia Treatment using AR-EBT

The first study offering a detailed description of a system for AR-EBT (Botella et al. 2005) used only *one-session* for the treatment of cockroaches phobia. Results of this study were very encouraging, and indicated that the AR-EBT system was capable of generating anxiety in participants; furthermore, their levels of anxiety and avoidance decreased. Other studies (Juan et al. 2005, 2006, 2004) confirm the efficacy of VR-EBT in the treatment of cockroaches phobia and arachnophobia using AR-EBT and offer data concerning the ability of the AR-EBT system to activate anxiety in participants suffering cockroach phobia or arachnophobia.

An open trial carried out with six participants diagnosed with cockroach phobia (Bretón-López et al. 2010) validated the stimuli included into an AR-EBT system depending on the capacity of the elements to activate the fear structure. The main aim of the study was to explore whether the various stimuli included into the AR-EBT system can induce anxiety in participants. Results supported the adequacy of AR-EBT system in inducing anxiety in all participants. The authors confirmed the results obtained in previous studies (Botella et al. 2005; Juan et al. 2005) regarding the capacity of the AR-EBT system to elicit sense of presence and reality judgment. The efficacy of this system in AR-EBT for cockroach phobia was demonstrated in a later open trial (Botella et al. 2010). The AR-EBT was applied using a one-session treatment and in addition, includes modeling, reinforced practice, and cognitive challenge. Results showed that AR-EBT was effective for treating cockroach phobia. All participants improved significantly in all outcome measures after the treatment; furthermore, the treatment gains were maintained at 3, 6, and 12 month follow-up assessment.

The only system reported in the literature using a *serious game by mobile phone* as tool for treating cockroaches phobia (Fig. 3.1) based in an *AR-EBT* has been tested in a case study (Botella et al. 2011). This system follows a series of clinical indications according to the existing knowledge of exposure therapy: (1) it includes different levels regarding the feared stimuli in order to make it possible to develop a hierarchy that would enable systematic and graduated exposure; (2) it allows users to gradually advance in the game, enhancing the sense of mastery and self-efficacy regarding being able to stay in a place where cockroaches are present; (3) it uses a neutral context; (4) it does not include any reference to dirt so that the user can overcome irrational thoughts associated with this; (5) it includes elements related to game and challenge; (6) it includes some kind of reward. Results showed that the use of the mobile phone serious game reduced the level of fear and avoidance. The participant found very helpful the use of the serious game and she was willing to use it after AR-EBT session as a homework assignment. The authors suggest that although the results of the case study are preliminary, serious game could be an emerging subject of research with high interest for treating specific phobias.

Another interesting tool is the *interactive projection-based AR-EBT system* for treating cockroach phobia and arachnophobia named *"Therapeutic Lamp"* (Wrzesien et al. 2013). This is a tabletop system that integrates the user's hands, a coffee mug, a cardboard box, a flyswatter, a finger and object detection, and a tracking over a flat surface (a table or a floor). For the small animal stimuli application,

Fig. 3.1 Botella's team AR mobile phone systems for cockroach phobia treatment

were modeled from small size to medium-size stimuli, in addition to a tarantula (for arachnophobia). The system was tested with a subclinical population sample. The results indicated that this system seems an effective, well-adapted tool for cockroach phobia and arachnophobia treatments.

Storm Phobia Treatment using VR-EBT

A versatile VR-EBT system without HMD has been used for treating storm phobia (Botella et al. 2006b). A case study showed the efficacy of this system for reducing phobic symptoms. The treatment was applied in two phases: in vivo exposure and VR-EBT simulating storms, rain, thunders, and lightings. For VR-EBT, was used a virtual meadow in which was included a storm with lightings, thunders of different intensity, and it was varied the time of day (from morning until night). The treatment consisted of a total of 7-sessions: two psycho-education sessions, three in vivo exposure sessions, and two intensive VR-EBT sessions. Results showed positive changes in the phobic symptoms; at the end of the treatment, the participant was able to confront the situations related to storms; results were maintained at 6 month follow-up. In addition, the participant reported a high sense of presence. The authors suggest a high potential of VR-EBT for treating storm phobia.

Figure 3.2 shows some examples of VR-EBT environments used for treating specific phobias.

Finally to mention that studies regarding the uses of VR-EBT in the treatment of specific phobias have been mainly focused in the treatment of adult population.

Fig. 3.2 Botella's team VR and AR environments for treating specific phobias

In the last years, it has also begun to study more specifically, the use of VR-EBT for treating *specific phobias in children*, for example for treating small-animal phobia or arachnophobia (Botella et al. 2006a; Bouchard 2011; Bouchard et al. 2007; Quero et al. 2014a; St-Jacques et al. 2010) or for treating school phobia (Gutiérrez-Maldonado et al. 2009). Considering the high prevalence of specific phobias in children, this is a field of study, which should be paid more attention.

Social Anxiety Disorder

According to the DSM-5, the individual with social anxiety disorder (SAD) is fearful or anxious or avoidant of social interactions and situations that involve the possibility of being scrutinized. These include social interactions such as meeting unfamiliar people, situations in which the individual may be observed eating or drinking, and situations in which the individual performs in front of others. The cognitive ideation is of being negatively evaluated by others, by being embarrassed, humiliated, or rejected, or offending others. The 12 month prevalence estimate of SAD for the USA is approximately 7%. Lower 12 month prevalence estimates are seen in much of the world using the same diagnostic instrument, clustering around 0.5–2.0%; median prevalence in Europe is 2.3%. The 12 month prevalence for older adults ranges from 2% to 5%. Prevalence in the USA is higher in American Indians and lower in persons of Asian, Latino, African American, and Afro-Caribbean descent compared with non-Hispanic whites. SAD is associated with elevated rates of school dropout and with decreased well-being, employment, workplace productivity, socioeconomic status, and quality of life. SAD is also associated with being single, unmarried or divorced, and with not having children, particularly among men (American Psychiatric Association 2013).

Efficacy of Virtual Reality in Social Anxiety Disorder and Fear of Public Speaking Treatments

Some studies have been published regarding the efficacy of VR-EBT in the treatment of people suffering SAD or fear of public speaking (FPS) and the few controlled studies that have been conducted also suggest that VR-EBT is effective in its treatment. However, research on the application of VR-EBT in this disorder remains limited. In most studies, the VR-EBT environments were scenes with an audience facing which participants had to talk (Anderson et al. 2005; Harris et al. 2002; Pertaub et al. 2002). These audiences were characterized by showing different attitudes towards the person in order to generate anxiety. The mean number of sessions was around four and five, in a range from one to 12 sessions. Frequency was weekly or intensive sessions (Anderson et al. 2003). Other studies have tested other scenarios as being in a subway, a bar, a coffee shop, or a job interview, in order to expose participants to other typical anxiogenic states to work the lack of assertiveness, interaction, intimacy, or evaluation by the others (Grillon et al. 2006; James et al. 2003; Klinger et al. 2005; Roy et al. 2003; Wallach et al. 2009).

The first study that investigated the usefulness of VR-EBT in the treatment of FPS (North et al. 1998) compared a VR-EBT environment with social anxiogenic scenes with another VR-EBT environment without social anxiogenic scenes. The treatment was carried out in 5 weekly sessions. In the study collaborated 16 participants. Results show significant differences, the group with VR-EBT and social anxiogenic scenes showed significant improvement.

Another early study that evaluated the usefulness of VR-EBT for FPS treatment (Slater et al. 1999) measured the emotional response when participants were exposure to a virtual audience seems attentive and interested, or when audience seems hostile and disinterested. Their main finding was that participants responded appropriately to negative or positive audiences; negative audiences evoked high anxiety levels, even when these are virtuals. These results were confirmed in a subsequent study (Pertaub et al. 2002) with a sample of 40 participants. A later study evaluated the response of persons with social anxiety regarding to a VR-EBT environment (Slater et al. 2006). The main contribution of these studies was to demonstrate the utility of VR-EBT in the treatment of FPS and the VR-EBT environment capability for generating sense of presence.

The RCT conducted by Harris et al. (2002) compared the efficacy of a VR-EBT treatment for FPS with a waiting-list group. The sample was composed of 14 participants how received four individual exposure sessions of approximately 15 min. Results suggested that four VR-EBT sessions were effective for reducing the symptoms of FPS.

One year later, a case study with two participants (Anderson et al. 2003) evaluated the efficacy of a VR-EBT when this was applying on 10 weekly sessions or six intensive sessions (during 3 days). Participants met criteria for SAD and FPS, and they were exposed to a virtual audience. The VR-EBT environments consisted of videos embedded within a virtual classroom, these proved its effectiveness for reducing social anxiety symptoms. In both case studies, scores on all measures of FPS decreased. Results from these two case studies suggested that VR-EBT may be a useful tool for SAD and FPS treatments. In a later study, a VR-EBT was evaluated in a sample of 10 participants diagnosed with FPS; treatment was carried out in eight sessions. Results suggested that 80% of participants were significantly improved after VR-EBT, and 75% of them maintained treatment gains at 3 month follow-up.

The first RCT that used VR-EBT for treating SAD (Roy et al. 2003) demonstrated its efficacy compared with a traditional CBT and a waiting-list group. The VR-EBT was evaluated in a sample of 10 participants suffering SAD. Participants were exposed to four VR-EBT environments that evoked performance, intimacy, scrutiny, and assertiveness. Each participant attends 12 sessions of VR-EBT. In a later RCT with a large sample of 36 participants diagnosed with SAD was compared a VR-EBT with a CBT (Klinger et al. 2005). Results showed statistically and clinically significant improvement in both treatments; these were highly effective to reduce social anxiety and social avoidance. The differences in efficacy between VR-EBT and CBT were not significant. In both studies the VR environments used for VR-EBT included situations that target fears other than fear of public speaking.

The efficacy of a VR-EBT was studied in another RCT with a sample of 88 participants with FPS (Wallach et al. 2009). The VR-EBT was compared with a traditional CBT and a waiting-list group. Treatment was carried out in 12 sessions. Results showed a large effect sizes for anxiety reduction following treatment both VR-EBT and CBT; therefore, the authors concluded that both VR-EBT and CBT are useful treatments for FPS. In addition, they found a lower dropout rate from VR-EBT in relation to the CBT; VR-EBT was found most attractive to participants. A later study including a 1 year follow-up (Safir et al. 2012) found that the positive VR-EBT treatment effects were maintained on anxiety symptoms. However, the authors note that treatment helped to reduce avoidance to a non-clinical level and that fear level had not yet been reduced to a non-clinical level; therefore, they suggest that perhaps fear reduction requires more than a 12-session program.

The RCT conducted by Anderson et al. (2013) with a 12 month follow-up, evaluated the efficacy of a VR-EBT compared with an in vivo exposure therapy and a waiting-list group. In the study took part 97 participants diagnosed with SAD. The treatment was carried out in eight sessions. Results showed that participants from VR-EBT and in vivo exposure group therapy significantly improved on all but one measure (length of speech for the exposure group therapy and self-reported fear of negative evaluation for VR-EBT). At 12 month follow-up, people showed significant improvement from pre-treatment on all measures. There were no differences between both exposure treatments. The authors suggest that VR-EBT is equally effective as in vivo exposure group therapy.

In a recent RCT to address the broad spectrum of social fears of people suffering from SAD, Bouchard et al. (2017) recruited 59 adults receiving a diagnosis of SAD that were randomly assigned to CBT with traditional in vivo exposure, VR-EBT and a waiting list. Participants in the active treatment conditions received 14 individual weekly CBT sessions with exposure sessions performed either only in vivo or only in virtuo. Assessment included anxiety scales and self-report questionnaires (e.g. LSAS, Social Anxiety Disorder Scale, Fear of Negative Evaluation, Beck Depression Inventory-II) and a BAT. Two sets of analyses were performed: (a) classical statistical inferences tests to find differences between the two active treatments, and (b) non-inferiority tests to document with statistical tests the lack of difference between the two active treatments. Results with the final sample and the follow-up data confirmed that both treatments were more effective than the no-treatment condition and as effective to each other. This finding is already interesting. But Bouchard et al. (2017) also documented the efforts required by therapists to conduct the exposure sessions and found important advantages of conducting exposure in virtuo, which was significantly less cumbersome and costly to conduct than in vivo ones, in terms of having access to relevant stimuli to induce ridicule, duration, preparation, worries about confidentiality, costs of gathering staff members to attend at public speaking exercises.

Table 3.3 show a summary of the treatment protocols, used in some of these RCT.

Table 3.3 VR-EBT sessions for social anxiety disorder and fear of public speaking

	Roy et al. (2003)	Wallach et al. (2009)	Anderson et al. (2013)
Session 1	-Therapy presentation & psychoeducation	-Therapy presentation & psychoeducation	-Therapy presentation & psychoeducation
Session 2	-VRET (performance environment)	-Training in automatic thoughts identification	-VRET including: *Self-focused attention*
Session 3	-VRET (performance environment)	-Cognitive restructuring	-*Perceptions of self and others*
Session 4	-VRET (intimacy environment)	-VRET -Cognitive restructuring	-*Perceptions of emotional control* -*Rumination* -*Realistic goal setting for social situations*
Session 5	-VRET (intimacy environment)	- VRET -Cognitive restructuring	
Session 6	-VRET (scrutiny environment)	- VRET. -Cognitive restructuring	
Session 7	-VRET (scrutiny environment)	- VRET -Cognitive restructuring	
Session 8	-VRET (assertiveness environment)	- VRET -Cognitive restructuring	-Relapse prevention
Session 9	-VRET (assertiveness environment)	-VRET -Cognitive restructuring	
Session 10	-VRET (environment chosen by the patient)	- VRET -Cognitive restructuring	
Session 11	-VRET (environment chosen by the patient)	- VRET -Cognitive restructuring	
Session 12	-VR (environment chosen by the patient)	-Relapse prevention	

Other specific factor in SAD, is the *eye contact avoidance*, which has been studied by using an eye-tracking system (Grillon et al. 2006). The treatment was carried out using a VR-EBT in a sample of eight participants with SAD. Results suggested a significant improvement after the treatment and a positive correlation between the decrease of anxiety and the decrease of eye contact avoidance; eye-contact avoidance diminished after the treatment.

In addition to the above, also mention that in SAD treatment using VR-EBT some issues has been little studied. For example, *free speech dialogues* with avatars is an issue poorly studied because most of studies have focused mainly on recreating a social setting (e.g., a bar, a shop, a dinner), or non-verbal language of avatars (e.g., attentive, boring, or tired). The work of Brinkman et al. (2012) evaluated a VR-EBT based on speech dialogues; therapists can select from a limited set of avatar's reply sentences, or they can speak live through a microphone to create the avatar's voice, this allow participants to be exposed to free speech dialogues with different avatars. The authors also suggest that a system with these characteristics could be used in a remote setting, where therapist and participants are located at different locations.

This system used a remote VR-EBT platform that supports remote treatment, using the Internet to connect the therapist and the patient computer.

Another issue poorly studied is the *interaction in real time with avatars* into VR-EBT environments. The study conducted by Powers et al. (2013) explored the possibility that virtual avatars interact and converse with the patient in real time. This technology allowing to therapist directly control the avatar (including speaking) during VR-EBT. Results showed that conversation in VR-EBT environment elevated fear ratings; however, in vivo conversation was rated as more realistic than the conversation in VR-EBT environment. The authors suggest that real time interaction or conversation in VR-EBT environment may prove useful for treating SAD in future studies.

Another recent studies have been able to replicate all these results, but also have found interesting findings that make the use of RV be much more effective in the treatment of this disorder (Anderson et al. 2017; Kim et al. 2017; Parrish et al. 2016).

Panic Disorder and Agoraphobia

The latest edition of DSM has separated panic disorder and agoraphobia. From this perspective, the person with panic disorder, experiences recurrent unexpected panic attacks and is persistently concerned or worried about having more panic attacks or changes in his or her behavior in maladaptive ways because of panic attacks. Panic attacks are abrupt surges of intense fear or intense discomfort that reach a peak within minutes, accompanied by physical and cognitive symptoms. Panic attacks may be expected, such as on response to a typically feared object or situation, or meaning that the panic attack occurs for no apparent reason. In the general population, the 12 month prevalence estimate for panic disorder across the USA and several European countries is about 2–3% in adults and adolescents. In the USA, significantly, lower rates of panic disorder are reported among Latinos, African Americans, Caribbean blacks, and Asian Americans, compared with non-Latino whites; American Indians, by contrast, have significantly higher rates. Lower estimates have been reported for Asian, African, and Latin American countries, ranging from 0.1% to 0.8%. Panic disorder is associated with high levels of social, occupational, and physical disability; considerable economic costs; and the highest number of medical visits among anxiety disorders, although the effects are strongest with the presence of agoraphobia. Individuals with panic disorder may be frequently absent from work or school for doctor and emergency room visits, which can lead to unemployment or dropping out of school (American Psychiatric Association 2013).

DSM-5 agoraphobia conceptualization, describes people who are fearful and anxious about two or more of the following situations: using public transportation; being in open spaces; being in enclosed places; standing in line or being in a crowd; or being outside of the home alone in other situations. The individual fears these situations because of thoughts that escape might be difficult or help might not be available in the event of developing panic-like symptoms or other incapacitating or embarrassing symptoms. Every year approximately 1.7% of adolescents and adults have a diagnosis of agoraphobia. Agoraphobia is associated with considerable impairment and disability in terms of role functioning, work productivity, and disability days. Agoraphobia severity is a strong determinant of the degree of disability, irrespective of the presence of comorbid panic disorder, panic attacks, and other comorbid conditions. More than one-third of people with agoraphobia are completely homebound and unable to work (American Psychiatric Association 2013).

Efficacy of Virtual Reality in Panic Disorder and/or Agoraphobia Treatments

Panic disorder and agoraphobia have received quite attention from the scientific community in the field of cyberpsychology. Since 1996, several studies have proved the efficacy of VR-EBT in the treatment of these disorders.

One of the first studies focused on the evaluation of the potential uses of VR-EBT in panic disorder and agoraphobia treatment (Moore et al. 2002) reported that the VR-EBT environment activated anxiety in non-phobic people. The study explored the *physiological responses of non-phobics* when placed in a VR-EBT environment. People without a diagnosis of panic disorder and/or agoraphobia, were exposed to four VR-EBT environments (elevator, supermarket, town square, and beach).

The first RCT (Vincelli et al. 2003) to evaluate the *efficacy of VR-EBT in panic disorder and agoraphobia treatment* compared the efficacy of VR-EBT, CBT, and a waiting-list group in a sample of 12 participants diagnosed with panic disorder and/or agoraphobia. The treatment protocol was carried out in eight sessions for VR-EBT group and 12 sessions for CBT group; in addition, several support sessions were required. The results showed that both CBT and VR-EBT could significantly reduce the number of panic attacks. However, VR-EBT procured these results using 33% fewer sessions than CBT; this datum suggest the authors, reflects that VR-EBT could be better than CBT in relation to the *cost-benefit of the treatment*, justifying the added use of VR-EBT equipment in the treatment of panic disorder.

In another RCT conducted by Botella et al. (2007b) with a larger sample and a 12 month follow-up with a larger sample and a 12 month follow-up, the *efficacy of VR-EBT in panic disorder and agoraphobia treatment* was also evaluated. The study compared VR-EBT and traditional CBT with a waiting-list group in a sample of 37 participants diagnosed with panic disorder and/or agoraphobia. The VR-EBT environments include some anticipatory anxiety objects (e.g., an answering machine with a message, a radio were shopping center are announced, or an anxiogenic conversations). They include anxiety modulators that can be adjusted by the therapist (e.g., the number of people, simulating unexpected events, the trip duration). Also they included interoceptive elements that can be conducted simultaneously to provoke bodily sensations (e.g., fast heartbeat, accelerated breathing, tunnel vision, blurred vision, and double vision). This study is the only study, which aimed to

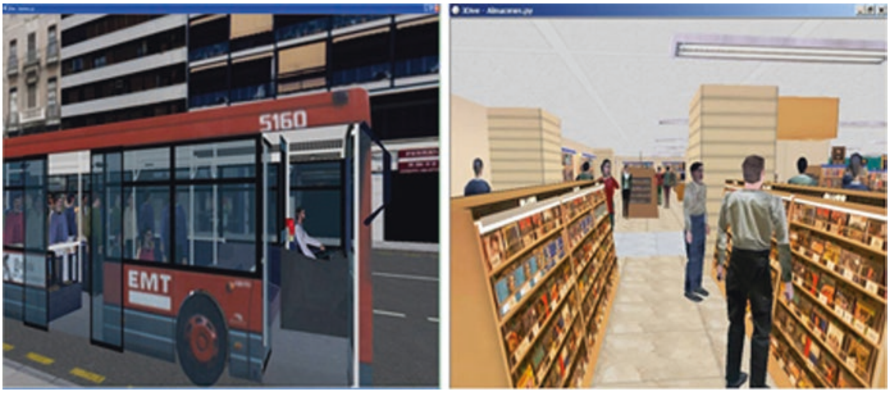

Fig. 3.3 VR environments for panic disorder and agoraphobia treatment (Botella et al. 2007b)

distinguish interoceptive exposure in traditional CBT from that in VR-EBT. The VR environments (see Fig. 3.3) designed by Botella's team (Botella et al. 2004c) include the ability to deliver VR-interoceptive exposure simultaneously with VR-EBT. While participants were exposed to virtual agoraphobic situations (e.g., living room), they were also exposed to heightened bodily sensations by means of VR-interoceptive exposure (e.g., fast heartbeat); or by means of traditional interoceptive exposure (e.g., hyperventilation triggered through exposure to the VR-EBT environments). This study also demonstrated the efficacy of VR-EBT in the panic disorder and agoraphobia treatment and showed that a multi-component CBT using a VR-EBT environment for the exposure to aversive objects or situations was superior to a waiting-list group and as efficacious as a traditional multi-component CBT with in vivo exposure. Furthermore, significantly therapeutic outcomes were maintained at 12 month follow-up; in addition, participants showed a high level of satisfaction with the VR-EBT component.

Few research studies have focused on the study of VR-*EBT effects in individuals with only a diagnosis of agoraphobia.* A RCT conducted by Peñate et al. (2008) found that using VR-EBT is as effective as traditional CBT for people with agoraphobia. The study evaluated the efficacy of VR-EBT compared with a traditional CBT. The study was carried out in a sample of 28 participants with chronic agoraphobia (with two or more years under psychoactive drug treatment). The treatment protocol included 11 weekly sessions. Results showed a significant improvement in cognition, body sensation, anxiety level, and depression symptoms in both treatment groups; this improvement remained in the 3 month follow-up. The authors reported that participants in the VR-EBT condition showed a slight amelioration of symptoms compared with the CBT participants group. In addition, changes regarding the use of pharmacological treatment were found from the end of the treatment until 3 month follow-up: 23.10% of CBT and 40% of VR-EBT patients discontinued drug use. The main limitation of this study was that participants had a combined pharmacological treatment, limiting confirms the real effect of VR-EBT or CBT on their improvement.

The RCT directed by Meyerbroeker et al. (2013) has also evaluated the *effects of* VR-EBT *in agoraphobic symptoms* in a sample of 55 participants, all of them diagnosed with panic disorder and agoraphobia. It was compared a VR-EBT and a traditional CBT with a waiting-list group. The treatment components were four sessions of cognitive techniques and six sessions with virtual or in vivo exposure. For agoraphobia symptoms, results did not show differences between VR-EBT and CBT; both were effective compared to no treatment. For panic symptoms was found that CBT was more effective than VR-EBT. The authors hypothesized that initial changes in agoraphobic cognitions during the cognitive phase predicted later changes in agoraphobic avoidance behavior. In addition, they found that VR-EBT or CBT tending to have larger effect sizes than the other treatment components.

Several studies have focused on different aspects involved in the treatment of these disorders. Two works studied the possibility of using *VR-interoceptive exposure* in the treatment of panic disorder and agoraphobia finding that using VR-interoceptive is as effective as traditional interoceptive exposure; in addition, VR-interoceptive was well accepted, and expectation and satisfaction of the participants were very positive. The first study (Pérez-Ara et al. 2010) evaluated the differential *efficacy of VR-interoceptive exposure* versus traditional interoceptive exposure in order to clarify its effects versus traditional interoceptive exposure. A sample of 29 participants diagnosed with panic disorder and/or agoraphobia received VR-interoceptive exposure to be exposed to visual and audio effects (fast heartbeat, accelerated breathing, tunnel vision, blurred vision, or double vision), simultaneously they were exposed to VR environments (Fig. 3.3) validated in previous studies (Botella et al. 2004c, 2007b). In contrast, participants who received traditional interoceptive exposure were first exposed to the VR environments and then were exposed to traditional interoceptive activities (e.g., physical exercises, hyperventilation, or spinning) in order to elicit bodily sensations. Figure 3.4 shows an example of VR and traditional interoceptive stimuli. Results showed no significant differences between VR-interoceptive and traditional interoceptive exposure; both treatment conditions were equally effective for reducing relevant symptoms related

Fig. 3.4 VR-interoceptive exposure vs traditional interoceptive exposure (Pérez-Ara et al. 2010)

to panic disorder and agoraphobia; results were maintained at 3 month follow-up assessment. However, the authors report that VR-interoceptive exposure provides some advantages versus traditional interoceptive exposure, for example, to control and provoke at any time some bodily sensations such as tunnel vision, blurred vision, or double vision, which are difficult to provoke with traditional interoceptive exposure. In a later study (Quero et al. 2014b) was examined the *VR-interoceptive exposure acceptability* versus traditional exposure. In addition, was explored the relationship between *participants' treatment expectation and satisfaction*, *and clinically significant change*. Results showed that VR-interoceptive exposure (fast heartbeat, accelerated breathing, tunnel vision, blurred vision, or double vision) and traditional interoceptive exposure (e.g., hyperventilation, running, spinning, breathing through a narrow straw, shaking one's head rapidly) were well accepted by participants. Expectation and satisfaction were evaluated as very positive in both interoceptive exposure conditions before and after the treatment, and in the 3 month follow-up. They also showed that VR-interoceptive exposure might create a more intense interoceptive experience overall by combining simultaneously with traditional interoceptive exposure (e.g., hyperventilation).

The *influence of different displays (HMD or CAVE) in the treatment outcomes and sense of presence* was evaluated in a study (Meyerbröker et al. 2011) including a sample of 11 participants diagnosed with panic disorder and/or agoraphobia who were assigned to an HMD or a CAVE treatment group, they were evaluated versus a waiting-list group. Participants received a VR-EBT which included 10 sessions focused on psycho- education, cognitive restructuring, interoceptive exposure, and VR-EBT. Results revealed that VR-EBT was more effective than no treatment. Results also indicated that there was no relationship between the level of presence and treatment outcomes; no differences in effectiveness were found between using an HMD or a CAVE system. A later study (Meyerbroeker et al. 2013) again demonstrated the effectiveness of a VR-EBT in agoraphobia and panic disorder treatment.

The effectiveness of using *VR-EBT with or without cognitive restructuring* has been evaluated in an open trial conducted by Malbos et al. (2013) with a sample of 18 agoraphobic participants. The treatment protocol included 10 weekly sessions lasting 90 min. The results reported that adding cognitive therapy did not provide significant additional benefit for agoraphobia treatment. The impact of the VR-EBT without cognitive restructuring was maintained across the 3 month follow-up; the authors suggest that adding cognitive therapy did not provide significant longer-term improvements. In a previous study (Malbos et al. 2011), the authors found similar results with a sample of 10 agoraphobic participants.

These studies, which have explored the use of VR-EBT for panic disorder and/or agoraphobia treatment, have demonstrated that using a VR-EBT is as effective as using a traditional CBT in the treatment of these disorders; they have also identified some advantages over traditional treatments and that results are maintained in the long term. Lists de measures included in assessment protocol of some controlled studies, Table 3.4 shows the treatment sessions of Vincelli's and Botellas's protocols for panic disorder and agoraphobia.

Table 3.4 VRET treatment sessions for panic disorder and agoraphobia

	Vincelli et al. (2003)	Botella et al. (2007b)
Session 1	-Psychoeducation	-Psychoeducation
	-Establishment of the VRET hierarchy	
Homework:	*-Record of panic*	*-Catastrophic interpretations recording*
		-Record of panic
Session 2	-Cognitive assessment	-Slow breathing training
	-Scheduling of in vivo self-exposure	-Cognitive restructuring
Homework:	*-Record of panic*	*-Practicing slow breathing*
	-In vivo self-exposure	*-Record of panic*
Session 3	- Cognitive restructuring	- VRET
	-VRET	- VR-interoceptive exposure
Homework:	*-Record of panic*	*-Record of panic.*
	-In vivo self-exposure	
Session 4	-VRET	-VRET
	-Cognitive restructuring	-VR-interoceptive exposure
		-Cognitive restructuring
Homework:	*-Record of panic*	*-Record of panic*
	-In vivo self-exposure	
Session 5	- VRET	-VRET
	-Interoceptive exposure	- VR-interoceptive exposure
		-Cognitive restructuring
Homework:	*-Record of panic*	*-Record of panic*
	-In vivo interoceptive exposure	
Session 6	- VRET	-VRET
	-Interoceptive exposure	-VR-interoceptive exposure
	-Cognitive restructuring	-Cognitive restructuring
Homework:	*-Record of panic*	*-Record of panic*
	-In vivo interoceptive exposure	
Session 7	- VRET	-VRET
	-Interoceptive exposure	-VR-interoceptive exposure
	-Cognitive restructuring	-Cognitive restructuring
Homework:	*-Record of panic*	*-Record of panic*
	-In vivo interoceptive exposure	
Session 8	-Cognitive restructuring	-VRET
	-Relapse prevention	- VR-interoceptive exposure
		-Cognitive restructuring
Homework:		*-Record of panic*
Session 9		-Relapse prevention

As was noted in this section, evidence has demonstrated the effectiveness of VR-EBT in the treatment of panic disorder and agoraphobia. Nevertheless, it is necessary to carry out more controlled studies to evaluate the role of each treatment component, the exclusion, or inclusion of some treatment component, or the necessary number of sessions for treatments. For example, in relation to characteristics of VR environments, it is suggested that one aspect that is very important to pay attention in

VR environment is the role of avatars because in agoraphobics, the interaction with other persons in different context produces anxiety responses; thus, the presence of avatars is necessary to create situations that are more realistic (Peñate et al. 2008). It has also been suggested that it is necessary to determine the efficacy of each treatment component in the specific case of people with agoraphobia (Malbos et al. 2011, 2013; Meyerbroeker et al. 2013; Meyerbröker et al. 2011; Peñate et al. 2008).

The most recent studies (Breuninger et al. 2017; Pitti et al. 2015; Quero et al. 2014b) continue to replicate these great results, thus reaffirming the effectiveness of this technology for the treatment of these two disorders.

Generalized Anxiety Disorder

DSM-5 describes generalized anxiety disorder (GAD) as persistent and excessive anxiety and worry about various domains, including work and school performance that the person finds difficult to control. In addition, the person experiences physical symptoms, including restlessness or feeling keyed up or on edge; being easily fatigued; difficulty concentrating or mind going blank; irritability; muscle tension; and sleep disturbance. Excessive worrying impairs the individual's capacity to do things quickly and efficiently, whether at home or work. The worrying takes time and energy; the associated symptoms of muscle tension and feeling keyed up or on edge, tiredness, difficulty concentrating, and disturbed sleep contribute to the impairment. Importantly the excessive worrying may impair the ability of individuals with GAD to encourage confidence in their children. The 12 month prevalence of GAD is 0.9% among adolescents and 2.9% among adults in the general community of the USA. The 12 month prevalence for the disorder in other countries ranges from 0.4% to 3.6%. GAD accounts for 110 million disability days per annum in the USA citizens (American Psychiatric Association 2013).

Efficacy of Virtual Reality in Generalized Anxiety Disorder Treatment

Very few studies have addressed the usefulness and effectiveness of VR in the treatment of GAD (Gorini and Riva 2008; Pallavicini et al. 2009; Repetto et al. 2013); databases only contain some jobs since 2008.

In a first approximation, a treatment protocol has been presented (Gorini and Riva 2008). This proposed the use *of VR to facilitate the relaxation process* by visually presenting key relaxing images in order to master anxiety management skills. The treatment protocol is based on 14 treatment sessions. The authors suggest that the visual presentation of a VR calm scenario can facilitate participants' practice and mastery of relaxation, making the experience more vivid and real than the one that most participants can create using their own imagination and memory, and triggering a broad empowerment process within the experience induced by a high sense of presence.

An open trial with a sample of 12 participants proposed improvement of treatment for GAD *using a biofeedback VR system* which was used to master anxiety management skills (Pallavicini et al. 2009). This system was tested in a mobile phone for allowing participants perform the VR experience in an out-participant setting. Participants were assigned to a VR intervention with biofeedback were the physiological data controlled the movement of the waves, for example, a reduction of the participants' physiological activation reduced the movement of the waves (until the ocean becomes completely calm); the other treatment was carried out without biofeedback and both treatments were compared with a waiting-list group. Participants who received the VR intervention with biofeedback reported a higher decrease in anxiety scores after the treatment. Regarding the participants' physiological responses in VR intervention with biofeedback, they found a decrease tendency in HR and GSR. Results showed that biofeedback used in combination with VR, increased its effect helping participants to better control their physiological responses and to gauge their success in a more efficient way. On the other hand, the authors suggest that using mobile phones could solve the problem of using VR in psychological treatments regarding the impossibility of using a VR system in the real life context of the patient. In other open trial with a large sample (25 participants), these results were confirmed (Repetto et al. 2013). Results suggest the possibility of using VR as a component of GAD treatment, and advocate the clinical use of VR supported by mobile phone to practice session contents at home. About the usefulness of mobile phone in the treatment, participants considered it helped them consolidate the relaxation training in the absence of the therapist. The authors consider that a critical issue related to the use of VR in the treatment of anxiety disorders, is the lack of availability of VR systems in the patient's real-life context to practice what was learned in sessions. In this perspective, add the authors, the availability of VR systems outside the therapist's office is critical to speed up the learning process and achieve quickly clinical results.

In summary, the very limited number of studies regarding the use of VR in GAD treatment reveals the need for further studies to explore the effectiveness of using this technology in the treatment of this psychopathology. It is also important to study other potential uses of VR in other GAD treatment components (e.g., intolerance of uncertainty) in addition to relaxation training and mastering anxiety management skills. Therefore, in order to generalize the effects of VR in GAD treatment, more controlled studies with larger samples and follow-up assessment are needed.

Conclusions and Future Directions of Virtual Reality in the Treatment of Anxiety Disorders

Regarding the efficacy of using VR-EBT in the treatment of anxiety disorders, during the last 20 years there has been sufficient empirical evidence regarding VR-EBT: data reveal the effectiveness of using VR-EBT with or without cognitive techniques for the treatment of anxiety disorders. Also nowadays, there are data regarding the effect of specific treatment components such as VR-interoceptive exposure for panic disorder and agoraphobia treatment, the acceptability, the differential efficacy between treatment components, or combining VR-EBT with other technologies like mobiles phones. In addition, combining VR with pharmaceuticals has proven successful in several studies (Rothbaum 2009; Wiederhold and Wiederhold 2013).

So far, it has been demonstrated that VR-EBT is effective in treating anxiety disorders and represents several advantages over traditional CBT, which converts VR-EBT into a powerful tool by which treatments are less aversive and more accessible. Most of studies have found no significant differences between the effectiveness of VR-EBT and traditional CBT; about this some authors hypothesize that with larger samples sizes and the use of more robust anxiety measures it could be possible to find those differences in favor of VR-EBT (Klinger et al. 2005).

Future Directions to Virtual Reality Treatments

Botella et al. (2007a) suggest that technology will evolve to support the knowledge society of the twenty-first Century and it will be rooted in the following areas: *Environmental intelligence* that allows through the development of networking technologies and intelligent sensors that capture physiological, psychological, and context information of the user. *Persuasive computing* that enable contents generation in order to change or reinforce users behaviors. *Ubiquitous computing* that enables the user to access to the system anywhere, anytime, and under multiple ICT supports and therapy systems including VR or AR technology and natural interfaces. However, more efforts are required to make the use of RV be more routinely by clinicians; because in as much complex and expensive is the technology, the probability that the user accept and incorporate it into their daily work is lower (Botella et al. 2006c).

For future development of VR systems, VR-EBT treatment protocols, and researches, it would be desirable to keep and strengthen the following issues that summarize the main conclusions regarding the use of VR in psychological treatments:

1. The measure of *physiological variables* can provide an objective measurement of improvement over the course of VR-EBT, in addition to self-report measures. Therefore, in the future it could be useful to promote the inclusion of standardized physiological measures in most assessment protocols; for example, heart rate variability, breathing rate, skin conductance, or blood pressure in order to further understand the process that occurs in people suffering an anxiety disorder (Wiederhold and Wiederhold 2003). It is also suggested to use routinely *BAT* in the assessment protocols before and after VR-EBT.
2. Currently there are good evidence regarding the effectiveness of VR-EBT in psychological treatment protocols; however, its usefulness and integration *in assessment protocols* (Rothbaum 2009) has been little studied (Mühlberger

et al. 2008; Wald et al. 2000). Likewise, it has been analyzed the inclusion of other assessment methods such as the magnetic resonance (Clemente et al. 2010, 2013).

3. Exploring the possibilities of *integrating VR-EBT into Internet* (Rothbaum 2009) in order to provide psychological treatment to more people in more places, at any time (for example, people with chronic agoraphobia who have difficulty leaving home would benefit especially). In this way, a pilot study (Yuen et al. 2013) has investigated the efficacy and feasibility of implementing an online VR treatment for SAD through Second Life. Analyses showed significant pre-treatment to follow-up improvements in social anxiety symptoms. Participants and therapists rated the treatment program as acceptable and feasible, despite frequently encountered technical difficulties.
4. Psychological treatments are evolving, and new guidelines begin to take hold regarding the *application of evidence-based CBT and VR-EBT or other technologies* (e.g., augmented reality or mobile systems). For example, AR-EBT systems or Serious Games have been used for treating cockroach phobia (Botella et al. 2010; Bretón-López et al. 2010; Wrzesien et al. 2013).
5. *Mobile devices* have demonstrated its usefulness in facilitating exposure therapy for treating cockroach phobia (Botella et al. 2011) and GAD (Pallavicini et al. 2009; Repetto et al. 2013). Nevertheless, there are few studies focused in these possibilities; therefore, this is an issue that should continue to be studied as well as the inclusion of *VR-EBT in other mobile technologies.*
6. Developing *open and flexible VR environments* that can be provide feedback to the patient (e.g., adding pictures, videos, audio-recorder, music, or specific sounds) and for adapting them to the nature and needs of each patient.
7. It is important to research on the *cost-benefit ratio* existing between the therapeutic procedure (e.g., money, time, emotional involvement) and VR-EBT outcomes.
8. More cross-cultural studies are needed in order to facilitate the generalization of treatment outcomes; for example, some VR environments used in the treatment of Spanish population have been used in Mexican population demonstrating its effectiveness (Cárdenas et al. 2009). A study (Wallach et al. 2009) suggests that VR environments culturally adapted could increase sense of presence and thus VR-EBT effectiveness.
9. In the process of research, it is important that the clinical experiences carried out in VR environments related to *real experiences*, within a flexible context that combines cultural, physical and cognitive aspects and in so doing, reach a high degree of sense of presence and reality judgment (Carvalho et al. 2010).
10. Although there have been some studies, is not conclusive the relationship between the level of sense of presence, the level of fear/anxiety and the treatment outcomes. Therefore, this issue should be explored further.
11. In order to assess the maintenance of the results of VR-EBT, more *studies with long term follow-up* (e.g., 6 or 12 month) are needed.
12. It has been widely demonstrated that VR-EBT is effective in the treatment of various anxiety disorders; however, the studies have been conducted mainly in

adult samples. Very few studies have evaluated the *efficacy of VR-EBT in the treatment of children* with anxiety disorders, and these have focused primarily on the treatment of specific phobias (Botella et al. 2006a; Bouchard et al. 2007; Gutiérrez-Maldonado et al. 2009; Miller et al. 2012; Quero et al. 2014a; St-Jacques et al. 2010). Bouchard (2011) stated that the use of VR-EBT with children suffering from more complex anxiety disorders, such as obsessive–compulsive disorder and post-traumatic stress disorder (López-Soler et al. 2011) must be studied. Therefore, this issue should be explored further.

On the other hand, it has been found that VR is well accepted as exposure technique in the treatment of specific phobias (García-Palacios et al. 2007), it can be used to support empirically validated treatment programs in order to increase its efficiency or to enhance its efficiency and acceptance. Likewise, several authors suggest other fields of application and further research of VR to improve the psychological treatments and in order to promote the health and people's quality of life. Riva et al. (2009) propose that VR can be more than a tool to provide exposure and desensitization, and it can be a clinical tool for *personal empowerment.* Botella et al. (2009) emphasize that unique feature of VR is very relevant for its use in clinical psychology. At the same time, it can raise several ethical issues and it is important to investigate the possible effects of blurring the distinction between real and virtual worlds in vulnerable populations. Carvalho et al. (2010) suggest that despite the great advance of VR use in psychotherapy, a great deal of its potential is still unknown, therefore requiring the creation of new VR environments so that controlled studies regarding its clinical application can be conducted. Throughout the process of elaboration and investigation, clinical experiences in VR environments must be related to real experiences in a flexible context that combines relevant cultural, physical, and cognitive aspects. These authors note that it is important the rapid results dissemination in order to help improve the development of VR environments and the speed at which they occur, thus preventing several researchers do trial and error as they develop similar work.

Based on all presented in this chapter, there are still several research questions to explore regarding the use of VR-EBT in anxiety disorders, for example:

- *Is it necessary to generate higher levels of sense of presence to get better treatment outcomes?*
- *Fully immersive systems like CAVE. Do they necessarily generate higher levels of sense of presence? In addition, does this improve the treatment outcomes?*
- *Is the use of VR-EBT via Internet as effective as the use with HMD or similar devices?*
- *Stimulating other senses in addition to sight and hearing (e.g., smell, taste, and/or touch), or including elements of augmented virtuality within VR-EBT. Could this improve or facilitate the conduct of therapy or treatment outcomes?*
- *Can VR facilitate or improve the assessment process for anxiety disorders?*
- *Can VR-EBT be adapted to mobile devices, entertainment systems (e.g., smart phones, tables, serious games by video game consoles), or to future mobile technologies?*

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Chapter 4
Virtual Reality Applications to Treat Posttraumatic Stress Disorder

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Introduction

Epidemiological surveys suggest that approximately 8–9% of individuals in the general population are at risk for developing PTSD at some point during their lifetimes (Breslau 2001; Hidalgo and Davidson 2000; Kessler 2000; Kessler et al. 1995). A more recent epidemiological study suggests that the lifetime prevalence rate of PTSD is 3.4% in men and 8.5% in women (McLean et al. 2011). Research suggests that certain populations are at increased risk for developing PTSD, such as sexual assault survivors (Amstadter et al. 2008), disaster relief workers (Duckworth 1986; Durham et al. 1985; Harvey-Lintz and Tidwell 1997; Marmar et al. 1999; 1996; North et al. 2002; Rosenczweig et al. 2002), and military service members (Dohrenwend et al. 2006; Prigerson et al. 2001). The deployment of approximately 2.6 million U.S. military service members to combat theaters in Iraq and Afghanistan (Institute of Medicine 2012) has lent a new urgency to efforts to expand and refine existing treatment approaches. These efforts are essential given that current estimates suggest that 5–25% of service members experience PTSD symptoms following deployment to Iraq or Afghanistan (Hoge et al. 2004; Milliken et al. 2007).

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The Current State of PTSD Treatment

The following section will review the literature on current evidence-based treatments for PTSD, with particular reference to recommendations made by expert treatment guidelines regarding which treatment modalities should be offered as first-line approaches.

Medications

Although pharmacotherapy is one of the most widely utilized treatments for PTSD, expert treatment guidelines for PTSD have come to different conclusions regarding the strength of the evidence supporting the use of pharmacotherapy as a first-line PTSD treatment. The US Institute of Medicine's (2008) report assessing the evidence in support of various treatment modalities for PTSD concluded that the evidence for all classes of drugs reviewed was inadequate to determine efficacy in the treatment of PTSD. The most recent clinical practice guidelines commissioned by the UK National Institute for Clinical Excellence (2005) recommended that medications be considered a second-line treatment for PTSD, behind cognitive-based therapies, which were recommended as first-line treatments. In contrast, other organizations have concluded that the evidence supports the use of specific classes of medications as first-line treatments for PTSD (American Psychiatric Association Practice Guidelines 2004; Foa et al. 2009), and the most recent US Institute of Medicine report (2012) on the treatment of PTSD in military and veteran populations found that there is reasonably strong evidence to support the use of selective serotonin reuptake inhibitors (SSRIs) in PTSD. The largest number of randomized clinical trials have been conducted on SSRIs, and in general, most guidelines are in agreement that the evidence is strongest for this particular class of drugs. For example, joint practice guidelines for PTSD issued by the US Department of Veterans Affairs and Department of Defense concluded that good evidence was found that SSRIs improve important health outcomes and recommended that clinicians provide SSRIs to eligible patients. In addition, two SSRIs, sertraline and paroxetine, have received approval by the US Food and Drug Administration as indicated treatments for PTSD. Although fewer studies have been conducted on the use of selective norepinephrine reuptake inhibitors (SNRIs), some practice guidelines, such as those issued by the US Department of Veterans Affairs and Department of Defense, and the International Society for Traumatic Stress Studies (Foa et al. 2009), have concluded that good evidence also exists for this class of drugs and have recommended them as first-line treatments.

Evidence-Based Psychotherapies

Although expert treatment guidelines differ in their conclusions regarding the efficacy of pharmacotherapies, treatment guidelines are in unanimous agreement that exposure therapies, which are typically classified as forms of cognitive-behavioral therapy (CBT) are effective treatments for PTSD following diverse types of trauma (Bisson et al. 2007; Bradley et al. 2005; Harvey et al. 2003; Schnurr et al. 2007). Indeed, expert treatment guidelines for PTSD published for the first time in 1999 recommended that exposure therapy should be the first-line therapy for PTSD (Foa et al. 1999b). Multiple mental health professional guilds and government agencies worldwide have since reaffirmed in various reports and updated treatment guidelines that exposure therapy is the only treatment for PTSD with substantial empirical support for its efficacy (American Psychiatric Association Practice Guidelines 2004; Australian Centre for Posttraumatic Mental Health 2007; Foa et al. 2009; Institute of Medicine (IOM) 2006; 2008; National Institute for Clinical Excellence 2005). CBT with exposure therapy has been validated across a diverse range of cultures and populations, such as those exposed to military combat (Monson et al. 2006; Nacasch et al. 2007; Rizzo et al. 2009), terrorism (Brewin et al. 2008; Difede et al. 2007a, b; Gillespie et al. 2002; Levitt et al. 2007), natural disaster (Salloum and Overstreet 2008), physical and sexual assault (Foa et al. 1999a; Resick et al. 2002), and motor vehicle accidents (Blanchard et al. 2003). In addition, the Department of Defense and Department of Veterans Affairs have recently initiated programs to disseminate two CBTs that involve exposure, Prolonged Exposure (PE) and Cognitive Processing Therapy, as part of a broader effort to expand access to evidence-based treatments for current and former US service members (Karlin et al. 2010).

Although a number of therapies involve some element of exposure, the most widely researched and well validated exposure treatment paradigm is PE (Foa et al. 1999b; 2005). PE is founded on Foa and Kozak's (1986) emotional processing theory, which proposes that phobias and PTSD are based on pathological fear structures that contain information about feared stimuli, responses, and meanings that are activated when an individual encounters information represented in the fear structure (Foa and Kozak 1986; Foa et al. 1989). Classical conditioning is believed to be a key mechanism underlying the development of pathological fear, in that the traumatic event is considered an unconditioned stimulus that has become associated with a number of harmless conditioned stimuli that then become capable of eliciting a conditioned fear response. Emotional processing theory proposes that successful treatment must accomplish two goals: first, activate the fear structure so that new learning may occur, and second incorporate new information that is incompatible with the pathological fear structure. The theory also proposes that cognitive avoidance of trauma-related thoughts, feelings, and images and behavioral avoidance of trauma-related stimuli serve to maintain PTSD symptoms by minimizing exposure to corrective information that disconfirms feared outcomes and allows for the development of a new and non-pathological competing fear structure.

PE typically consists of between 8 and 15 weekly 90 min individual therapy sessions and includes both imaginal and in vivo exposure. In imaginal exposure, the patient is guided in repeatedly recounting memories of the trauma in a safe environment in order to facilitate extinction learning, whereby the cued fear response to memories of the trauma is extinguished and the patient is better able to distinguish between thinking and talking about the trauma and feeling as if it is recurring. During in vivo exposure, the therapist helps the patient begin gradually confronting feared memories and situations that are not realistically dangerous but are avoided because they are associated with the trauma and thus trigger anxiety. Imaginal exposure typically begins in the third session and is followed by processing of the exposure, in which the therapist engages the client in a discussion of thoughts and feelings that arose during the exposure, with the goal of allowing the patient to integrate and consolidate new information about the meaning of the trauma and disconfirm distorted beliefs that may have developed in the aftermath of the event.

Limitations of Current Treatments

Despite compelling evidence for the efficacy of exposure therapy for PTSD, the nature of imaginal exposure, whereby patients are asked to repeatedly recount their most traumatic experience to a therapist, presents a challenge for some patients given that avoidance of trauma-related memories, thoughts, and cues are, by definition, part of the diagnostic criteria for the disorder. Thus, many individuals with PTSD fail to seek treatment, some who seek treatment do not engage in the treatment, and others who profess willingness struggle to engage emotionally with the trauma memory. As studies suggest that lack of emotional engagement predicts poor treatment outcome, these patients often do not improve (Jaycox et al. 1998). Finding effective ways to motivate these patients and facilitate emotional engagement in therapy is thus critical.

Virtual Reality Therapy

New developments in virtual reality (VR) technologies have expanded the range of possible treatment options for anxiety disorders, including PTSD. Researchers first applied VR to treat simple phobias, including acrophobia (Rothbaum et al. 1995a, b), arachnophobia (Carlin et al. 1997), claustrophobia (Botella et al. 1998; 2000), and fear of flying (Smith et al. 1999), with positive results. The theoretical basis for applying VR to phobias underpinned the hypothesis that VR would also help to engage an individual's trauma-related fear structure in the treatment of PTSD.

Virtual Reality Exposure Therapy (VRE) for PTSD draws upon similar principles as imaginal exposure to reach patients who are reluctant or unable to recount their traumatic experiences using traditional imaginal exposure. VR provides a sensory-rich computer-generated environment in which patients are able to encounter and gain mastery of their trauma. Patients recount the details of their experience aloud, while gradually proceeding through increasingly detailed virtual simulations of their traumatic event that are closely monitored by the therapist. By allowing the therapist to program the virtual environment to control what the patient experiences, treatment can be tailored to the needs of the individual patient, and proceed at a pace that is tolerable for that individual. Moreover, VRE therapy can promote emotional engagement and processing of the trauma memory by offering not only visual, but auditory, olfactory, and haptic sensory cues to facilitate immersion in the virtual world.

The Framework of Virtual Reality for PTSD

VR technology integrates visual computer graphics with multiple sensory cues in order to create an evocative environment that patients may find emotionally engaging. Participants wear a specialized helmet with two miniature LCD computer screens affixed to the front. After the user dons the helmet, the screens are positioned one to two inches in front of the participant's eyes taking up the majority of their visual field. The room is kept dark in order to minimize distracting visual stimuli. Sensitive motion-tracking sensors are built-in or attached to the helmet and inform the computer of slight changes in the participant's head position. Thus, a participant looking up, down, or to either side sends immediate feedback to the computer program, which results in corresponding changes in the visual display. Users may also move their visual field forward, backward, or sideways using a hand-held controller allowing them to "interact" with the virtual environment. Participants wear headphones that deliver audio stimuli from the virtual scenario as well as any instructions that the clinician gives through a headset microphone to communicate with the patient during his session. A raised platform beneath the participant contains audio-tactile sound transducers that create customized vibrations comparable to a high-powered rumble pack on a video game controller. Participants seated or standing on the platform receive haptic cues that coincide with auditory events (e.g., an explosion). Finally, a scent machine comprised of scent cartridges relevant to the virtual environment or trauma event (e.g., body odor, diesel fuel, market spices) may be used to release an odor using a series of fans and an air compressor.

The clinician interface of a VR setup consists of two monitors: one that displays the control panel and the other that shows what the patient sees through the VR helmet. The VR software contains elementary scenarios made to resemble the setting and context that are central to a traumatic event. Before beginning the session, the clinician builds upon this basic setting to customize the virtual environment to resemble the patient's trauma as closely as possible. During the session, the clinician uses preprogrammed keys to manipulate the aforementioned multi-sensory cues. Thus, the clinician can introduce appropriate environmental stimuli that coincide with an event in real time as the patient retells his trauma.

The clinician remains connected to the patient at all times during the VRE session. Using a headset microphone linked to the user's headphones, the clinician prompts patients to recount their story and monitors their self-reported distress using the Subjective Units of Distress (SUDS) measure on a scale of 0–100 at regular intervals to ensure the exposure remains at a therapeutic level (e.g., distressing but not overwhelming to the patient).

The History of Applying Virtual Reality for PTSD

Virtual Vietnam

The first application of virtual reality to the treatment of PTSD was developed by researchers at Emory University and the Georgia Institute of Technology to treat PTSD in Vietnam Veterans. The virtual environment offered two common scenarios, the first of which consisted of riding in a virtual Huey helicopter where the patient saw the backs of the pilots' heads and the view of typical Vietnam terrain from the helicopter's side door. The second scenario involved being in a clearing surrounded by jungle landscape with the sounds of helicopters, gunfire, and explosions, as well as men shouting, "Move out!" Rothbaum et al. (1999) conducted a case study using Virtual Vietnam to treat a 50 year-old Caucasian male with severe combat-related PTSD from his military service as a helicopter pilot approximately 26 years before participating in the study. The trial consisted of fourteen 90 min sessions conducted twice weekly over the course of 7 weeks, during which the individual was immersed in both virtual environments. The study found that he improved on all measures of PTSD, including a 34% decrease on the Clinician Administered PTSD Scale (CAPS) and a 45% decrease on self-reported PTSD, and that he maintained these gains 6 months after completing treatment.

Following this case study, an open clinical trial of 16 male Vietnam Veterans with PTSD found significant reductions in PTSD and related symptoms after an average of 13 VRE sessions in the 8 participants who completed the 6 month follow-up (Rothbaum et al. 2001). At the 6 month follow-up, there was an overall statistically significant reduction in PTSD symptoms from baseline in symptoms associated with specific reported trauma experiences as measured by the CAPS. Of the 8 participants who completed the 6 month follow-up, all 8 reported reductions in PTSD symptoms ranging from 15% to 67%. Notably, none of the 16 participants decompensated due to exposure to the virtual environments, and no one was hospitalized for complications related to the treatment during the study (Rothbaum et al. 2001).

Virtual World Trade Center

Following the terrorist attacks on the World Trade Center (WTC) on September 11, 2001, Difede and Hoffman (2002) published a case study of WTC-related PTSD. The virtual WTC environment used in the study consists of 11 scenes, which the clinician proceeds through at an optimal pace for emotional processing after receiving the patient's verbal assent. The protocol was designed to evoke a level of response that created tolerable discomfort, but not to overwhelm patients with affect. The early stages of the scenario begin with a view of the Twin Towers and a jet that flies past safely; then a jet collides with the first tower but does not create an explosion; an explosion is added; and then sound effects are introduced to create a more realistic collision and explosion. The next stages gradually incorporate fire and smoke escaping from where the jet collided into the first tower; sound effects of people in the area screaming; and individuals jumping from the first tower. In the final stages, the second jet collides into the second tower with sound effects for the explosion and people screaming; the second tower collapses and creates a large dust cloud; followed by the first tower collapsing into the dust cloud. The patient concludes the scenario when they are able to view the full sequence of events in its entirety. Throughout the process, the clinician controls the environment and introduces relevant feared stimuli to gradually and systematically expose patients to a virtual representation of their specific traumatic experience. In the first case study with Virtual WTC, the participant was a 26 year-old African-American woman who had worked in the WTC and had previously failed to improve with imaginal exposure therapy. After six, 60 min weekly sessions, the patient's PTSD symptoms were reduced by 90% as measured by the CAPS (Difede and Hoffman 2002), offering initial support for Virtual WTC as a treatment tool.

Subsequent to these promising results, Difede and colleagues (2007a) compared the use of VRE therapy in 13 participants with direct exposure to the WTC attacks, including firefighters, disaster workers, and civilians, with 8 participants in a matched waitlist control group. Due to two non-completers and one dropout, there were 10 participants in the VR group who completed the treatment protocol. Participants in the treatment condition showed a significant decrease in PTSD symptoms on the CAPS as compared to pretreatment and to the control group, who showed no improvement; participants maintained treatment gains at 6 month follow-up. It is important to note that five of the VRE participants had previously undergone imaginal exposure therapy and not shown improvement. Notably, no participant reported becoming overwhelmed by the evocative scenario. Furthermore, these promising results lent support to the use of a standardized virtual environment for a wide range of traumatic experiences, benefiting both disaster workers and civilians.

BusWorld

After the September 2000 Palestinian uprising, frequent acts of terrorism targeting Israeli civilians led to more than 1100 fatalities and 6700 wounded (Freedman 2009). In response to numerous attacks on civilians using public transportation, Josman et al. (2006), in collaboration with Hoffman and his team at the University of Washington, developed a virtual reality terrorist bus bombing scenario dubbed "BusWorld." In the scenario, participants begin by standing on the sidewalk in an urban street scene across the street from a bus stop resembling those in Haifa, Israel. A bus appears in the next stage and pulls up to the stop, but does not explode. In the final stages, explosions are added with visual and auditory effects, and the bus is set on fire with sound effects of people screaming in Hebrew and police sirens in the background, signaling that help has arrived. They then conducted an analog pilot test with 30 non-symptomatic individuals to test the validity of the virtual environment and its ability to evoke increasing levels of anxiety as the virtual scenario escalated (Josman et al. 2008). These individuals reported significantly more distress with each stage of the VR scenario, as measured by SUDS ratings, corroborating the scenario's ability to provide graded exposure.

Freedman et al. (2010) conducted a case study of a 29 year-old male patient who developed PTSD after becoming trapped on a crowded public bus when an attacker used a bulldozer to flip his and a second bus on their sides and crushed multiple cars, leaving three dead and dozens injured. The BusWorld virtual scenario was adapted in order to meet the needs of the patient, so that only the early levels (a street scene and bus stop with a bus approaching) were utilized. The patient entered treatment approximately 1 month after the traumatic event. He was treated with 10 sessions of therapy, 3 of which involved imaginal exposure while immersed in the BusWorld environment, and one of which involved imaginal exposure without VR. As measured by the CAPS, the patient's PTSD symptoms showed a significant decrease from a pretreatment score of 79 to zero posttreatment (Freedman et al. 2010). These treatment gains were maintained 6 months later. Interestingly, the patient was able to improve using the early levels of the BusWorld environment despite having experienced an attack for which the scenario was not specifically designed. Thus, this study provided initial evidence that a PE protocol using imaginal exposure augmented by VR was effective in treating PTSD following a terrorist attack in Israel. Furthermore, it demonstrated how a virtual environment could be used in conjunction with imaginal exposure therapy to facilitate the care of individual patients.

Virtual Motor Vehicle Accident

The high frequency of motor vehicle accidents in which individuals are injured or killed often results in psychological consequences as well, so much so that these collisions have been identified as a leading cause of PTSD (Norris 1992). For patients trying to confront their fears, real world "in vivo" exposure may entail potentially unsafe driving or traffic conditions. Using VR to treat MVA-related PTSD reduces safety risks associated with in vivo uncontrolled driving situations and provides a safe way for patients to process memories associated with the trauma (Beck et al. 2007). Following promising evidence in which VR scenarios were used to treat driving phobias (Wald and Taylor 2003), Beck and colleagues published the first report on the use of VR in the treatment of post-collision PTSD.

Beck et al. (2007) designed several virtual, customizable driving scenarios to help treat individuals with acute PTSD following a motor vehicle accident in the first effort to assess the efficacy and acceptability of VRE in this population. The virtual apparatus includes a steering wheel, gas and brake pedals, and stereoscopic glasses that both the patient and therapist wear to view a large 10 foot × 8 foot projection of the simulation in 3D. The virtual environment itself was designed to simulate a real-world driving experience – not a motor vehicle accident – so that the driver chose their own route to take in a rural, suburban, urban, or highway setting and feared driving events (e.g., tailgating) occurred in real time. In an uncontrolled case series, the authors examined the use of a weekly, 10-session VRE protocol for 6 individuals with full or subsyndromal PTSD who had been involved in a serious road accident in the last 6 months (3.5 months on average). Clinically significant reductions between pretreatment and posttreatment were found on the CAPS total score, the CAPS Reexperiencing cluster, and the CAPS Avoidance/Numbing cluster, with effect sizes ranging from $d = .79$ to $d = 1.49$. No difference was found on the CAPS Hyperarousal cluster score. Participants scored high in overall satisfaction scores on the Client Satisfaction Questionnaire (CSQ; Larsen et al. 1979) and achieved high levels of presence in the virtual environment. However, participants also reported higher levels of disorientation relative to published norms, which the authors speculate may be due to the use of stereoscopic glasses to view the VR simulation on a screen 5 feet away, and which the authors suggest may be reduced by switching to a head-mounted display, as simulation sickness is less likely with this type of system. These preliminary results suggest that VRE may be effective for survivors of traumatic motor vehicle accidents.

Virtual Iraq/Afghanistan

In a landmark 2008 study, RAND estimated that 14% of Iraq and Afghanistan Veterans suffer from PTSD (Tanielian and Jaycox 2008), and subsequent studies have suggested that this figure may be as high as 25% (Kok et al. 2012; Ramchand et al. 2010; Thomas et al. 2010). Along with Traumatic Brain Injury, these "invisible wounds of war" are having a devastating impact on military personnel, many of whom have had multiple deployments, putting them at greater risk for subsequent mental health problems. Researchers at the USC Institute for Creative Technologies, led by Albert "Skip" Rizzo and Jarrell Pair, developed Virtual Iraq between 2005–2007 to aid in the treatment of combat-related PTSD (Rizzo et al. 2005). The virtual environment and clinician interface of Virtual Iraq evolved to reflect feedback from Iraq and Afghanistan service members and clinicians (Reger et al. 2009; 2010). The 2007 version of Virtual Iraq consisted of 4 customizable environments, including 3 Humvee scenarios, and a Middle-Eastern city scene that included a marketplace, crowded or desolate streets, a checkpoint, building interiors, and rooftops (Rizzo et al. 2010). In order to increase the number of scenarios and degree of user customizability, a revised and expanded version of Virtual Iraq/Afghanistan, termed BRAVEMIND, was developed in 2011. This redesigned system increased the number of scenarios from 4 to 14 and added a number of new features to increase customizability and usability. This highly complex environment was designed to give clinicians the flexibility to place patients in a virtual setting and context that resembles their traumatic event and provide relevant stimuli.

Research has supported the acceptability of technology-based mental health approaches among service members. For instance, in a study of soldier attitudes toward receiving technology-based behavioral health care, 58% of the 352 service members surveyed reported some willingness to use VR treatment (Wilson et al. 2008). Additionally, one third of those surveyed who stated they were unwilling to use traditional psychotherapy were willing to use at least one kind of technology-based mental health treatment (e.g., video teleconferencing, Internet-based treatment, or VR), suggesting that technology and VR may help overcome barriers to accessing care in this population.

Wood and colleagues published a case report on the first active-duty service member with combat related PTSD to complete treatment with VR graded exposure therapy with physiological monitoring within a randomized study comparing this treatment with cognitive behavioral group therapy for active duty military personnel (Wood et al. 2007). Following 10 sessions of VR treatment, the patient's scores on the PCL-Military Version (PCL-M) decreased to below the threshold for PTSD diagnosis. Subsequent case reports on VR graded exposure therapy with physiological monitoring for combat-related PTSD in male (Wood et al. 2008) and female (Wood et al. 2009) US Navy personnel have yielded similar findings.

Gerardi, Rothbaum, and colleagues (2008) published results of the first Iraq veteran to complete treatment within an ongoing controlled study of VRE using Virtual Iraq. The 29 year-old Caucasian male patient had served in the National Guard and was deployed for a year in support of Operation Iraqi Freedom. Approximately 6 months post-deployment, the individual entered treatment. After four, 90 min sessions of VRE over 4 weeks, the patient's PTSD score on the CAPS decreased by 56% compared to pretreatment scores (Gerardi et al. 2008). The patient stated he felt comfortable with the VR technology, and no adverse effects were reported. This brief therapy resulted in both clinically and statistically significant change, providing early support for VRE with Iraq veterans suffering from PTSD.

Reger and Gahm (2008) conducted a case study using Virtual Iraq with an active duty soldier in the Army who had been diagnosed with combat-related PTSD. The trial consisted of 6 90 min sessions of VRE with the virtual military convoy scenario over the course of 4 weeks. As measured by the PCL-M, the participant's pretreatment score of 58 decreased to 29. Additionally, self-report data on the Behavior and Symptom Identification Scale-24 (BASIS; McLean Hospital 2006), which assesses treatment outcome according to five symptom and functioning domains, corroborated a positive treatment outcome.

McLay et al. (2010) were the first to use VRE with active duty soldiers while deployed in a combat theater using a parallel case series design. Individuals seeking treatment for deployment-related PTSD at the Combat Stress Clinic in Camp Fallujah, Iraq, from February to November 2008 were offered either traditional exposure therapy or VRE. The study reported the results of a retrospective record review; therefore, therapeutic procedures were not standardized. Exposure therapy was administered based on the methods outlined in Foa et al. (2007). Both traditional VRE and VRE with arousal control were administered, wherein participants are taught how to monitor their physiological responses to help them tolerate trauma-related stress. Due to the realities of being deployed, participants were treated anywhere between 10 days and 13 weeks, and were surrounded by trauma-related cues. Of the six participants who received VRE, all showed improvement on their PCL-M scores, with an average decrease in symptoms of 67%, and five no longer met criteria for PTSD by the end of treatment. None of the individuals who received VR experienced adverse effects while in treatment. The four participants who received imaginal exposure therapy also showed improvement and none met criteria for PTSD upon treatment completion. This was the first study of active duty military personnel deployed to a combat theater undergoing exposure therapy with and without virtual reality. Despite the additional stressors of serving in military operations, no patients decompensated or dropped out of the study, and all patients showed symptom improvement. Overall, the authors founds that both types of therapy could be delivered safely and effectively during a combat deployment.

Multiple studies have now examined the use of VRE with active duty service members following deployment to Iraq or Afghanistan. Reger et al. (2011) conducted a retrospective study of a mixed, clinical sample of 18 active duty soldiers with PTSD and 6 soldiers diagnosed with anxiety disorder not otherwise specified who did not meet full criteria for PTSD. Thirteen participants had failed to report significant clinical benefit from other forms of psychotherapy, including four patients who had undergone exposure therapy. The treatment provided was based on a manualized prolonged exposure treatment (Foa et al. 2007), adapted for use with VR, with an introduction to the virtual environment in Session 2. Participants received an average of 7 sessions (range 3–12) lasting approximately 90 min each. There was a significant decrease in PCL-M-based estimates of PTSD with 62% (n = 15) of the sample reporting a reliable change of 11 points or more (Reger et al. 2011). In another study of active duty service members, McLay et al. (2011) compared VR-graded exposure therapy to treatment as usual in 20 active duty military personnel with combat–related PTSD. The authors found that 7 out of 10 participants in the VR condition showed 30% or greater improvement on the CAPS while only 1 out of 9 participants in the treatment as usual condition showed similar improvement.

Additionally, McLay et al. (2012), with funding from the Office of Naval Research, conducted the first open clinical trial to develop Virtual Iraq/Afghanistan and a treatment protocol. Forty-two active duty service members were enrolled in intent-to-treat analysis, and 20 completed treatment. Participants received treatment twice weekly in sessions ranging from 90 to 120 min each. Since an aim of the study was to develop a treatment protocol, the number of sessions varied with early participants (n = 26, including 14 who completed the protocol) and was later fixed to 12–15 sessions over a maximum of 10 weeks. Of the 20 participants who completed treatment, 75% (n = 15) no longer met criteria for PTSD based on PCL-M at the post-assessment. Furthermore, these fifteen participants showed improvement by at least 50% on the PCL-M. No patient experienced an adverse event related to participation in the study. This study helped to determine the optimal protocol for VRE using Virtual Iraq/Afghanistan resulting in a published treatment manual (Rothbaum and Ressler 2009).

These promising results provide additional support for the efficacy of virtual reality-enhanced exposure therapy. This is particularly important in the context of treating combat-related PTSD, since prolonged exposure therapy may not be as effective with this population (e.g., Bradley et al. 2005).

Future Horizons in Clinical Work and Research

The past decade has witnessed a burgeoning of research on VRE for PTSD. Studies focused on PTSD stemming from diverse types of trauma, including combat exposure in Vietnam, Iraq, and Afghanistan, motor vehicle accidents, and terrorist attacks in the US and Israel, have demonstrated that VRE is an effective exposure therapy treatment. Moreover, VRE may offer several unique advantages over imaginal exposure therapy that make it particularly well-suited to the challenges faced by veterans of the conflicts in Iraq and Afghanistan. Foremost among these is the perceived stigma associated with seeking treatment for mental health problems. Studies among Iraq and Afghanistan veterans have found that treatment seeking for psychological problems may be inhibited by fears of negative perceptions, being considered weak, or damaging one's career (Stecker et al. 2007; Warner et al. 2008). Unfortunately, fear of stigma and other treatment barriers may be particularly relevant to those most in need of treatment, as one study found that Iraq and Afghanistan veterans who met screening criteria for a psychiatric disorder were more likely than those who did not to report such fears (Pietrzak et al. 2009). It has been proposed that VR may offer one avenue for addressing these concerns as part of a redesigned post-deployment treatment approach. In such an approach, VRE could be offered to veterans with PTSD as one component of a standard post-deployment training that all veterans completed, possibly decreasing perceived stigma since such training would be one of many routine post-deployment duties (Rizzo and Shilling 2018). In addition, younger service members, who are likely more familiar with digital gaming and training simulation technology, may be more attracted to and comfortable with participating in VRE than traditional talk therapy (Reger and Gahm 2008), which may promote treatment seeking among this population (Leaman et al. 2013; Rizzo and Shilling 2018). Given the pressing mental health needs of the current generation of veterans and concurrent low rates of treatment engagement (Hoge et al. 2004), finding acceptable forms of mental health treatment for returning service members is critical (Leaman et al. 2013). As part of a broader array of novel and innovative approaches, VRE may offer one such tool to facilitate treatment and emotional engagement, particularly in difficult-to-reach populations.

There are several remaining avenues for the next generation of research on VRE to explore. A substantial evidence base has demonstrated that VRE is an effective exposure therapy for PTSD resulting from various traumas. An important question is whether VRE offers benefits above those of established treatments. It will be valuable for future studies to examine not only whether VRE is associated with a greater decrease in PTSD symptoms than established treatments, but also whether individuals who fail to respond to established treatments show improvement with VRE. Randomized controlled trials comparing VRE with imaginal exposure for combat-related PTSD are now being conducted, which should offer insight into the first of these questions, but additional studies should examine whether individuals who have completed established treatments with little improvement may benefit from VRE. If differences emerge between imaginal exposure and VRE in direct comparisons, or if research reveals that VRE reduces symptoms in those who have not responded to established treatments, this will pave the way for studies to examine specific patient or trauma characteristics associated with treatment response, which may offer the opportunity to better match patients with treatment modalities. Another question for future research is whether the addition of a pharmacologic agent can enhance the efficacy of VRE. Although studies examining the use of pharmacologic agents to enhance exposure rather than palliate PTSD symptoms have been mixed (de Kleine et al. 2012; Difede et al. 2014; Litz et al. 2012), an outstanding question is whether such cognitive enhancers are differentially effective when used with imaginal exposure versus VRE. Studies exploring this issue may offer greater understanding into the extinction of conditioned fear responses and are ongoing. As new developments in VR technologies have flourished over the past 15 years, a growing literature has established that VRE is an effective treatment for PTSD. Future research that expands upon this strong foundation to address the next generation of questions facing VRE represents a promising area for further investigation with the potential to yield valuable treatment advances.

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Chapter 5
Using VR for Obsessive-Compulsive and Related Disorders

Stéphane Bouchard, Mylène Laforest, Pedro Gamito, and Georgina Cardenas-Lopez

Definition of OCD and Related Disorders

With the publication of the fifth version of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5, American Psychiatric Association 2013), obsessive-compulsive disorder (OCD) was moved from the anxiety disorders section to form a new diagnostic category called obsessive-compulsive and related disorders. This change fits better with the concept of a spectrum of disorders related to OCD. This section of the DSM-5 includes OCD, body dysmorphic disorder (BDD), hoarding disorder, trichotillomania (hair-pulling disorder), excoriation (skin-picking) disorder, and several variations on OCD-related conditions induced by substance, medication, medical conditions and variations on OCD-related conditions that do not precisely fit the diagnostic criteria. OCD is also in a category of its own, separated from phobic anxiety and other anxiety disorders, in the International Statistical Classification of Diseases and Related Health Problems 10th Revision (ICD-10,

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World Health Organization 2010). No matter which classification OCD falls under, it is considered a severe and chronic mental disorder affecting between two and three percent of the general population and causing significant social and functional impairments (APA 2013; Kessler et al. 2005a, b; Leon et al. 1995).

As defined by DSM-5, OCD is characterized by mental and behavioral rituals that spawn as an attempt to avoid or mask the fear of a thought, an image or an impulse. More precise diagnostic criteria revolve around the presence of obsessions and/or compulsions that are time-consuming, causing clinically significant distress or impairment in functioning, and that cannot be better explained by symptoms of another mental disorder or by substances or medical conditions. Formally, obsessions are recurrent and persistent ideas, thoughts, impulses or images that, at least at some time during the disorder, are experienced as intrusive, unwanted and distressing, and would cause anxiety in most people. People suffering from OCD attempt to ignore, neutralize or suppress these intrusive thoughts. Compulsions are described as repetitive behaviors (e.g., hand washing, checking) or mental acts (e.g., counting, repeating words silently), that the person feels driven to perform in response to an obsession, or according to rules that must be applied rigidly. The behaviors or mental acts are performed to prevent or reduce anxiety or distress, or avert some dreaded event. However, these behaviors are either excessive or not realistically connected with the event or situation they are meant to avoid. Many people suffering from OCD will manifest a good insight and recognize that their beliefs are probably not true, but others will lack such insight to the point of being entirely convinced that their beliefs are true.

OCD obsessions usually appear in the form of fear of contamination, pathological doubt, aggressive impulses, blasphemous or immoral ideas, sexual impulses, somatic fears, victimization, or rigid concerns about symmetry and order (APA 2013; Radomsky et al. 2014). Compulsions usually involve washing or cleaning, checking, repeating, counting, ordering, etc. (APA 2013; Clark 2004.) Although obsessive thoughts and compulsive behaviors can occur separately, most patients exhibit both (Foa et al. 1995).

In an international endeavor, almost 800 non-clinical adults from Africa, Asia, Australia, Europe, North America and South America took part in a comprehensive personal semi-structured interview, and 90% said that they experienced at least one intrusive thought in the last 3 months (Radomsky et al. 2014). What distinguishes people suffering from OCD from the general population is not so much the content of their intrusive thoughts and repetitive behaviors, but rather the appraisal and avoidance/control strategies related to these phenomena (Clark 2004; Clark and Simos 2013; Clark et al. 2014; Rachman 1997 1998; Salkovskis 1985, 1996a). Although this is an imperfect explanation that remains open to debate (e.g., see Julien et al. 2007), it is a credible model that describes the experiences of adults from all six inhabited continents (Clark et al. 2014; Moulding et al. 2014) and leads to empirically validated treatments (Clark 2004; Katzman et al. 2014; Rachman 2003; Whittal et al. 2010).

The dysfunctional appraisals associated with OCD include an inflated sense of responsibility, perceived threats, over-importance given to thoughts and their occurrence, perfectionism, and the need to control thoughts (APA 2013; Clark 2004; Clark et al. 2014; Moulding et al. 2014; OCCWG 1997; Salkovskis 1996a). People who have OCD misinterpret unwanted, intrusive thoughts as a threatening mental event that they are responsible to prevent by ensuring that the anticipated threat will not occur (Clark 2004; Clark and Simos 2013; Clark et al. 2014; Rachman 1997, 1998; Salkovskis 1985). What maintains the pathological cycle in OCD is the attempts to control thoughts, neutralizing them, seeking safety or engaging in avoidance behaviors (for more detailed models, see Clark 2004; Clark and Simos 2013; Rachman 1997, 1998; Salkovskis 1985, 1996a).

BDD is characterized by clinically significant distress, or impairment in many areas of life caused by preoccupations with one or more perceived physical defects or flaws that are not observable by others (APA 2013). At the core of the disorder, a person becomes preoccupied with an imagined defect in appearance, believing that it looks ugly abnormal, unattractive or deformed. Any area of the body can be a source of pathological preoccupation, including perceived asymmetry of body areas. As is the case with OCD, people try to alleviate distress by engaging in time-consuming, repetitive behaviors, such as mirror checking, reassurance seeking, and body checking. Worries about appearance must be different from concerns about weight or body fat that would meet the diagnostic criteria for an eating disorder. If an actual physical anomaly is present on the person's body, it cannot be observable or appear only slight to other individuals.

Few studies have used virtual reality (VR) with people suffering from BDD, considering the importance of body image disturbance and body dissatisfaction in people suffering from this disorder (e.g., Osman et al. 2004). This chapter addresses some VR studies focusing on dissatisfaction with, or disturbance in, body image, as they relate to some extent to BDD (for more extensive coverage of VR with people suffering from obesity or eating disorders, see Chap. 7). In describing VR-related studies that do not strictly focus on BDD, we hope to stir interest in studying disturbed perceptions of specific body parts.

Finally, DSM-5 (APA 2013) now considers hoarding disorder as different from OCD (no longer as a subtype of it). Hoarding is defined as a persistent difficulty discarding or parting with possessions, due to a perceived need to save the items, regardless of their actual value. Discarding the items generates significant distress, and therefore the individual accumulates possessions to the point that they congest and clutter active living and working spaces and significantly compromise their intended use. In some cases, the clutter may be controlled somewhat by significant others or authorities keeping these areas free of items or possessions. Normal collecting of items, such as stamps, does not produce the clutter, distress, and impairment of hoarding disorder, and possession of collectible items may have an objectively significant value. The hoarding must not be better explained by another medical or mental disorder. This disorder will be addressed briefly since only preliminary work using VR has been reported. We cannot discuss other disorders in the OCD spectrum-related disorders category because no work on VR is available.

VR and OCD

VR, OCD, and Checking Behaviors

The first systematic attempts to use technology with OCD come from the work conducted in the late 1980s by Baer et al. (1987, 1988). This group developed a portable computer program to help patients adhere to behavioral treatment and reduce checking rituals. This program also evolved to include a telephone-based system (Baer and Greist 1997), as well as other adaptations (e.g., Clark et al. 1998). The computer-based tools have proven useful in the treatment of OCD (Kim et al. 2009; Lack and Storch 2008), but will not be discussed further as they do not involve immersion in VR. Research involving VR with OCD appeared only recently and currently addresses three aspects of OCD: checking behavior, fear of contamination, and slowness associated with doubt and perfectionism. There exists, however, a vast body of data on the induction of OCD-like response using experimental paradigms where people were invited in a disorganized office space (Coles et al. 2005) or asked to repeatedly check stimuli such as a gas stove on a computer screen (van den Hout and Kindt 2003; van Dis and van den Hout 2016) or in a functioning kitchen (Radomsky et al. 2006), sometimes while wearing an eye-tracking device (Bucarelli and Pudron 2016). These tasks are now being applied, and refined, in VR.

The first study on OCD and VR addressed checking behaviors and was published in 2008 by Kim and collaborators. The goal was to document if people suffering from OCD would perform in a virtual reality as they do in the physical reality. The hypothesis was that people suffering from OCD would check more often and experience more anxiety than non-OCD controls. The researchers invited 33 people with OCD and 30 healthy controls matched by age, gender, IQ and experience with VR, to conduct three tasks while immersed in VR using an affordable head-mounted display (HMD), a three-degree-of-freedom motion tracker, computer speakers and a joystick. The first task consisted of a training phase when participants were immersed in a virtual apartment and had to get up in the morning and get ready for work. During the simulation, they received programmed instructions to flick on a light switch, to open a window and the front door, to activate the gas valve and gas burner on the stove, to turn on the water faucet, etc. All virtual stimuli were left on or open at the end of the training phase. During this phase, participants learned how to navigate *in virtuo* (i.e., in virtual reality), but also to give relevance to the virtual stimuli in the hope of inducing some feeling of responsibility (e.g., "If I can activate a flame by turning on the gas burner in an apartment where I have been, maybe something could happen to this apartment if I leave with the gas turned on!"). The second phase involved a distractive task to direct attention away from the actions previously performed. Participants were asked to choose various non-threatening objects that disappeared once taken by them, such as an umbrella or a book. In the third and core experimental task, participants were invited to freely check everything in the virtual apartment before leaving it. The number of reported operations performed for checking rituals and the time spent performing checking behaviors were measured during the immersion. When compared to the control condition, the clinical sample took significantly more time to check. OCD sufferers also performed more checking behaviors, although the difference did not reach statistical significance. Anxiety scores before checking were significantly higher in the OCD group and anxiety decreased significantly in both groups after checking. Among participants having OCD, levels of anxiety after checking were significantly and positively correlated with the severity of OCD symptoms, the level of general anxiety, and the time spent checking. With this study, researchers from Korea demonstrated that it is possible to replicate in VR some of the clinical observations found in physical reality, with OCD patients being more anxious and taking more time to check typical and potentially threatening stimuli associated with inflated responsibility (gas stove, door, etc.). All this even though nothing dangerous could happen with virtual stimuli. This study suggests the value of VR as a potential anxiety-provoking option, and consequently its usefulness as a potentially credible replication of real-life situations with OCD sufferers.

This finding has significant implications. Operating a standardized VR environment in a research lab can significantly facilitate experimental research. It enables the study of emotions, behaviors, thoughts, and neuropsychological functions involved in OCD within an entirely controlled and easily manipulated context to isolate experimental variables. The experiments can also be replicated in other centers. Furthermore, cognitive-behavior therapists can apply an efficient therapeutic tool called "exposure" or "exposure and response prevention" (Abramowitz et al. 2001; Bouchard et al. 2007; Clark 2004; Franklin and Foa 2007; Rachman 2003; Whittal et al. 2010). Finally, neuropsychological testing can be conducted in virtual environments with greater ecological validity than paper-and-pencil tests, while fMRI studies can occur in settings that approach the complexity of real-life situations. However, because OCD patients did not check significantly more than the controls in the Kim et al. (2008) study, more research was needed to refine the tasks and research protocol.

Following their 2008 study comparing OCD and control participants, Kim et al. (2010) examined further the possibility of using VR environments to assess checking behaviors in OCD patients. They used the same three tasks as in 2008, but with small modifications, such as the addition of a second virtual environment (a virtual office where participants had to get ready to go home) and more elaborate assessment of typical obsessive checking behaviors, including the frequency of checking behavior, time taken to look/gaze at an object during checking behaviors, length of the trajectory traveled during the immersion and time spent performing checking behaviors. The training phase allowed 10 mins per environment, the distraction phase lasted 5 mins, and there was no time restriction during the third phase. The number of items turned off by participants at least once was similar in both conditions (about 70%). This time, people diagnosed with OCD significantly and statistically differed from the control participants by performing about three times more checking behaviors, spending about twice as much time gazing at the virtual stimuli during checking behavior, traveling longer trajectories in the virtual environments, and spending more time checking (almost 2 mins). There was a correlation between the severity of a participant's OCD condition and the frequency and duration of checking behaviors, as well as gazing time while checking. The severity of compulsive checking in a patient's daily environment correlated significantly with checking time and gazing time while checking in the virtual home, but not in the virtual office, suggesting that using the virtual home might be more effective, or that tasks in the virtual office may need to be improved.

To further refine their findings to the subtype of OCD patients specifically presenting checking compulsions, Kim et al. (2012a) used the virtual apartment, and tasks and measures from Kim et al. (2010) with three groups of participants assessed by psychiatrists and a symptom-rating scale: (a) those with OCD whose main compulsion was mostly checking (n = 22); (b) those suffering from OCD without checking symptoms (n = 17); and (c) healthy controls (i.e., not exhibiting OCD symptoms; n = 31). The methodology was similar to Kim et al. (2010), but with a refined assessment of checking time and no assessment of state anxiety induced by the task. The time specifically spent in checking areas was isolated from the general time spent in the virtual apartment during the third phase. The feeling of presence and the percentage of items turned off at least once (about 60%) was analogous in all three groups. Results confirmed that OCD patients who specifically exhibited checking compulsions differed in some of their reactions in the virtual environment. Compared to the other OCD group, they took more time checking, spent more time in general in the apartment before leaving, and traveled more often back and forth in the apartment. Actual checking behavior and gaze time were higher in the OCD-checker group compared to the non-checker OCD patients and the healthy controls, but they did not reach statistical significance. The lack of difference between these two variables may be due to the wide variance in scores in the group of OCD participants with checking compulsions.

Replication of results from Kim's research group is inconsistent for the frequency of checking behaviors (one out of three studies) and gaze time during checking (one out of two studies). Also, all participants had forgotten a significant proportion of potentially threatening stimuli in both studies that reported this measure. It is possible that the seven threat-generating stimuli were not seen as posing an equal threat, some may have been more salient to recall or have elicited more urges to check than others (e.g., the stove versus the light switch). Examining checking behavior for specific stimuli, increasing the perceived threat of the most relevant stimuli and removing stimuli that are quickly forgotten even by normal controls may improve the specificity of the task and reveal a stronger impact on checking behaviors. Perceived responsibility or consequences could also be intensified by modifying the virtual environment (e.g., changing some stimuli on the list, making the fire more visible when the gas burner is turned on, putting towels and paper very close to the gas stove fire), or by manipulating the narrative given to the participants (e.g., "If something happens to this apartment you'll be held responsible." or "This is a test to show how safely you behave in your own home.").

Although they did not behaviorally check more often, compulsive patients checked for a longer period, suggesting they may have been more meticulous in their ritualistic checking. Qualitative differences in performing checking and other ritualistic behaviors are consistent with OCD (Clark 2004; Rachman 1997, 1998) and may be more difficult to objectively measure than simply counting how often an animation is activated in a computer program (e.g., a patient may click only twice, but following a rigid sequence and while staring at the stimuli).

Nevertheless, results from this series of studies from Sun Kim, Kwanguk Kim and collaborators proved that under some primed-situations people suffering from OCD and compulsive checking react differently from other people and—consistent with the expectations about this clinical population—show more anxiety, spend more time repeatedly checking and walk longer distances.

VR, OCD, and "Just Right" Behaviors

Researchers have explored the use of a virtual environment for compulsions related to symmetry, arrangement, and perfectionism. Some people suffering from OCD have rigid and repetitive compulsive behaviors to place things "in the right order," or until it feels "just right" (Clark 2004; Ecker et al. 2014). They can spend significant time precisely ordering, arranging and repositioning objects until they look "as they should." The "just-right" perception can also apply to the patient's assessment of their behavior for deciding when a compulsive ritual is adequately done, which sometimes accounts for the slowness of some OCD sufferers. Pathological doubt and checking behaviors, which are slightly different from perfectionism and achieving things "just right," also contribute to the observation that some OCD patients act more slowly (Tolin et al. 2001). In any case, all these OCD symptoms can be addressed *in virtuo*.

Roh et al. (2010) designed a 3D task where objects were placed disorderly on a desk and participants had to rearrange them until they felt their task was complete. In the first study, 28 adults not suffering from OCD completed the task and their performance was correlated with a general measure of OCD and a specific measure of symmetry. The time participants took to place the objects until they felt they were at the right place, and the total number of clicks required were significantly and strongly correlated with the ordering sub-score of the Obsessive Compulsive Inventory – Revised and the total score of the Symmetry, Ordering and Arrangement Questionnaire.

In a subsequent study (Kim et al. 2012b), the researchers tested a modified version of the task and focused on assessing anxiety. Participants not suffering from OCD had to complete three tasks, sequenced in a random order, and to repeat it on two additional days: (a) free to rearrange the objects, (b) with a time limit of 70 seconds, and (c) with a limit of 35 operations. The elapsed time and the number of clicks were continuously displayed to participants in all three conditions. Anxiety was measured on a zero to 100 scale before each task, shortly after the task started, before the end of the task (or after 93 s if there was a time limit or a specified number of operations), and after completing the task. The analyses essentially revealed three conclusions. First, the free-ordering task did not induce anxiety. This result was to be expected with a non-clinical population (as opposed to a clinical sample). Given the correlations found in the previous study, the free-ordering task would have been likely to induce anxiety among OCD sufferers exhibiting compulsions of symmetry and rearrangement. Indeed, anxiety scores when starting the time-limited task correlated significantly with the questionnaire about symmetry, ordering, and arrangement symptoms. Second, having to rearrange the objects within a time limit induced anxiety. This result was to be expected, yet remains interesting. It shows the tool can be tuned to induce anxiety, even in normal controls. The third finding is that anxiety was induced only on the first testing day. None of the three tasks had an impact on anxiety when repeated over time. Kim et al. (2012b) interpreted this finding as a sign that habituation can occur in this virtual environment. Further studies with a clinical population are needed to confirm this hypothesis. Both studies from this group are encouraging and are leading the way for possible use of virtual stimuli in assessing and treating compulsions that involve the "just-right" perception, which represent a significant issue among more than 20% of people with OCD.

A research group from Italy also used VR to measure clinical dimensions of OCD (La Paglia et al. 2014; Raspelli et al. 2010). Their work focuses on validating a new psychometric test that would be sensitive to neuropsychological impairment. The main advantage of VR over traditional neuropsychological assessment tools is its potentially greater ecological validity. Because virtual scenarios represent a standardized real-life situation, the hope is that people's performance in VR tests will relate significantly with day-to-day problems encountered by patients (see Chaps. 14 and 15 for more on this issue).

An increasing number of studies are reporting poor performance of OCD patients on neuropsychological tests involving classic tasks (e.g., Abramovitch et al. 2011). Some claim that such results reflect neuropsychological abnormalities in OCD patients, including so-called "breaks in volition" (Cipresso et al. 2013), or the inability to freely perform intended actions. Yet, several clinical symptoms of OCD could be connected to slower and poorer performance on neuropsychological tests, including the "just-right" impression, perfectionism, pathological doubt, distrust about one's memory, preoccupation with symmetry or worries associated with contamination (Clark 2004; Salkovskis 1996b; Tolin et al. 2001). Considering the complexity and breadth of functional impairments associated with OCD (APA 2013), it is quite possible that poor performance of people with OCD on neuropsychological tests can be the consequence of the disorder and not a sign of an underlying brain dysfunction. Indeed, studies have shown that such neuropsychological (Kuelz et al. 2006) and neuroanatomical (Baxter et al. 1992; Nakatani et al. 2003) abnormalities disappear after effective treatment. This topic has been a subject of debate for a while. For an active discussion, see exchanges between Salkovskis (1996a, b) and Pigott et al. (1996a), (b), or Abramovitch et al. (2011) for more recent data. Until there is compelling evidence that poor performance of OCD sufferers on neuropsychological measures is caused by preexisting functional abnormalities, the authors of this chapter will consider results on those tests as consequences of clinical impairments.

As such, results from La Paglia et al. (2014) are most interesting. This study recruited 30 people with OCD and 30 healthy controls. The task was performed using NeuroVR (see http://www.neurovr2.org for more information), a free software allowing psychologists to easily build low-tech virtual environments. A VR version of the Multiple Errand Test was devised to assess executive functions and users' ability to plot a course for solving daily life problems. After a training session, participants were invited to enter a supermarket and select and purchase various commodities, including fruits, vegetables, frozen food, garden and animal products, and hygienic items. Participants were allowed to plan and choose the sequence of actions to complete the task, as long as they followed a few rules. These included not going in the same aisle more than once, not entering any aisle except for collecting an item, not purchasing more than one article from the same category, and not talking to the experimenter. A battery of neuropsychological tests was run before the experimental task. Three noteworthy findings emerged from the study. First, the scores of OCD sufferers on the neuropsychological tests were within the normal range, although they were significantly worse than participants in the control group. Second, compared to the control group, OCD participants reported lower levels of divided attention, more errors (in total and related to specific rules including purchasing more than one item per category and asking questions to the experimenter), more inefficient strategies and self-correction, and taking more time to complete the entire task. Third, subscales of the virtual task correlated significantly and inversely with neuropsychological measures, including frontal lobe functions, executive functions, short memory and spatial memory. Significant correlations were also found with selective attention. Taken together, these findings reveal that VR can be used to assess planning, problem-solving, divided attention and mental flexibility in people with OCD. These findings complement those of Roh et al. (2010) regarding the time taken by OCD patients to perform a virtual task involving decision-making, planning actions and performing a limited number of actions. Having rules to follow provided additional information.

Anxiety, attention, flexibility, and specific behaviors during immersion appear to be promising variables to include in a comprehensive assessment of OCD severity in VR. Indeed, one lesson from this line of research is that VR offers a unique opportunity to record and analyze the behavior of people with OCD. Because the VR software tracks and registers each action performed by the user, clinicians have access to an extensive body of information about repetitive behavior, behavioral patterns, trajectories followed to explore the environment, proximity with each stimulus, time taken, and hesitations about touching an object, type of objects avoided, etc. It is possible to track the user's position and head rotations (and infer gaze at objects), while additional tracking solutions can accurately record eye-gaze patterns or instances where the hand touches and grabs objects. It may also eventually be used in treatment, as hoped by Kim et al. (2012b).

VR, OCD, and Contamination

Fear of contamination is a third OCD aspect that has been examined by VR researchers. Intrusive thoughts about contamination are, along with pathological doubt, among the most frequent obsessions, and have been reported to occur on every continent (Radomsky et al. 2014). It often appears along with washing and cleaning compulsions. People with OCD may fear contamination from various sources, including dirt, bacteria, body fluids, disgusting stimuli, radiation, and toxic chemicals. They may also sense a threat from diseases and conditions that are not communicable from objects, such as cancer, AIDS, or bad luck. Fear of contamination is often a criterion to assess the severity of OCD (Clark 2004). Behavioral avoidance tests can be devised to measure the intensity of contamination fear and avoidance, for example by asking patients to perform feared behaviors such as putting a hand in an ashtray and recording if they do so, for how long, and at what level of discomfort. Physiological monitoring of heart rate or skin conductance can also accompany this procedure to provide objective data. Behavioral avoidance tests are sensitive to treatment effects, making them an appealing objective outcome measure in clinical trials (Clark 2004).

A team of researchers from Canada developed several virtual environments for fear of contamination, checking, doubt, and intrusive images (see Figs. 5.1, 5.2 and 5.3). For obsessions and compulsions related to contamination, a virtual public restroom was developed. It comprised three levels of dirtiness for the entire public restroom (e.g., from clean to soiled floor with dirty walls and used syringes on the sink counters), each with progressive levels of disgustingness and dirtiness, from the first to the last toilet stalls and urinals (from clean to extremely unclean and clogged). To address broader clinical symptoms of OCD beyond the fear of contamination, a virtual apartment was set up with potential contaminants such as raw chicken, warm

Fig. 5.1 Six screenshots of a virtual public restroom and an apartment developed for fear of contamination

Fig. 5.2 Four screenshots of a virtual apartment developed for checking rituals

Fig. 5.3 Six screenshots of a virtual environment developed for pathological doubt and intrusive images about violence

mayonnaise, a bathtub and toilet, rotten food, live fish, blood and images related to disease and death (Fig. 5.1). In some cases, images with content that could elicit intrusive thoughts could be selected, disabled, or replaced by a picture brought in by the patient. Based on selections available on the menu before starting immersion *in virtuo*, it was possible to display stimuli related to checking rituals such as the stove oven, electrical appliances, light switches, doors, windows (see Fig. 5.2). Other options in the virtual apartment were meant to address pathological doubt (see Fig. 5.3) with images related to aggression or sexuality and homosexuality displayed either in a flash (e.g., for a second or less) or in the user's peripheral vision (i.e., the virtual stimuli disappeared when the user tried to look at them directly). These environments are useable with low-cost VR hardware, high-end HMD, and peripherals, or in fully immersive rooms such as CAVEs.

The virtual dirty public restroom was tested to assess contamination fears and related rituals and see if it could elicit anxiety in OCD patients and if their emotional reaction differed from non-OCD controls (Laforest et al. 2016a, b). A sample of 12 adults suffering from OCD and whose central obsession and compulsion focused on contamination was compared to 20 adults not suffering from OCD. Participants were immersed in a CAVE-like VR system (a ten-foot cube with stereoscopic images retro-projected on all six walls nicknamed Psyché), first in a neutral environment to familiarize themselves with being immersed and allow researchers to determine reference levels of anxiety and presence. During the subsequent immersion in the third and dirtiest level of the public restroom, participants were invited to venture into the different areas, touch walls and toilet seats, etc. There was a definite increase in anxiety among OCD participants, but not within the control group, as documented by self-reporting and heart rate. Regarding fear of contamination, this finding replicates what was found by the Korean group about checking rituals: an immersion in VR can indeed elicit anxiety if the environment includes stimuli typically feared by OCD patients. It extends this notion from checking rituals to fear of contamination. Again, we must emphasize that external contamination is not possible in the virtual environment. The fact that virtual stimuli can elicit anxiety despite actual danger has been extensively documented in anxiety disorders (see Chap. 3 or Wiederhold and Bouchard 2014), and will be discussed in the chapter's conclusion. One final note about this study relates to unwanted negative side effects induced by immersion in VR (commonly referred to as cybersickness). The researchers found more cybersickness among OCD participants, compared to the control group, *before* the first immersion, no difference after the immersion in the neutral/familiarization environment, and again more cybersickness after the immersion in the contaminated environment. These patterns replicated other findings (Bouchard et al. 2009, 2011) suggesting that reports of cybersickness are often confounded with apprehension and anxiety.

Contamination was also studied using a less immersive technology. Belloch et al. (2014) reported on an experiment with four adults aged between 22 and 42 diagnosed with OCD and exhibiting contamination fears and rituals. The virtual stimuli were projected on a 46-inch television rather than an HMD or a CAVE. However, real-time immersive interactions were possible thanks to the use of Kinect, which allows users to "see themselves inside the TV." The tasks involved picking up objects in a virtual kitchen (e.g., a lettuce, a dirty cloth, an uncovered piece of cake) and performing various actions presenting a contamination hazard (e.g., cutting bread or an apple with a knife that was picked up from an unclean bench, removing a bottle from the dustbin, filling it with juice and drinking from it). The sample size was too small to conduct analyses, but based on data and impressions from the experimenters, the researchers were enthusiastic about the potential of this technology.

Because immersion in specific VR scenarios has the power to induce anxiety, it can be useful for therapists conducting cognitive-behavior therapy. This form of therapy is the first line of recommended psychological treatment, based on empirical research (Abramowitz et al. 2001; Franklin and Foa 2007; Katzman et al. 2014).

As mentioned previously in this chapter, one of the key ingredients is called "exposure" or "exposure with response prevention." This technique allows patients to develop and memorize new and more adaptive mental representations and associations of feared stimuli with lack of threat (Bouchard et al. 2012; Powers et al. 2006). The process leading to this adaptive emotional learning requires the patient to progressively confront, or be exposed to, what they are afraid of, without engaging in their typical preventive behavioral response, avoidance or neutralization. This process is usually associated with an increase in anxiety, although the level of anxiety experienced during exposure is a poor predictor of treatment outcome (Richard and Lauterbach 2007; Wiederhold and Bouchard 2014). This technique is used as part of a broader set that calls on individual case conceptualization and a strong working alliance with the patient (for more about this therapy, see Beck and Emery 1985; Clark 2004; Rachman 2003; Wiederhold and Bouchard 2014). Studies presented so far in this chapter have shown that VR can be used to provide exposure. The next step is using VR in therapy. Rigorous single-case studies are required, however, before conducting large randomized control trials.

Laforest et al. (2016a) used a semi-structured clinical interview to recruit three adult OCD sufferers. Participants were included in a research protocol using single-case design with randomized assignment to multiple baselines across subjects. In this kind of protocol, all participants start a daily baseline assessment for a fixed minimum duration (in this case, three, four or five weeks) that serves as a control condition. Treatment is introduced one patient at a time, after progressively longer baseline measurements, with patients serving as their own controls and comparing the effect of the delayed introduction of treatment to correctly attribute changes in patient's clinical status to the intervention. With idiographic analysis and systematic control of the introduction of treatment after different baseline measurements, it becomes possible to draw conclusions about the efficacy of the treatment, which is a strong point of this protocol (Kazdin 2002). Its weakness is the small sample size, which limits generalization of results and highlights variations associated with individual differences. The treatment comprised 12 weekly sessions and focused primarily on exposure during sessions 4–11. All participants reported dominant obsessions and compulsions about contamination, with two patients being worried by germs and one by sexually transmitted diseases. Treatment integrity was ensured by reliance on a treatment manual, and supervision and review of recorded therapy sessions. Immersion occurred in Psyché, the six-wall CAVE-like system mentioned earlier. An intriguing twist of the (Laforest et al. 2016a, b) study is the use of both time-series statistical analyses to document whether the intervention would have a more significant impact than expected, and clinical analyses to determine if the effect of the observed change would be meaningful. Results revealed a statistically significant reduction in intensity and severity of obsessions and compulsions for all three participants, although these changes were clinically meaningful only in the two patients afraid of germs and not in the third OCD patient whose fears were less specific to toilets and bathrooms. So far, these findings are promising and lay the ground and justifications for obtaining funding and starting large randomized control trials of *in virtuo* exposure for OCD.

It is worth mentioning that other virtual environments have been developed for OCD by a group in Mexico (Cardenas-Lopez and Manoz-Maldonaldo 2012). In collaboration with a team of clinicians and educational psychologists, this group developed four interactive virtual environments: a virtual bus, a traditional Mexican restaurant, a public toilet and a bedroom. The first three environments focused on fear of contamination and the last one targeted compulsions of symmetry and order. They included OCD-relevant stimuli leading to urges to wash hands, avoid contaminants, sit at dirty restaurant tables, check if drawers are closed, or objects are organized "the right way," etc. The toilet and the bus environments allowed the therapist to adjust the level of dirtiness, and the restaurant included virtual characters coughing and belching. These environments are currently being validated.

VR and Body Dysmorphic Disorder (BDD)

We are not aware of published studies using VR specifically with people suffering from BDD. However, a few studies have examined body satisfaction (Purvis et al. 2013), body dissatisfaction (see Ferrer-Garcia and Gutiérrez-Maldonado 2012 for a review) and body image disturbance (See Chap. 7 for a review). Body dissatisfaction is associated with seeking body characteristics that are different from actual appearance and with negative thoughts and affects related to the discrepancy between idealized and actual body (Grogan 2008). There remains a need to develop and test with non-clinical and clinical populations realistic virtual environments that would allow clinicians to quickly modify specific body parts of the user's avatar (e.g., nose length, knee size, arm length) in real time during immersion. Nevertheless, because BDD involves the dysfunctional perception of physical appearance, it is believed that some results from research on VR and general body dissatisfaction can apply to dissatisfaction with specific body parts that is at the core of this disorder.

Purvis et al. (2013) investigated the potential of VR to influence body satisfaction, as opposed to considering it as a stable trait, and exploited the potential of VR to trigger body comparison, selective attention and body checking. During immersion, participants were exposed to five scenarios: (a) a control situation depicting the physical lab, (b) an empty beach, (c) a beach populated with virtual humans, (d) an empty party scene, and (e) a party scene populated with virtual humans. In this study, the relative body size of the virtual humans in the environment, not of the user, varies from thin to overweight. The impact of the immersion was measured according to answers to questionnaires on body satisfaction, as well as behavioral data related to body checking and the distance that the user kept from each virtual human. Results from people satisfied and dissatisfied with their body were also compared. This study describes the typical research approach used in the field, notably with the use of a virtual environment that can easily trigger social comparison of one's body (a beach or a swimming pool with people in bikinis) and populating the environment with virtual humans that vary from very thin to overweight.

Some experimental studies have already found relevant results in samples of participants that are manifesting actual discomfort with their body image although not to the point of reaching clinical status. In a group of 27 women not suffering from a mental disorder, Aimé et al. (2012) found that visiting a virtual swimming pool with virtual characters in bikinis that are both thin and obese induced significant anxiety and concerns about weight, shape, and food in participants that were dissatisfied with their body. This was not the case with participants who were satisfied with their body. The distinction between body satisfaction and dissatisfaction was based on a score differing or not from normative samples on the drive for thinness and body dissatisfaction scales of the Eating Disorder Inventory (Criquillion-Doublet et al. 1995). Immersion in a virtual buffet with a variety of foods also negatively influenced body dissatisfaction, although results were less significant than those from the swimming pool. The immersion was conducted with an affordable HMD and a virtual environment developed with NeuroVR, suggesting that low-cost immersive technologies can trigger negative emotions.

Further research by Aimé and her group (Guitard et al. 2011; Aimé et al. 2012) explored the dimensions of social comparison and the impact of comments on physical appearance. Using Psyché, they twice immersed a non-clinical sample of 24 women dissatisfied with their weight but having a body mass index in the "normal" range in a virtual bar where two male customers loudly expressed socially inadequate comments about the waitress's physical appearance. In one immersion, the waitress had a thin body size whereas in the other she was overweight. Only the physical shape of her body varied, with "sexy" clothing, breast size and behaviors remaining identical. The negative comments by the male customers led participants that were dissatisfied with their body to feel even more dissatisfaction and anxiety. This was particularly significant for those who were first exposed to the overweight and then to the thin waitress. Therefore, immersion in VR that includes elements of social comparison and explicit comments about physical appearance can trigger emotional reactions in women worried about their appearance. It would be interesting to conduct a similar study with people suffering from BDD because comments from the virtual male customers might elicit negative emotions and self-focused attention in anyone displeased by their appearance, and maybe also checking behaviors.

Interestingly, much work has been conducted on the treatment of body image dissatisfaction. Ferrer-Garcia and Gutiérrez-Maldonado (2012) and Riva et al. (Chap. 7) reviewed the literature on VR and body image disturbances in people with eating disorders and obesity. Compared to BDD, eating disorders represent a different group of mental disorders that have distinctive features (e.g., worries about weight and shape of the entire body, dysfunctional issues with food and food-related situations). Obesity is not a mental disorder and does not necessarily imply a dysfunctional body image. Nevertheless, in the absence of data on BDD, exploring this research field may provide valuable information. In a nutshell, results with people suffering from eating disorders and obesity demonstrate that immersion in VR can elicit anxiety, a depressive mood, concerns about weight and physical appearance, overestimation of body size, and body dissatisfaction. VR is also a productive asset in the cognitive-behavioral treatment of eating disorders and obesity. Because studies involving non-clinical samples may report findings relevant to BDD, some of the research in this field is summarized below.

Riva and his team were pioneers in the use of VR with people worried about their body image (Ferrer-Garcia and Gutiérrez-Maldonado 2012; Riva et al. 2009). They developed a series of software packages to assess and treat body-image disturbances (Riva 1998; Riva and Melis 1997). Their virtual environments included several scenarios relevant to BDD, such as a room where users had to choose, among several body types, the one that best represented their perception of their current body size and ideal body. The discrepancy between the virtual images served as an indication of levels of dissatisfaction. One scenario comprised several images of female models expected to elicit emotions by social comparison, and another presented a room with doors of different sizes where users were invited to go through the door that fit precisely their body width and height. These virtual environments are available as part of the free NeuroVR software. Riva conducted five studies with non-clinical samples that targeted body image disturbance (Ferrer-Garcia and Gutiérrez-Maldonado 2012; Chap. 7). Overall, 223 non-clinical males and females were immersed in virtual scenarios developed to treat body image disturbance, usually for eight ten-minute sessions. Some immersion and therapeutic tools tackled issues specific to food consumption and body weight, which may be less relevant to BDD, but other immersions also targeted body dissatisfaction. Statistically significant reductions in body image disturbance and body dissatisfaction were reported and replicated in all studies. In sum, Italian researchers Riva et al. (2009) repeatedly demonstrated that immersion in VR could serve to modify image disturbances, even in people who do not suffer from the specific dysfunctional cognition, emotions, and behaviors that characterize eating disorders and, to a different extent, obesity. Their program was also effective in improving body image and mood in a patient who was dissatisfied with her body image after losing weight through bariatric surgery (Riva et al. 2012). We mention this case because the impact of the immersion was not associated with additional weight loss, but to changes in physical and emotional well-being associated with increased self-confidence and perceived self-efficacy.

Riva's work is significantly adding to information gathered on samples with non-clinical participants preoccupied with their body image suggesting that VR can be used to conduct psychotherapeutic work with people suffering from perceptual distortions specific to one or more body parts. Because eating disorders such as anorexia can have a link with poor insight about true physical appearance, and VR has been shown to be useful for this population, the issue of insight about actual physical defects in BDD may not pose a problem after all. What remains to be explored with VR is the obsessive and compulsive nature of BDD, with its constant checking, reassurance seeking, behaviors intended to hide perceived body flaws, self-focused attention, etc.

Researchers from Spain have also conducted work on body image disturbance that is applicable to BDD (Ferrer-Garcia et al. 2009; Perpiñá et al. 2000). Ferrer-Garcia et al. (2009) exposed 108 non-clinical controls and 85 people suffering from eating disorders to a series of virtual environments developed following an empirical assessment of situations that cause body image discomfort. Most of their virtual environments are related to food, but one is not and depicts a swimming pool populated with virtual humans that are slim, young, fashionable, from both gender and with females wearing bikinis and making comments about the user's bikini. The male and female virtual characters also made positive and negative comments about the physical appearance of other virtual characters. Even among normal controls, the swimming pool environment induced a significant level of anxiety. The use of a swimming pool scenario, comments expressed by other virtual characters, and presence of virtual humans in bikinis confirms the usefulness of the work conducted by others on social comparison and its potential for BDD-related fears.

Perpiñá and his team used their own VR software (Perpiñá et al. 1999), which includes food-relevant scenarios as well as others addressing body dissatisfaction, with rooms with mirrors and one with posters of female models. In an interesting twist, it is possible in one immersive environment to adjust the size of various body parts of a virtual human with a slide bar. Users can thus change their avatar to make it look thinner or larger, based on their perceived or desired body shape and other characteristics. Riva's application also has a situation where the user can choose between several body sizes. That environment allows only global assessment of self-perceived and desired body image and excludes variations in different body parts. Perpiñá et al. (1999) application focuses on weight (from anorexia to obesity) and the virtual images created cannot be animated to navigate and interact with the virtual environment from a first-person point of view. It is getting closer, however, to the requirements for BDD.

There may be merit in following Perpiñá et al. (1999) lead and develop a virtual environment for BDD that would allow patients to modify their avatar to represent the specific perceived physical defects, flaws or asymmetries that are a source of concern. There is software to design and modify virtual bodies, but it is impossible for clinicians to currently use it unless they have expertise in 3D modeling, animation, and programming. Nor can such avatars be easily imported in a real-time rendering software where patients could interact *in virtuo* with other virtual stimuli and characters. Among the challenges inherent to this application, one must adapt the animations of the modified avatar. Unless a complex system made up of several trackers attached to body parts is used, the visual representations of the virtual body and its movement must rely on preprogrammed animations that are blended as the action unfolds. Additionally, systems that track body in real time will not accurately display an altered (i.e., "wrong") version of the user's body in real time. Therefore, if arm length, hip size or knee height compared to the other knee are modified, pre-recorded animations of the virtual character and its movement will be either distorted or fit poorly with other objects in the environment. For example, without creating a new animation, a longer arm will bend awkwardly and "pass through" a door if a shorter version was correctly extending to grab a doorknob. Technological solutions to this problem are undoubtedly soon to be found. Otherwise, it is possible to conceive and handle minor modifications to the physical appearance (e.g., size of facial attributes, details on the skin), or more complex modifications not intended for use during immersion with real-time rendering. In an immersion where a user cannot see their avatar, the therapist could modify the computer representation of the patient to take the form of their feared appearance, and make the patient believe that this is their physical appearance in the virtual environment, although it would not be the case (i.e., the avatar is not modified but the user cannot know it, so they assume that this is their physical appearance). Working recently on illusions of body ownership (for example, creating the illusion that the size of one's body varies from that of a doll to a giant, van der Hoort et al. 2011), researchers have devised protocols to make patients believe that specific virtual body parts or deformities are real and their own. Conversely, representing the perceived flaws and physical defects of the patient may not be useful at all in treatment. These open research questions deserve empirical testing.

VR and Hoarding Disorder

There is almost no research on the pathological collecting of "useless" objects, which was previously considered a subtype of OCD (APA 2013). O'Connor et al. (2011) have conducted preliminary work using NeuroVR. They recruited three women suffering from hoarding disorder. The therapist used personal pictures of actual objects they amassed and collected. A virtual apartment was then cluttered with these real images of personal objects. As part of a pilot case study, patients were invited to pick up these "important" belongings they had been accumulating and sort them. Later in the session, they were invited to delete them. Although not immersive, the tasks were occasions to learn to organize and discard items, including dealing with the anxiety associated with performing these behaviors. All three participants reported discomfort in the cluttered virtual environment and became aware of the severity of their hoarding problem. According to the therapist, the sessions had a beneficial motivational impact. Discarding some hoarded items induced anxiety and frustration.

These researchers continued their investigation and now have enrolled 14 patients in a more controlled protocol (St-Pierre Delorme and O'Connor 2014). After 24 sessions of inference-based therapy (a form of CBT focusing on pathological doubt, O'Connor et al. 2011), participants were randomly assigned to five VR sessions where an apartment was cluttered using either pictures of personal objects (the experimental condition) or generic objects from daily life (the control condition). During these sessions, the same sorting and discarding tasks were performed as in the pilot case study. Comparisons before and after the use of VR show that sorting and discarding personal images in a virtual environment lead to a statistically more significant improvement on the scale assessing the level of clutter in the patient's bedroom (the bedroom subscale of the Clutter Index Scale) compared to the control condition. However, on all other measures, discarding generic virtual objects not representing patients' personal belongings appeared not to be an inactive control after all. Improvements in the control condition using already available images of daily life objects were as substantial as in the experimental condition using personal images. Results of this ongoing trial suggest that VR may be useful for people suffering from hoarding disorder and these people may even be able to create a bond with generic objects that they no longer want to discard in VR. The researchers did not use an HMD because they considered it too cumbersome with NeuroVR so that results may be even stronger with a more immersive experience. It is unfortunate that no stable control condition would allow stating convincingly that improvements could be attributed to VR. Moreover, VR was used after active treatment. The observed improvement post VR can be ascribed to the success of the inference-based therapy. Nevertheless, these results are encouraging as precursors of larger controlled outcome trials and suggest the need for a more inactive control condition than using standard objects.

Conclusion

People who wonder about the efficacy of VR for anxiety disorders in general (see Chap. 3 for detailed information) naturally ask whether it is a beneficial treatment for OCD and related disorders. The simple answer is that we are not there yet. No large randomized control trial has been conducted for OCD or other associated disorders such as BDD or hoarding disorder. The science of developing effective VR treatment for disorders involving anxiety, perceived threats, and avoidance usually follows a simple path. Situations that can be clinically relevant to reproduce in VR are created and subjected to basic in-house quality control assessments, and then experimentally tested with non-clinical and clinical samples. Once it is known that expected emotions, beliefs, and behaviors are triggered, and therapists feel they can control the intensity of the experience, small pilot trials are conducted. Pilot studies are either non-control open trials or single-case design studies. If the findings are encouraging, the next step is to seek funding to conduct and replicate large randomized control trials, which are often followed by studies examining treatment mechanisms, effectiveness with various populations and settings, dismantling the protocols, or comparing mediators and moderators (see Wiederhold and Bouchard 2014 for illustrations of this process).

Results have demonstrated that VR can induce anxiety and serve for exposure-based treatments with OCD patients presenting compulsions related to checking, contamination, and ordering. Regarding checking behaviors, the impact of VR is stronger among patients who specifically display checking rituals and extends to time spent checking and trajectory length within the environment. However, refinements are needed to either increase the number of checking behaviors in checkers or fine-tune the assessment of checking behaviors to be able to detect differences in behavioral rigidity. Only a couple of pilot outcome trials have been conducted so far for OCD and hoarding. These studies confirmed that sufficient anxiety can be induced by exposure and that treatment may be effective. Indirect evidence suggests that VR can also help to challenge body image in people suffering from BDD. Further research is now needed to provide empirical evidence supporting these claims.

One point that has been repeated a few times in this chapter is the potential of VR to elicit an emotional reaction even though stimuli are fake, and nothing can happen to the user. The situation with OCD might be different from disorders such as phobias, where merely seeing the phobogenic stimuli elicits anxiety. OCD patients react when they perceive a threat in the virtual stimuli, which implies feeling personally responsible if an unfortunate event were to happen in a virtual place or that they could contract a disease from virtual germs. In the same vein, virtual people in bikinis sunbathing around a virtual pool cannot formulate actual judgments about the physical appearance of a BDD user immersed in VR. By nature, emotions are not rational, which may explain why VR can elicit strong reactions even in these populations. The dominant hypothesis involves appraisal and how the brain processes information (Wiederhold and Bouchard 2014). The limbic system reacts to a stimulus within a few milliseconds, which triggers an initial emotional reaction. A few milliseconds later, the cortical areas of the brain come into play to process waves of inputs that modulate the emotional reaction (Pessoa and Adolphs 2010; Phillips et al. 2003). Essentially, the emotional response is triggered based on a very rapid and incomplete appraisal of the perceived threat. The more complete and rational understanding of all elements involved in a situation comes after additional information processing, which includes more logical assessment and access to information stored in long-term memory. Therefore, if relevant stimuli are perceived as “sufficiently” credible, they will elicit an emotional reaction based on the patient’s appraisal of perceived threat, disgust, control, self-efficacy and available coping options. When feeling present in a virtual environment, users forget that they are *in virtuo* and process information as if they were *in vivo*. Based on this model, presence is not necessarily a linear predictor of emotional reactions induced by virtual stimuli. However, some minimal level of presence is probably associated with emotional triggering. The non-linearity between presence and emotional reactions, as well as minimal levels of presence and realism required to trigger emotions, are still poorly understood (Wiederhold and Bouchard 2014). There is, however, substantial evidence that anxiety is associated with presence in clinical populations (see Ling et al. 2014 for a review and meta-analysis).

One neglected issue so far is the severity of OCD. This disorder can be extremely debilitating (APA 2013; Kessler et al. 2005a, b) up to the point that it may become difficult to distinguish this condition from delusional and psychotic disorders. It would be thought-provoking to investigate the relationship between the severity of a patient’s condition and both the impact of immersion in VR and the potential usefulness of *in virtuo* exposure. Can virtual environments be effective with patients suffering from severe obsessions and compulsions? Evidence related to other anxiety disorders (see Chap. 3) suggest that VR can elicit emotional responses in people with severe anxiety disorders; in fact, people’s reactions in VR get stronger as severity increases (Robillard et al. 2003). If such is the case with OCD, BDD, and hoarding, how can we gauge the immersion or adjust the intensity of the VR experience to make sure that patients can tolerate it and achieve the therapeutic purpose of this emotional experience? Again, given that VR is also useful for patients suffering from delusions and schizophrenia (see Chap. 13), immersion in VR may be especially suitable for severe patients who have poor or no insight. If people suffering from OCD-related disorders trust entirely in the veracity of their beliefs, and also in the genuineness of the VR experience, could we use immersion to test the reality principle, or more precisely, how to distort perceptions during appraisal of reality and rules governing it? These remain open questions for clinicians and researchers. Further studies should address other fears typical among OCD sufferers, such as pathological doubt, aggressive or sexual impulses, and immoral ideas.

For OCD, most efforts of VR researchers have focused on compulsions. Intrusive thoughts are rarely targeted. However, exposure exercises have also been developed for intrusive thoughts (Clark 2004; Salskovskis 1985, 1996a). It is assumed that these exposure exercises have to be highly individualized according to the idiosyncrasies of the patient's worse obsessions and mental scenarios. Developing new associations with lack of threat is done with exposure to specific cues involved in intrusive thoughts, obsessions and their meaning for the patient. However, it would be interesting to test whether being exposed to generic scenarios depicting intrusive thoughts could be therapeutic. Using generic stimuli appears to be efficient for hoarding disorder, and research conducted with patients suffering from generalized anxiety disorder suggested that standardized virtual scenarios can elicit anxiety (Guitard, Bouchard, Bélanger and Berthiaume, 2019), even though worries typical of this population vary significantly from one patient to another. It would, therefore, be intriguing to devise immersive situations where the user feels present in an embodied experience where he or she is either actually performing a dreaded action, or witnessing a dreaded action being performed from a first-person point of view. Such a scenario should include the occurrence of the feared dramatic consequence (e.g., the house burning or people being stabbed with a knife), as it is part of traditional imaginal exposure for obsessions in CBT (Clark 2004; Rachman 2003; Salkovskis 1996a). This is also possible for other anxiety disorders (Richard and Lauterbach 2007), and it allows patients to conclude that thoughts are just thoughts, anxiety is a manageable experience, such things will not happen, and if ever they do, the patient will be able to cope with them. Even if all the details are not part of the scenario, this may be effective clinically, at least in the early stages of the exposure hierarchy, which could be a topic for further research.

For BDD, most studies using social comparisons involved females. The only studies significantly involving males are from Riva's group, but the protocols involved several environments remotely associated with BDD. Although this disorder is most prevalent among women (APA 2013), more research is needed with males preoccupied with their body image. Also, as repeatedly stressed in this chapter, studies focused more on weight-related issues and worries than on perceived physical defects or flaws unrelated to thinness. Obesity is not an eating disorder, and both are different from BDD. Undoubtedly, we can apply some findings on body dissatisfaction and negative image disturbance to other populations. Riva et al. (2009) propose that body perception involves the integration of different sensory input from both an egocentric and an allocentric reference frame. These two reference frames hold sway respectively on the perceptions arising from within the body and from an observer's perspective. These reference frames influence how information is stored in and retrieved (see Riva 2011; Riva et al. 2009) from memory. Overreliance on information gathered from external sources (e.g., the look of others) may lock patients in an allocentric viewpoint despite evidence from their own eyes. This hypothesis is cited by Riva (2011) as a possible advantage of using VR with people suffering from eating disorders. Obesity may also be relevant to BDD and should be explored.

Broadening the discussion to all OCD-related disorders, it is interesting to note the widespread use of the NeuroVR software. It is free (http://www.neurovr2.org) and researchers can easily share their environments as part of a growing community of supporters. Its main advantage is its simplicity so that people without much technical knowledge can use it. It includes an extensive library of environments and objects that can be customized and tailored to the patient's needs. It can be used with some old-generation HMDs and trackers, although integration of peripherals is sometimes cumbersome. Its drawbacks are the reverse of its qualities; because it is free and simple to use, its options are limited, the visual quality does not match that of 3D games and other immersive environments, and it does not support current and popular HMDs. Nevertheless, useful results have been found using this software. The previous discussion on the emotional nature of patient's reactions to virtual stimuli also applies to the realism of virtual stimuli. Virtual reality does not have to be a perfect replica of the physical reality to elicit therapeutic emotional reactions in patients (Bouchard et al. 2012; Ling et al., 2014; Wiederhold and Bouchard 2014). The required degree of realism sufficient to treat OCD-related disorders remains an empirical question, but it is different from what most current and competitive entertainment and marketing businesses require.

Aside from exposure *per se*, emotional reactions triggered by immersion in VR can also serve other purposes in CBT. For example, they can help prevent relapse by putting patients in an emotionally challenging environment to test their coping abilities and normalize their reactions (e.g., having to use a filthy bathroom or children laughing at the patient's physical appearance). Putting the patient in an aroused emotional state can also be used to conduct cognitive restructuring (Beck and Emery 1985). Challenging a patient's dysfunctional beliefs is part of traditional CBT. Clinicians may find another purpose for VR when addressing "hot cognitions" (David and Szentagotai 2006), that is thoughts and beliefs associated with meanings and emotions. Cognitive restructuring seems more efficient and long lasting when patients are emotionally aroused while challenging their thoughts, as opposed to cold factual rationalization. Immersions in VR can be used to put patients in a mood, or a context, where their beliefs are challenged while less rational and already in a mode of emotional processing. It remains to be tested whether this facilitates memory consolidation of alternative beliefs, mood dependent recall and long term integration into autobiographical memory.

More experimental research can be conducted with people suffering from OCD related disorders. Immersions in VR can open new paradigm for fMRI and brain imaging studies, where patients could be submitted to the subtleties of situations triggering intrusive thoughts and compulsive behaviors, body dissatisfaction, hoarding, extinction processes, etc. It may also facilitate the transfer of treatment gains from one context to another.

As noted previously, there is still a debate about the extent to which neuropsychological assessment of OCD measures stable underlying causes, or abnormalities that can change thanks to neuroplasticity, or an epiphenomenon. One way to address this issue would be to develop immersive tasks that can tease out the role of anxiety and other psychological mechanisms from core neurological dysfunctions (for example, combining the assessment of executive functions, such as the Tower of London, performed by people suffering from OCD while immersed in a progressively dirty and filthy public restroom). The underlying idea is to manipulate within the same standardized and realistic setting both the difficulty of the neurological test and the emotional challenge associated with the psychological features of the virtual environment. In a task such as entering a supermarket and purchasing products (La Paglia et al. 2014), the type of product to pick up (e.g., a towel versus raw meat packed with blood), and their locations (e.g., a clean or dirty shelf) can also be chosen by the test developers based on their likelihood to elicit fear and disgust in people suffering from OCD. The task can then include standardized elements of memory and interference from the meaning associated with the stimuli. More elaborate testing tools could also be devised to test the interaction between clinical features caused by perceived threat and avoidance, and those reflecting real deficits in memory or other fundamental cognitive impairments. Measuring with neuropsychological tests clinical features with OCD could remain relevant even if it does not tackle fundamental cognitive impairments. It would provide a rich understanding of the cognitive challenges associated with OCD. However, researchers, clinicians, patients and the public would not jump to the conclusion these are causative elements.

As a closing statement, this chapter illustrated the potential of virtual reality for people suffering from obsessive-compulsive disorder, body dysmorphic disorder, and hoarding disorder. There is an excellent potential, and we propose a research agenda for several years to come.

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Chapter 6
Virtual Environments for Substance Abuse Assessment and Treatment

Patrick S. Bordnick and Micki Washburn

Introduction

I am on my way to a party and cannot stop thinking about having a beer, and then of course, about avoiding drinking beer. I feel the familiar tension and craving rising as a result of wanting a drink. I have rehearsed this in my head a thousand times, "I will not drink, I will ask for a soda or bottled water". I think about how I may escape the situation if I am unable to fight off the urge to drink. I repeat to myself over and over, "I will make it through this evening. I will not fail again."

I am now 1 week sober and ready to give-up, realizing that I can't stop drinking. I am now on my way to a party where I know there will be plenty of alcohol and everyone will be drinking. I need to clear my mind. "Just relax" I think as my car stops on the street in front of the house. Suddenly the demons I inevitably struggle with hit me again. Self-doubt creeps in as I walk toward the front door, with my eyes fixed on the cracks in the sidewalk. I keep my head down but can't avoid noticing a man and a woman laughing and enjoying themselves just inside the entryway.

"Dammit," I think as I lose focus on the sidewalk. I am immediately fixated on the beer in their hands. I feel the anxiety of not having a drink in my hand and the intense craving that follows it. My mind starts racing, and my chest feels that familiar tightness. I take another

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> deep breath and say hello to the couple on my way in, hoping that my ever-rising desire to drink will magically disappear with each step forward. As I enter the kitchen, it feels as if a bomb of anxiety has just exploded inside me. My chest is heavy, I'm screaming inside my head, as I feel the intense urge to drink when I smell pizza, cigarette smoke, and beer. I see the six packs, too numerous to fit in the fridge, bottles of liquor and mixers and red plastic cups all sitting peacefully on the table. I have but one thought, "I need a drink now or I have to get the hell out of here."

The previous scenario is based on a first-person recollection of attending a party that was developed into a virtual reality scenario by Dr. Bordnick at the Virtual Reality Clinical Research Lab. This scenario was used to construct a virtual reality platform to assess and eventually decrease alcohol craving, offering a novel approach to substance abuse treatment.

For centuries, people have consumed substances, specifically, drugs and alcohol in various forms for a multitude of reasons. These include religious ceremonies, recreation, or coping with physical pain or psychological distress. As of 2014, it was estimated that approximately 21.5 million Americans ages 12 and older met the criteria for a substance use disorder within the last year (Center for Behavioral Health Statistics and Quality 2015). Substance misuse is a significant public health concern that costs our nation over $600 billion annually, including costs directly associated with substance abuse treatment, as well as indirect costs such as lost productivity, and involvement in public systems like child welfare and the legal system (Substance Abuse Mental Health Services Administration 2013; National Institute on Drug Abuse 2012). Vast resources have been allocated to investigate the mechanisms of substance abuse, reasons for relapse, and the development of evidenced based therapies. Although billions of dollars are spent each year on drug and alcohol treatment, most interventions have had limited success (Lopez-Quintero et al. 2011; McLellan et al. 2000). Given the high rates of relapse (McLellan et al. 2000), increasing prevalence rates, and mortality associated with substance use and abuse (Rockett et al. 2012), innovative treatment and assessment approaches must be developed to increase abstinence and reduce relapse.

Virtual Reality (VR) is an innovative technology that has the potential to advance substance abuse research and treatment far beyond where we are today. Since the first reported use of VR for substance abuse issues in 2001 (Kuntze et al. 2001), clinical uses of VR have gained momentum and have been employed for the assessment and treatment of drug and alcohol use disorders (Bohil et al. 2011; Gorrindo and Groves 2009; Bordnick et al. 2012; Fleming et al. 2009). Virtual reality software applications based on cue exposure and reactivity are extensions of the key behavioral principles of conditioning, reinforcement, and extinction (Rescorla and Wagner 1972), which have shown real promise in the treatment of addictions. This chapter presents an overview of advances in virtual reality and their applications related to substance abuse assessment and treatment. We will review the theory behind drug craving and highlight advances for using VR environments to augment traditional treatment methods. Finally, we will offer suggestions for future research and applications of this novel technology to improve client outcomes.

Current Substance Abuse Treatment Methods and Associated Challenges

There is a wide variety of current treatment methods for drug and alcohol abuse. Most approaches focus on total abstinence. Typically, they require the user to spend time in a secure environment where he or she can go through the detoxification process and receive medical attention if necessary, followed usually by 30–90 days in a controlled living environment. During this time recovering users participate in individual and group therapy, from either a psychodynamic, interpersonal process or cognitive behavioral perspective in the hopes of remediating acute stressors and identifying problematic situations or "triggers" for substance use. Outpatient after-care focuses on the development of adaptive coping skills and emphasize the importance of group support as ways of decreasing the possibility of relapse. Many current treatment paradigms also incorporate a strong spiritual component, encouraging clients to accept the fact that they are powerless over their addiction(s) and will always be an alcoholic or drug addict (Alcoholics Anonymous World Services I 2001).

Unfortunately with each of these approaches, high relapse rates remain (McLellan et al. 2000). The most obvious limitation of traditional treatment approaches is that they usually involve removing clients from their typical social environments (Marlatt et al. 2011). This approach continually reinforces avoidance of social and contextual cues and other craving inducing stimuli as a preferred coping method, rather than attempting to extinguish them (Gorrindo and Groves 2009; van Dam et al. 2012). Thus, from a practical standpoint typical treatment approaches often fall short. Substance users in recovery cannot continually live in a controlled environment, devoid of access to drugs and alcohol and apart from any cues that may stimulate craving and urges to use. This is especially important in light of the fact that the majority of social and cultural events in the United States often incorporate alcohol as a component of the function (Peele and Grant 2013); thus avoidance is not as easy as one would hope. Many drugs of abuse are no further away from one's medicine cabinet down the hall or in the local neighborhood. Similarly, since alcohol and cigarettes are readily available at every grocery and corner store (Babor 2010), individuals in recovery attempting to avoid these cues all together would potentially never be able to leave their homes. This is especially problematic in the case of traditional age college students (Larimer and Cronce 2002; Knight et al. 2002) who are often in environments where substance use and abuse are the norm, rather than the exception.

Inpatient treatment and intensive outpatient treatment for substance abuse is expensive, costing on average from $7000 per month for those with Medicare or Medicaid coverage to an average of $20,000 Lee (2011) per month for those with private insurance for a typical, non-luxury facility, leaving many in need of treatment priced out of the opportunity to access. Prior to implementation of the Affordable Care Act, approximately 27.5% of adults with substance abuse disorders were currently uninsured (Donohue et al. 2010), and paying for inpatient treatment is virtually impossible for many without health insurance coverage. Although access to treatment may be improved by the expansion of health care coverage under the Affordable Care Act (Buck 2011), this type of treatment is still quite costly. Furthermore, higher coverage rates may lead to increased utilization but decreased availability of treatment due to demand far outpacing the availability of beds in currently existing treatment facilities.

Even if one is able to pay for inpatient treatment and extended aftercare, there is a high level of stigma associated with hospitalization and substance abuse treatment (Keyes et al. 2010; Schomerus et al. 2011; Livingston et al. 2012). Furthermore, those opting for long term inpatient treatment may be at risk of losing employment or may leave loved one's without the necessary financial support due to loss of income during that time (Beck et al. 2011). Individuals in treatment are separated from their primary support structures (Beck et al. 2011) while working on addiction issues, which may further complicate long term client outcomes. Similarly, if familial or interpersonal difficulties are contributing factors for continued use or relapse, separation from one's family only prevents the user from addressing these contextually relevant cue and dynamics in recovery.

Other complications arise from typical treatment paradigms. Therapies reinforcing one's belief that he or she is powerless in their addiction can also be problematic and do not assist in building the self-efficacy needed to tolerate distress associated with craving (Bandura 1989; Burling et al. 1989). These approaches have limited utility in relation to the development and refinement of the negotiation and communication skills necessary to keep one's self on track when exposed to people or environments in which one would normally engage in substance use. Some treatment paradigms assert that it is necessary for a client to engage in treatment indefinitely to retain his or her sobriety, and that if not, he or she will most certainly relapse, leaving some clients overwhelmed at the prospect of life long treatment.

Methods that allow the client to feel as if he or she can affect change in relation to his or her drug and alcohol use is essential for successful long term, continuing treatment success (Warren et al. 2007; Burleson and Kaminer 2005). Traditional cognitive behavioral/relapse prevention (CBT/RP) therapies have shown efficacy for decreasing use and promoting abstinence (Witkiewitz and Marlatt 2004; Barrett et al. 2001). One key component in CBT/RP is the incorporation of coping strategies with the goal of equipping the client with skills to prevent use and relapse (Marlatt and Witkiewitz 2002; Marlatt and Donovan 2005). Traditional CBT/RP uses role-playing in an office or lab setting to practice and rehearse these skills. The role-playing context (office or lab setting) and the use of live actors are limiting factors, artificial, and lack congruence with real world use situations and interactions. The client is expected to imagine or suspend critical judgment in a clinical setting that lacks meaningful cues and contexts. We believe skills training conducted in laboratory or office based environments will result in less than optimal transfer or generalization of skills in the real world. Ideally, the most effective intervention would bring real world cues and contexts into the lab or clinical setting; however this has been logistically difficult to achieve (Bordnick et al. 2013).

Cues, Craving, and Extinction Related to Substance Abuse

Craving is defined as an intense desire, or want to consume. It is believed to consist of both behavioral and biological processes working in concert often leading from initial use to continued misuse and dependence. Craving is elicited by a trigger, also known as a cue, which prompts or signals the craving episode. The most recent edition of the Diagnostic and Statistical Manual of Mental Disorders, DSM5, associates craving with changes in brain neuro-circuitry that are linked to relapse when one is exposed to drug-related stimuli (Association AP 2013). Accordingly, substance craving has been added as one of the criterion necessary for the diagnosis of a DSM substance use disorder, a criterion that was not required in the prior editions of DSM (Association AP 2000), reinforcing the continued importance of the relationship among cues, craving, and substance abuse.

There are two primary types of cues related to craving: proximal and contextual. Proximal cues are defined as objects directly related to, or in close proximity to a substance such as the alcohol or drug itself, bar ware, or drug use paraphernalia such as pipes, syringes, spoons, or razor blades. Contextual cues are more indirectly related to the substance and are defined as the settings or social contexts in which the substances are used such as a bar, party, shooting gallery, or any other place in which one may use. "Complex" cues,(Traylor et al. 2011) resulting from the integration of both proximal and contextual cues most closely approximate real world environments and are thought to become conditioned via repeated paring with substance ingestion. After repeated pairing these cues become generalized and result in the strengthening of the physical or psychological response produced by consuming the substance even in the absence of the actual substance itself. Consider an example of craving based on cues that most Americans can relate to– the craving for french fries. This craving is related not only to the fries themselves, but also to their smell, to the way they look in advertisements, or to seeing a sign for your favorite restaurant. You see a commercial on TV for the fries, you crave fries. You go into a restaurant planning on not eating fries, and then smell the fries, you crave fries. There is a good chance that you will end up ordering fries because of these cues.

Substance craving works much in the same way. For example, when someone is trying to quit smoking, craving may be induced by cues such as seeing or touching cigarettes, but it can also be triggered by the smell of cigarette smoke, seeing others smoking, pictures of cigarettes in magazines, or just being in a place where one used to smoke. The craving resulting from these cues may lead to relapse. Unfortunately, cue reactivity is not only limited to the duration for which one actually consumed the substances, but has been reported to occur from weeks to years after abstaining from use (Gawin and Kleber 1986; Manschreck 1993; Prakash and Das 1993), making it one of the most prominent and difficult withdrawal symptoms to manage.

These conditioned associations triggering craving are at the heart of VR exposure treatment for substance abuse. Treatment via VR focuses on the situational and contextual cues associated with substance use. Cue exposure methodologies for investigation of drug craving for alcohol, nicotine, and cocaine have been extensively discussed in the substance abuse literature. Cue exposure is a method used to repeatedly expose a person to drug or alcohol related cues to extinguish the paired associations between the reinforcing properties of the substances and the context/cues (Marlatt and Witkiewitz 2002; Collins and Brandon 2002; Conklin and Tiffany 2002; Hammersley et al. 1992). The process of cue exposure requires the identification of which proximal, contextual, and complex cues trigger craving, then exposing the user to these cues without the drug to extinguish the craving sensation associated with those cues. How sensitive one is to cues, and how many cues trigger craving is thought to be related to the abuse liability of a substance and relapse potential.

Basic Cue Exposure Studies

Traditionally, laboratory based cue-exposure studies have involved exposure to cues via imagined scripts, actual substances and/or paraphernalia, or multimedia rather than recreation of environments. Typically, sessions are conducted in a non-descript laboratory to avoid any potential triggering from outside sources. Participants are exposed to cues in a laboratory environment where physiology, self-reported mood state, and craving responses are recorded. Studies related to smokers suggest that when smokers are exposed to visual, auditory, olfactory, and tactile smoking cues, there is an increase in physiological arousal and associated craving and urges to smoke when compared to neutral (non-smoking related) cues.

Research has also been conducted on proximal cues in relation to the use of alcohol. Multiple studies (Cooney et al. 1997; Glautier and Drummond 1994; Drummond and Glautier 1994; Hutchison et al. 2001; Szegedi et al. 2000; Monti et al. 1993) suggested that visual, auditory, olfactory, and tactile drinking cues increase physiological arousal and subjective reports of craving in both moderate and heavy drinkers. These findings are consistent with (Wikler 1973) and colleagues' early (1973) assertion that presentation of proximal alcohol cues in a laboratory setting will result in increased physiological reactivity in chronic alcoholics. These studies have provided a framework for research on conditioned responses to alcohol. Zironi & colleagues also found that a context that was previously paired with drinking was shown to induce relapse in laboratory animals (Zironi et al. 2006), providing further evidence supporting environmental context as a conditioned stimuli.

(Carter and Tiffany 1999) conducted a meta-analysis spanning the literature from 1976–1996 comparing the cue reactivity of nicotine, cocaine, heroin, and alcohol. They found that although presentation of proximal alcohol cues consistently leads to increased craving, effect sizes reported for the alcohol studies (+0.53) were significantly lower than those found for the other substances (+1.1 and higher) indicating that this may be due to decreased cue reactivity exposure for alcohol conducted in artificial settings such as a lab. It is hypothesized that lab settings are insufficient to bring about significant changes in craving and long term use due to a lack of environmental/contextual cues that seem to be key in craving and use for all drugs, but especially for alcohol. Furthermore, it is frequently suggested that conducting exposures to proximal cues in real world environments or simulated real world context would better approximate actual use settings and would lead to increased effects and increased ecological validity (Conklin and Tiffany 2002; Bordnick et al. 2008; Ludwig 1986; Ludwig et al. 1974).

To date, cue exposure therapies offered apart from the context in which one usually consumed drugs or alcohol have failed to offer robust results in reducing incidences of relapse. This could be explained by renewal reinstatement, spontaneous recovery and reacquisition as suggested by (Conklin 2006). Renewal is a key factor to success in extinction trials, as it results in the reinstatement of an extinguished behavior that was conditioned in a different context. Conklin found that smokers had increased craving to proximal smoking cues but also to smoking environments, even when presented separately (Conklin 2006), further supporting the belief that environmental context is a key factor in craving and must be addressed to decrease renewal effects and potential relapse (Thewissen et al. 2006). Other factors such as spontaneous recovery (Conklin 2006; Bouton 1993; Pavlov 1927), generalization of training cues and attentional bias (Field et al. 2004; Field and Cox 2008), individual differences, reward salience, reward value (Rose and Behm 2004), timing, and length of extinction sessions could also partially explain these results, as conditioned behaviors in general may be subject to differences in these factors. Although context may not be the only factor influencing the limited success in prior lab based extinction studies based on cue reactivity research, it is important to consider.

Contextual Cue Exposure Studies

Environmental context is defined as the social atmosphere and setting in which substance use occurs. Over time substance administration becomes paired not only with proximal cues but with the environmental contexts in which ingestion of the substance occurs. Thus, it can be hypothesized that the reactivity to substance cues extends beyond the presentation of proximal cues to include the entire context or situation. Extinction studies in humans involve extinguishing craving to proximal cues and have been easy to execute. However, extinguishing craving related to context of the drug or alcohol use behavior has been more difficult to execute due to logistical issues (Collins and Brandon 2002; Conklin 2006; Thewissen et al. 2006).

Previous studies focusing on proximal cues have lacked the incorporation of cues presented in congruent environmental contexts, thus offering an artificial exposure situation for participants (Bordnick et al. 2008; Ludwig 1986; Ludwig et al. 1974; Bordnick et al. 2004a). In studies of exposure to physical context related to drinking, increased craving and reactivity have been reported (Zironi et al. 2006; McCusker and Brown 1990). Prior studies also indicate that alcohol is consumed at higher levels in congruent drinking contexts compared to laboratory (low congruence) settings (Wall et al. 2000, 2001; Wigmore and Hinson 1991). Conditioned reactivity to environmental contexts previously associated with use without proximal cues present may trigger alcohol or drug seeking behaviors in users who are in abstinent resulting in relapse (Drummond et al. 1990; O'Brien et al. 1998). Similarly, the importance of environmental context is further supported in conditioned place preference (CPP) studies in animals (Biala and Budzynska 2006; Gremel et al. 2006; Le Foll and Goldberg 2005; Tzschentke 1998). In CPP studies, the rewarding effects of addictive substances are tested in environments where use/administration has occurred. The organism associates the context (distinct cage or contextual setting) and stimuli with the drug. Thus, the cage or contextual setting serves as a cue, itself capable of triggering craving and reactivity. Context becoming a strong stimulus is not difficult to comprehend since many addicted persons report specific places (e.g., bar, party, at home) in which they have formerly used leads to craving and urges to use.

While the mechanism of craving is not fully understood, it has been hypothesized that drug craving is a response conditioned through direct drug use, and elicited by environmental cues related to the individual's past substance use (Prakash and Das 1993; Childress et al. 1993; O'Brien et al. 1993; Satel 1992; Wallace 1989; Obuchowsky 1987). Research has demonstrated that exposure to conditioned cues can lead to physiological arousal and craving, suggesting that cue exposure and evaluation of cue reactivity should be an important element in the treatment of addiction (Szegedi et al. 2000; Childress et al. 1993; Drummond 2001; Johnson et al. 1998; Rohsenow et al. 1991; Tiffany and Hakenewerth 1991). Drug craving and exposure to cues in nicotine, alcohol, and cocaine dependent populations have been reported as factors related to drug use and have been implicated as antecedents to relapse (Miller 1991; Gawin 1991). In fact, Smith and Frawley (1993) contend that craving or urge to use is the most powerful predictor of abstinence loss. This contention is supported by additional research with cocaine dependent individuals indicating that craving may be a factor initiating relapse (Bordnick and Schmitz 1998). Measures of craving and drug use during hospitalization, outpatient treatment, and subsequent follow-up indicate that context is also important to craving. While in a controlled environment where they had limited exposure to drug related cues respondents reported low levels of craving. However upon discharge to an outpatient setting with far fewer restrictions on drug related cues, respondents experienced a significantly higher levels of drug craving (Johnson et al. 1998; Bordnick and Schmitz 1998), a contention that is supported by most substance abuse treatment professionals. Overall, these findings indicate that there is an interaction between drug cues and one's immediate social environment which may lead to actual substance use resulting in relapse.

Complex Cue Exposure Studies

Cue exposure and cue reactivity research would be extended if more research was conducted *in vivo* in a variety of contexts such as a bar, a party, or at home, and included the social interactions associated with these contexts coupled with real-time evaluation methods. Studies support greater cue reactivity being elicited in cases where complex cues are presented, in relation to those using proximal or contextual cues alone (Traylor et al. 2011; Bordnick et al. 2008). This has important implications when utilizing cue reactivity and exposure to extinguish substance use behaviors. Advances in exposure based therapies have yielded encouraging results in relation to the treatment of addictions (Conklin and Tiffany 2002; Marissen et al. 2007; Coffey et al. 2005; Lee et al. 2007). However, there are confidentiality and safety concerns associated with in-vivo exposures for therapists and clients alike in relation to individuals who are purchasing and consuming substances in unsafe environments such as heroin shooting galleries and crack houses. Thus, while in-vivo exposure is usually the preferred method of exposure therapy, it is not always feasible and often may be inadvisable (Carvalho et al. 2010; Pallavicini et al. 2013).

To address these limitations, a novel virtual reality based system which provides exposures in a simulated context (such as a virtual party) that approximates real world use environments, but still maintains experimental control, has the ability to manipulate complex cues as well as environmental context, and can collect real-time data on cues and craving would be ideal for conducting this type of research.

VR Offers Promise to Extend Cue Reactivity Research and Address Shortcomings of Traditional Approaches to Substance Abuse Treatment

Although the application of VR for treatment of substance abuse disorders is relatively new, the principles behind VR based exposure therapy have been around since the late nineteenth century (Schwartz et al. 2002; Higgins et al. 2008). From the times of Pavlov, Watson, and Skinner, principles of behaviorism have been successfully applied to the treatment of psychological disorders. VR employs active behaviorally based strategies built on the principles of exposure, extinction, and skills acquisition.

Virtual reality has the potential to transcend traditional methods of assessment and treatment of substance abuse, blurring the lines between reality and virtual worlds, allowing significant advances in addiction research and treatment. VR incorporates a human-computer interaction providing active participation within a three dimensional virtual world designed to immerse the user. It involves the use of a head-mounted display and tracking systems which respond to user movement by changing the scenes being displayed in real-time as if one was looking around. Directional audio (stereo), graphics, microphones, vibration platforms, tactile (hand grasp), and scent cues all add to the fully interactive VR experience. VR systems can present complex cues that engage all five senses under full control of the experimenter (Bordnick et al. 2008, 2004a; Baber et al. 1992; Bordnick and Graap 2004; Bordnick et al. 2004b). For example, the user can enter a bar, hear music, and observe a person being served a drink. The user then could order a drink for him or herself and pay for it. Upon the drink being served, the user can smell the beverage scent (e.g., whiskey) and pick up the drink providing a real-time, realistic experience similar to one's local bar.

When considering the use of virtual reality, questions arise on how learning in virtual environments translates or generalizes to the real world (Kozak et al. 1993). Several studies have addressed this, and support the contention that clinical gains (e.g. treatment effects) made in VR generalize to the real world (Anderson et al. 2003; Rothbaum et al. 1999; Rothbaum 2006; Gallagher et al. 2005; Garcia-Palacios et al. 2006). Numerous studies demonstrating successful treatment in VR leading to real world benefits in patients have been reported for fear of flying (Rothbaum et al. 2006), stroke rehabilitation (Lam et al. 2006), social anxiety disorder and public speaking (Anderson et al. 2003, 2013; Parsons and Rizzo 2008), post-traumatic stress disorder (Rothbaum et al. 1999; Kenny et al. 2008; Gerardi et al. 2008), organic brain damage (Rose et al. 2005), eating disorders (Ferrer-Garcia et al. 2013; Ferrer and Gutiérrez-Maldonado 2011; Engel and Wonderlich 2010), and attention deficit hyperactivity disorder (Parsons et al. 2007; Schultheis and Rizzo 2001). These studies support the assertion that the effects of VR for substance abuse treatment will translate into real world environments as well.

The key feature distinguishing VR from a traditional multimedia experience, videogame, or interactive computer graphic display, is the sense of presence that the users report. It is critical that VR environments for use in behavioral health are not video games resembling fantasy. Virtual environments must be realistic representations of real world contexts and social interactions if they are to be useful for assessment and treatment. In as much, developmental progression is key and involves the follow iterative process: (1) Review of the current literature, (2) Consultation of experts in the respective areas of study, (3) Field research, (4) Collaborative development process between scientists and programmers, and (5) Real world pilot testing.

Virtual reality based therapy is a flexible and innovative approach that addresses many of the shortcomings of traditional treatments with an individualized, yet systematic approach through the use of exposure and skill acquisition. Since VR therapy is highly individualized, treatment via virtual reality can be tailored to the specific substance of abuse, and assist with the completion of exposures in virtual environments that are unique to each client's individual needs. Due to the immersive nature of VR, clients do not get the sterile "feel" of a lab or the overly controlled calmness of a therapists office, both of which may be so far removed from the client's actual substance use environments that these settings may have less than optimal impact skill acquisition and transfer (Bordnick et al. 2013). Assessment and treatment are conducted in VR environments (e.g., party, bar, crack house) that are congruent with past drug use rather than a clinical setting. VR based treatment does not require a hospital stay, nor does it require an individual to commit to long periods of time away from friends and family, thus minimizing the economic and emotional impact on one's family that often results from extended inpatient treatment. Sessions can be conducted in both inpatient or outpatient settings, thus increasing access to effective treatment.

VR Improves Upon Traditional Cue Exposure Treatment and In-Vivo Exposures

Prior research has led us down a clear path in support of using cue exposure to proximal, environmental, and complex cues as an evidence-based alternative to traditional substance abuse treatment methods. However, why VR is the preferred method of cue exposure treatment rather than simply using traditional lab based interventions or true in-vivo treatments warrants additional discussion. Although many studies support the use of in-vivo exposure as a way of decreasing reactivity to environmental cues through the processes of exposure and extinction, it is often difficult (Coffey et al. 2005; McNally 2007) to encourage the client to engage in these types of real world exposures. Many in-vivo exposures are contraindicated for a client to engage in on his/her own, especially early on in treatment (Foa et al. 2007). Thus, someone trained must be available to accompany the client on these exposures. It is costly to have a mental health professional leave the office and accompany his/her client on multiple exposures to the environments in which he or she was engaging in substance use. Often the substance use is occurring during the evenings and weekends, making logistical issues even more of a concern.

Safety and confidentiality concerns are paramount when doing exposure therapy (Foa et al. 2007), and safety and confidentiality of both the client and the mental health professional can be severely compromised when exposures are related to the people and places that the client encounters when he or she is using substances. This is especially problematic when the client is using illegal drugs versus alcohol or nicotine.

There is also a serious issue with lack of control of one's environment in in-vivo exposures (Carvalho et al. 2010; Maltby et al. 2002; Powers and Emmelkamp 2008), especially in places where most people in the immediate vicinity are under the influence, the context can change at a moment's notice. In addition, clients engaging in in-vivo exposures in these types of environments may not have an easy way to end the exposure (exit the situation) once they are in the substance use environment. If the exposure gets to be too much, panic can set in and increase the clients urge to use following the exposure. This may also decrease the client's motivation to participate in subsequent exposure sessions (Huppert et al. 2006; Otto et al. 2004), and potentially lead to dropout (Hembree et al. 2003).

VR cue exposure treatment improves upon traditional lab based treatments in the following ways. First, treatment is done in a virtual environment, rather than a lab which is decorated to look like places that one would use, there is an exponential increase in the amount of detail and realism that the client will experience in relation to the environmental context. In fact, many places where individuals actually use drugs and alcohol are extremely difficult to recreate in a traditional lab-based setting, (Traylor et al. 2011; Bordnick et al. 2008) especially if these places are outside or in settings other than a bar or a house. Thus, VR can provide true recreations of contexts specific to substance use situations beyond just those associated with alcohol and nicotine (Saladin et al. 2006; Culbertson et al. 2010).

As mentioned, numerous studies have supported the use of VR for treatment of alcohol or nicotine dependent using individuals, which could extend to other substances of abuse.

VR Beyond Alcohol and Nicotine

Looking toward the future, it is exciting to note, that after 15 plus years of VR development and research in substance abuse, Dr. Bordnick's work continues with the development of VR based substance use assessment and treatment scenarios for both desktop and smartphone based systems at Tulane University School of Social Work (https://tssw.tulane.edu/). Going forward, VR platforms can be developed to recreate heroin shooting galleries, abandoned buildings, public restrooms, and clubs where opiates and stimulants are often consumed. Although still in the nascent stages, there is an emerging body of literature that supports the utility of VR based interventions to the treatment of opiates and stimulants. In 2015, while at the University of Houston, VR treatment scenarios for both heroin injection drug users (IDU) and non-injection drug users (NON-IDU) were created under the direction of Dr. Bordnick. An emerging body of evidence also supports the use of VR as a viable treatment for stimulants of abuse such as cocaine (Saladin et al. 2006) and methamphetamine (Culbertson et al. 2010) based on the craving research related to these substances. Saladin and colleagues found that craving was significantly elevated in individuals exposed to a virtual crack cocaine environment than those exposed to a virtual aquatic (neutral) environment, and that craving was at its highest for individuals immersed in scenes depicting active cocaine use. Similarly, Culbertson and colleagues(Culbertson et al. 2010) reported eliciting higher levels of craving and physiological arousal in non-treatment seeking methamphetamine users who were exposed to VR methamphetamine environments in comparison to those exposed to video based methamphetamine scenarios or neutral VR or video-based scenarios, indicating that craving for stimulants can be effectively elicited in virtual environments. Additional research concerning the ability of virtual stimulant environments to extinguish craving for these substances is still in the developmental stages. Further extension of this research to prescription stimulants of abuse could potentially revolutionize interventions with teens and young adults who are particularly prone to abusing these substances (Wilens et al. 2008; Compton and Volkow 2006; White et al. 2006; Setlik et al. 2009).

Virtual environments offer the ability to provide exposures to simple, complex, and environmental cues all working in concert to trigger craving and maintain substance use patterns. Clients can be exposed to a multitude of cues or "triggers" at once, making VR exposures potentially more efficient than those done in traditional laboratory setting. Since problematic substance use behaviors are conducted in a variety of settings, they are maintained by complex cues occurring in more than one context (Conklin and Tiffany 2002; Havermans and Jansen 2003). Many former addicts report being able to maintain sobriety in certain situations but not in others differing significantly from those where the lab based exposure therapy occurred. The technology of VR exposures eliminates this problem by allowing cue exposure to occur across a variety of contexts, leading to increased generalization across different areas of one's life. An additional advantage that VR has over laboratory based exposure treatment is that participants can experience multiple contexts during one exposure session simply with the click of a mouse, an option that is completely unavailable in traditional clinical or lab settings.

Social interactions are key cues involved in drug and alcohol use. VR exposures can contain a few or many virtual humans as indicated for social interactions related to use. This is especially important when attempting to recreate scenes at a busy club or circuit party for the treatment of stimulant drugs such as cocaine and methamphetamine. Cues in VR exposures can be changed with each exposure experience and they can be recreated exactly time and time again depending on the needs of the client, much the same way as is done when doing prolonged exposures for post-traumatic stress (van Dam et al. 2012; Foa et al. 2007). The predictability of VR also increases the safety of the exposure and the control that the experimenter has over the exposure experiences. Finally, VR exposures allow communication between mental health professionals and the participant in real time, allowing the professional to integrate other proven cognitive and behavioral techniques into the virtual scenario without losing client immersion (Robillard et al. 2003; Pausch et al. 1997). The client is still fully involved in the virtual scene, attending to all the cues he or she is surrounded by, in addition to being able to communicate with the mental health professional and practice coping skills.

Examples of Virtual Reality Environments for Drugs and Alcohol

VR environments have been fully developed for assessment and treatment protocols for nicotine, alcohol, and heroin. Each will be summarized with supporting literature and a description of the environments. All environments are currently available for research and treatment purposes.

Nicotine

Over 15 years ago, the first immersive VR environment for smoking was developed. This simple environment based upon traditional cue reactivity exposure and consisted of three rooms. The first room was a neutral cue that contained digital artwork of fish aquariums that served as a non-smoking related control condition. The second room contained proximal smoking cues only and no social interactions. The third and final room contained complex cues consisting of both proximal and contextual stimuli along with social interactions culminating in an offer to smoke by another party goer. Testing of this environment provided the first empirical evidence that VR smoking cues can elicit craving in smokers (Bordnick et al. 2004a). Seeking to progress beyond simple cue assessment, Dr. Bordnick was funded by National Institute on Drug Abuse (NIDA) to develop the first VR treatment for nicotine dependence. Two years of development and testing yielded seven immersive nicotine specific exposure environments including: a social party, a convenience store, an airport smoking lounge, a car/parking garage, outside of office courtyard with smoking areas, and a restaurant. Screenshots of VR smoking environments are depicted below (see Fig. 6.1). All environments included embedded videos to engage users in social interactions featuring peer pressure. A clinical treatment trial followed using cognitive behavioral relapse prevention (CBT/RP) techniques to augment exposure in the VR environments. During the clinical sessions, therapists taught coping skills in real time while the participants were immersed in the VR environments. This clinical trial demonstrated that CBT/RP augmented with VR cue significant reduces nicotine craving and lead to high rates of cessation compared to traditional nicotine patch therapy (Bordnick et al. 2012) and offered the first successful use of VR serving as a platform to teach coping skills in drug dependence.

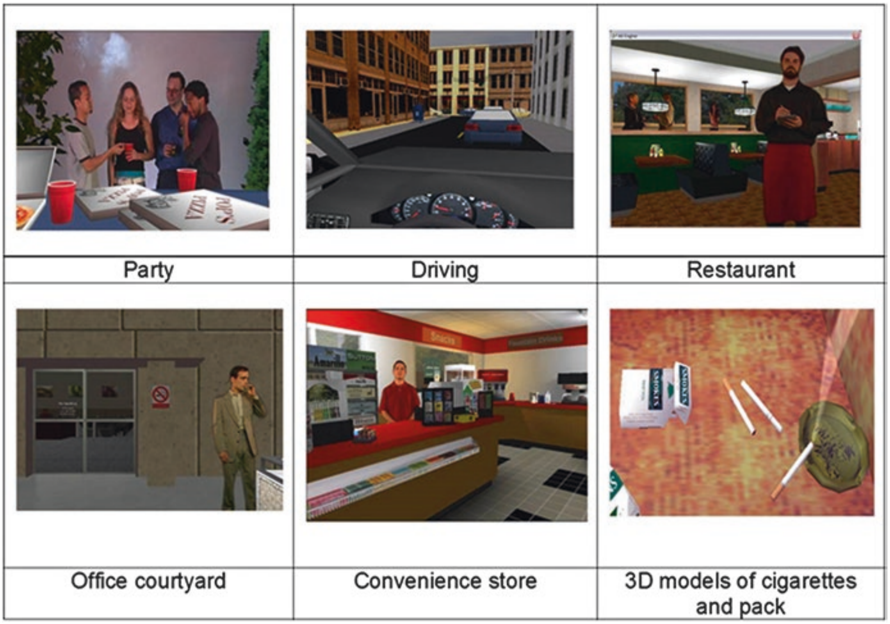

Fig. 6.1 Smoking VR environments

Alcohol

In 2005, the first VR immersive alcohol cue reactivity environment was developed. Building upon previous smoking platforms, these VR environments focused on alcohol as the primary cues and the basis for social interactions. Development for alcohol followed the same systematic process as nicotine, first beginning with the development of proximal cues and then progressing to interactive environments with social exchanges involving drinking. To improve realism related to total sensory input, scent was incorporated during the development of these platforms using a USB enabled sent device. This device provided both specific (beer, pizza, whiskey) and contextual (smoking filled bar, food in a restaurant) scents. The biggest hurdle during the developmental phase was creating detailed alcohol drinks with ice, garnishes, and realistic liquids, as well as alcohol related items such as beer cans and wine or liquor bottles. After months of trial and error computer graphic artists created an entire bar of high resolution realistic 3D drinking proximal cues. VR drinks are depicted in Fig. 6.2. The first VR alcohol environment was tested for cue reactivity comparing neutral cues to alcohol cues in a sample of heavy drinkers. Result clearly demonstrated that VR based alcohol proximal and social cues significantly increase craving compared to neutral cues (Bordnick et al. 2008). Building upon this success, VR environments were created to provide exposure to alcohol based proximal cues and social interactions across a variety of real world contexts. Seeking to improve upon the social interactions depicted in our virtual environments, Dr. Bordnick and his team decided to move from video social interactions to more advanced high definition avatars (Fig. 6.3), which allow for additional flexibility and realism. Various VR based alcohol environment are depicted in Fig. 6.4.

Fig. 6.2 VR alcohol drinks

Fig. 6.3 High definition avatar

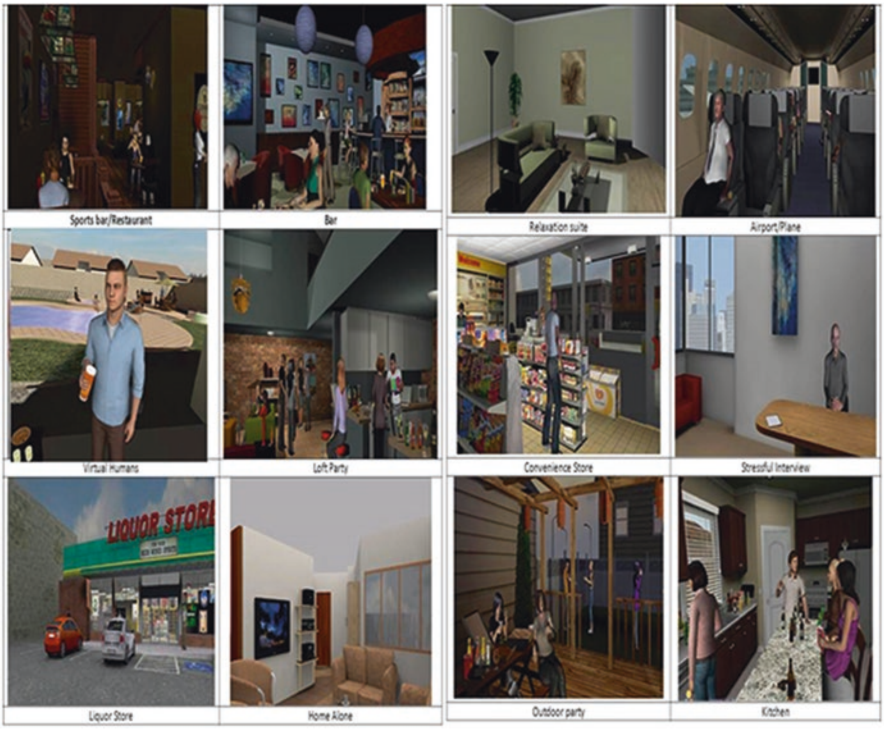

Fig. 6.4 VR alcohol environments

Environments range from a social party to a liquor store and are currently being used to teach coping skills in real prevention studies for alcohol dependence. Using current technologies, these alcohol environments offer several advances including text to speech and real time serving of drinks. For example, a client can order their drink of choice and the bartender will serve them their drink complete with accompanying scent. Another unique feature of the alcohol environments includes: text to speech which allows the therapist to personalize exposure and interaction in real time. For example, the avatars can address the clients by their name and have personal discussions during an exposure session.

Opiates/Heroin

In 2012, building upon our expertise in VR and ongoing studies with Mexican-American heroin users, our team developed two heroin use scenarios to assess craving and provide exposures to extinguish craving and urges to use. Two scenarios were proposed, one for older injection drug users (IDU's) and one for younger non-injecting heroin users (NON-IDU). The non-IDU environment consists of a home in an urban neighborhood where young adults are having a party. The party is populated with both users and non-drug users. Inside the house people are drinking, and in one of the bathrooms, two young men are cutting and snorting heroin off the sink (Fig. 6.5). The IDU VR environment consists of a row house where older men are hanging out on the front yard drinking beer, while inside two men are high, and one fixes and injects heroin. The outside of the shotgun house is depicted in Fig. 6.6.

Fig. 6.5 VR avatar snorting heroin (Non-injection scenario)

Fig. 6.6 VR heroin (Injection scenario) Shooting gallery house

These environments were developed based on photographs, input from former users, and field workers with experience conducting interviews in shoot houses (a.k.a. shooting galleries). Since VR heroin environments had not previously existed, the team had to create everything from the ground up. The avatars injecting and snorting heroin were based on videos of a former user simulating injecting and snorting behaviors to include all nuances of these actions such as tying off, taping the arm, and cooking the heroin in a spoon. These videos then served as the basis for a motion captured actor who would perform the injecting and snorting behaviors. The resulting animation was then added to high definition avatars.

The avatars offered the greatest challenge since they needed to accurately depict Mexican American users, without being canned or stereotypical. For example, the avatars needed to have realistic tattoos that represented gang membership, traditional art, and local themes, such as the 713 area code on arm or fingers or Houston sports team logos prominently displayed (Fig. 6.7). Focus groups were convened during the development process to provide input across all detail areas from clothing to gestures. The final IDU and NON-IDU VR environments are accurate scenarios that represent state-of the-art assessment tools combining expertise from behavioral and computer science disciplines, along with input from our field team members.

Fig. 6.7 Avatar with tattoos

Additional Applications of VR and Next Steps for Substance Use Prevention and Treatment

There is an ever expanding body of literature supporting the use of virtual reality in clinical and educational settings (Fleming et al. 2009; Kenny et al. 2007; Parsons et al. 2008; Cook et al. 2010). Numerous medical schools world-wide use virtual reality and other simulation based training methods for students to learn procedural skills, practice assessment and diagnosis, and improve interpersonal communication (Cook et al. 2010, 2011, 2012). As technological advances continue to evolve, the potential uses of VR in the realm of substance abuse treatment continue to evolve as well. In terms of client education, VR could be used immediately following detoxification or during the early stages of treatment to simulate how a particular substance may affect the body and brain of the user, as well as provide simulations related to the short and long term psychological and physiological consequences of substance use.

Cognitive and behaviorally based treatment protocols for co-occurring mental disorders in dual diagnosis clients would be enhanced through concurrent treatment via VR for both substance abuse and mental health issues. Within the virtual world, clients could engage in multiple forms of virtual exposures for a variety of issues related to their substance use and abuse, treating not only the symptoms of substance abuse but also the underlying anxiety depression and/or post-traumatic stress that tends to maintain it (Gorrindo and Groves 2009; Foa et al. 2007). Concurrent VR treatment may be an efficient, cost effective way to increase treatment gains through the integration of a substance use component into already established VR platforms such as Virtual Iraq/ Virtual Afghanistan (Gerardi et al. 2008; Rizzo et al. 2010; Kim 2005). The introduction of substance abuse components into existing platforms could also extend to the treatment of co-occurring eating disorders (Ferrer-Garcia et al. 2013; Ferrer and Gutiérrez-Maldonado 2011), and recurrent self- injury. Laptop based virtual environments may present a novel approach to the treatment of internet addiction, shaping the user's behavior away from technology for cruising or watching pornography Philaretou et al. (2005) to using it for treatment and adaptive management of emotional states (Riva 2005; Glanz et al. 2003).

Public health gains could be augmented by the use of virtual environments developed for individuals who were active in the "party and play" scene to assist with development of skills for safer sex practices and for engaging in sexual behaviors without ingesting methamphetamine, thus reducing risk of HIV transmission (Halkitis et al. 2001). These platforms could also be modified to assist in the treatment of co-occurring sex addition (Döring 2009). Other education based scenarios may be used to assist the client in learning about safer injection practices and other HIV/HCV risk reduction techniques. Existing VR platforms may be adapted to assist with medication adherence which is often problematic for individuals who have cyclical sobriety and relapse patterns, and could be especially helpful in the prevention of the transmission of sexually transmitted infections in those who are abusing substances.

As mentioned before, a key element of VR exposure treatment is skills building for relapse prevention. VR platforms have the potential to help build client efficacy concerning negotiation and communication skills. For example, a client could practice how to turn down substances when offered, and practice this repeatedly with a variety of potential outcomes and responses from those in the virtual social environment. Virtual environments provide clients with safe, controlled opportunities to try out newly acquired skills sets, and get immediate feedback concerning performance.

Finally VR, virtual environments and virtual patients have the potential to improve mental health professionals' assessment and diagnostic skills in relation to substance use disorders (Riva 2005, 2009; Gregg and Tarrier 2007). For example, students may use virtual environments to practice and refine therapeutic skills used with clients having substance abuse disorders. This is an especially promising approach for novice clinicians (Beutler and Harwood 2004) who may not have adequate opportunities to practice with this population unless they are working in inpatient treatment settings. Given that substance abuse issues affect such a large percentage of the US population (Center for Behavioral Health Statistics and Quality 2015; National Institute on Drug Abuse 2012), it is imperative that all mental health professionals and primary care physicians are well versed in the assessment and treatment of substance use disorders.

VR therapy is emerging as an effective evidence-based treatment strategy for numerous mental health disorders (Parsons and Rizzo 2008; Powers and Emmelkamp 2008), including substance abuse. However, as with any technology, there must be more research concerning how virtual environments can be used to assist in the assessment and treatment of substance use disorders. It is important to extend the current body of research concerning the efficacy of VR treatment when it is paired with medication for management for substance abuse issues, much in the same way prior studies investigated the efficacy of anti-depressant and anti-anxiolytic medications in combination with CBT for treatment of mood and anxiety disorders (Butler et al. 2006). Future studies may not only investigate the additive effects of VR plus medication in relation to mood management, but also investigate if VR is a moderator in relation to the efficacy of stimulant and opiate antagonist medications.

VR could also be used for "virtual therapy" for individual interventions (Rothbaum 2006; Parsons and Rizzo 2008; Riva 2005). The popularity of technology based counseling is currently on the rise due to its privacy, and increased accessibility. Sessions with a virtual therapist trained in the treatment of substance use disorders within the VR lab could provide a unique alternative to traditional outpatient treatment. Individuals could participate in "virtual groups" delivering specialized treatment interventions well suited to substance abuse treatment such as dialectical behavior therapy (Harned et al. 2010; Becker and Zayfert 2001) (DBT) in areas where trained DBT therapists are unavailable or for those who do not have access to live DBT based program in the area. VR sessions could be paired to and interfaced with other forms of technology such as smart phone or tablet apps to assist clients by reinforcing concepts presented during VR exposure and skills training sessions, facilitating clients' real time trigger management and the associated craving and urge to use.

Challenges for Widespread Use of VR for Substance Abuse Treatment

The business of substance abuse treatment is a multi-billion-dollar industry often resulting from repeat business. As previously mentioned, substance use disorders in the US cost the government, private and community based organizations, and individual tax payers *billions* of dollars annually. Thus, the development of effective treatments is ultimately cost effective. VR has numerous advantages over other traditional forms of substance abuse treatment interventions. That is not to say, however, that VR is without it drawbacks.

One of the most commonly cited concern about the widespread use of VR for treatment or education in general is the cost associated with the equipment and the development of virtual environments (Cook and Triola 2009). Although cost effective overall, setting up a VR lab requires substantial start-up costs in both equipment and in training related to the proper use of the equipment and treatment protocols. As with any technology, cost decreases as a function of increased use and adaptation. For example, in 2000, an entry level head mounted display cost $6000 alone. Currently, an entry level complete VR system begins at $3500 including the head mounted display (HMD), tracker, and computer system. This decrease makes VR more affordable and ready for prime-time dissemination by clinics, hospitals, and groups of private practitioners.

Similarly, the development of the virtual environment scenarios such as a bar, shooting gallery, or frat house is also quite costly. However, as our technological acumen expands, so do the possibilities for cost containment and widespread use of VR. One of the easiest ways of addressing this concern is to focus on development of basic, common VR platforms and use them as a basis for a variety of virtual environments by adding specific details and types of interactions. For example, a VR party environment for social anxiety disorder could be modified for use in drug and alcohol treatment to teach coping skills by adding alcohol cues and social interactions related to drinking. Another logical way to contain cost is through sharing of virtual environments between departments within one University as well as between Universities world-wide. If a University has a medical school which uses VR simulations for training, some of this technology could be modified for use in social work and psychology departments for clinical training and/or treatment protocols. In an age of limited state and governmental funding for both higher education and substance abuse treatment and prevention, cooperation among institutions is critical to meeting the needs of our substance abusing clients. Along these same lines, time and resources spent on development of alternatives to traditional VR labs such as laptop or tablet based VR delivery systems would help contain cost further and make the technology more accessible to those who could benefit from it.

Fear of technology and of traditional paradigms of treatment becoming obsolete also drive the objections to the widespread acceptance of VR technology for the treatment of substance abuse. Certain clients may be reluctant to try any treatment that incorporates technology, especially those who have limited technological savvy (Garcia-Palacios et al. 2006; Baños et al. 2011). However, interactions with trained personnel can address these fears and build efficacy in using VR in even the most technologically challenged individuals. Although certainly there are individuals with specific health issues such as epilepsy, schizophrenia, or heart disease that may not be indicated for VR treatment (Gregg and Tarrier 2007), many more people would benefit from its wide scale use.

There are also concerns raised by some in the helping professions against the process of evidence-based practice due to the supposed lack of the human element (Coeckelbergh 2010) and the shift away from relationships towards interventions (Bean et al. 2006; Wilson et al. 2009; Zayas et al. 2011a; Gibbs and Gambrill 2002). These objections have been well documented in the literature but are largely based on a mischaracterization of the process of evidence-based practice as applying the same intervention to every client in the same way (Thyer and Pignotti 2011; Mullen and Bacon 2004). On the contrary, it is the ability to customize exposure sessions and skills training that make VR based interventions truly client centered. VR offers an alternative to powerlessness by empowering the client to be active in his or her own recovery, and assisting the client to understand the psychological and physiological science of addiction.

There is a fear of some clinicians and substance abuse treatment professionals that if VR treatment is effective and is widely implemented, they will lose status or be out of a job (Spiegel 2013). The second author, who is also a practicing mental health professional and supervisor of clinical interns, welcomes the day when this will happen. It *should* be our goal as mental health and substance abuse professionals to put ourselves out of a job. At that point we will know that we have done our jobs well (Zayas et al. 2011b). When the need for our services is decreased through improved efficacy of interventions, everyone wins. It is important to note, that the

VR drug and alcohol applications described in this chapter, requires a trained clinician. We have an ethical obligation to provide our clients with interventions and treatments that are known to be effective (Myers and Thyer 1997). To deny them the opportunity to utilize these interventions or to discount them out of hand appears to border on professional malpractice (Thyer 2008).

Clearly, VR technology has significant potential for the effective assessment and treatment of substance use disorders. From 2007–2016, under Dr. Bordnick's leadership, the Virtual Realty Clinical Research Laboratory (VRCRL) at the University of Houston, Graduate College of Social Work developed VR environments for drugs, alcohol, and obesity. Currently, Dr. Bordnick continues developing and testing VR applications for substance abuse other behavioral health disorders at the Tulane University School of Social Work. Dr. Washburn at the University of Houston, has recently evaluated the use of virtual humans to teach clinical assessment skills to graduate students (Washburn et al. 2016; Washburn et al. 2017). Dr. Washburn's future research will explore the use of VR for opiate misuse and dependence. Future studies in these areas, will expand the use of VR into traditional behavioral based approaches to decrease relapse rates. Through evaluation of baseline physiological arousal and mood, followed by extinction of craving via prolonged exposure and finally relapse prevention in the form of skills training, VR could be the substance abuse treatment of choice in the future that we can begin to utilize today.

In summary, virtual reality has been used to study substance abuse and food craving. Specifically, significant increases in drug craving have been observed in virtual parties, bars, restaurants, and drug using environments demonstrating that VR is a viable medium to explore relapse behaviors. Since VR is established as a method to study craving, VR environments are now used to teach coping skills and relapse prevention strategies to improve cessation rates. In a seminal study described previously, Bordnick et al. 2012 demonstrated that coping and relapse prevention skills learned in VR decreased smoking rates and led to increased confidence to resist smoking in the real world 6 months post-trial (Bordnick et al. 2012). This study supports the theory that skills learned in virtual environments translate to actual skill use in the real world, marking an important step for VR in clinical treatment. Building upon years of research, the next step for VR is a move towards the use of smartphone based VR (e.g., Google Cardboard, Samsung Gear) to bridge the gap between clinical and real-world settings. The use of portable VR on smartphones provides a needed tool for clinicians to extend gains realized in the clinic to patient's daily lives. The future of VR in behavioral health care (addiction and mental health) will be realized in smartphone-based applications and portable high quality HMD's, which will lead to widespread dissemination an impact. Dr. Bordnick provides an overview and demonstration of VR uses for behavioral change and the move towards smartphone based applications during his 2015 TEDx talk "How can virtual reality help us deal with reality?" (https://www.youtube.com/watch?v=OPfQQw72kus). Overall, VR is a novel tool that can be used to augment traditional intervention approaches and enhance therapeutic gains towards the goal of long-term sustained recovery.

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Chapter 7
Virtual Reality in the Assessment and Treatment of Weight-Related Disorders

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Introduction

The use of Virtual Reality (VR) in behavioral health has become widespread (Riva 2005; Riva et al. 2016a, b). Recently, a paper assessed the 27 available reviews and meta-analyses exploring the efficacy of VR in this field (Riva et al. 2016a, b). The authors' findings supported the use of this technology for the treatment of anxiety disorders, stress-related disorders, pain management, and eating and weight disorders. In particular, three different randomized controlled trials (Cesa et al. 2013; Gutiérrez-Maldonado et al. 2016a, b; Marco et al. 2013) have shown at one-year follow-up that VR had a higher efficacy than the gold standard in the field, i.e., cognitive behavioral therapy (CBT) in treating eating disorders (ED) and obesity.

This vision also is shared by three different reviews of the field that were published recently (Ferrer-Garcia and Gutierrez-Maldonado 2012; Ferrer-Garcia et al. 2013a, b; Koskina et al. 2013). For example, the review by Ferrer-Garcia and colleagues (2013) stated: "There is fair evidence for the effectiveness of VR-based treatments in relation to body image disturbance in ED and obesity." Similarly, Koskina et al. (2013) suggested that VR exposure therapy "may be a useful

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intervention for ED, and its implementation is recommended either as a standalone treatment or as an intermediary step prior to *in vivo* exposure."

In fact, the clinical use of VR with these disturbances is based on key theory-driven psychological treatment techniques. First, VR can reduce eating-related anxiety during and after exposure to virtual food, helping to disrupt the reconsolidation of adverse, food-related memories (Koskina et al. 2013; Pla-Sanjuanelo et al. 2015). Second, a recent neuroscientific model of body image disturbances – the Allocentric Lock Theory – suggested that eating disorders may be associated with impairment in the ability to update a stored, negative allocentric (offline) representation of one's body with real-time (online/egocentric), perception-driven inputs (Dakanalis et al. 2016; Riva 2014). As demonstrated by two of the above RCTs (Cesa et al. 2013; Gutiérrez-Maldonado et al. 2016a), the addition of VR sensory training to unlock the body memory (body image rescripting protocol) by increasing the contribution of new, egocentric/internal, somatosensory information directly related to the existing allocentric memory was able to improve the efficacy of CBT at one-year follow-up.

Finally, the evolution of VR technologies is now allowing multisensory bodily illusions such as the Full Body Illusions that offer illusory ownership over a virtual fake body (Keizer et al. 2016; Serino et al. 2016a; b). As demonstrated by two recent studies (Keizer et al. 2016; Serino et al. 2016a, b) these techniques are able to temporarily correct the individual's experience of distorted body shape and size that characterizes these pathologies.

The next paragraphs will try to deepen these points by starting from the role played by body image disturbances in the etiology of these disorders.

Do Eating Disorders and Obesity Have a Common Etiology?

Eating disorders and obesity are serious health concerns due to their diffusion and negative effects on public health.

The raising prevalence of weight-related disorders, is pushing eating disorder and obesity researchers to start a collaboration between the fields to address them. In particular, their effort is focused on the identification of risk factors that are shared between these weight-related disorders (Haines and Neumark-Sztainer 2006): apparently, unhealthful weight-control behaviors – such as fasting (going without eating for 24 h for weight control), vomiting or laxative abuse – are the common antecedents of both obesity and eating disorders (Haines and Neumark-Sztainer 2006; Johnston 2004; Neumark-Sztainer 2009; Neumark-Sztainer et al. 2006; Stice et al. 2008; Stice et al. 2005). For example Neumark-Sztainer and colleagues (Neumark-Sztainer et al. 2006), discussed the results of the Project EAT II (Eating Among Teens), a longitudinal study involving 2516 ethnically and socioeconomically diverse adolescents. They report that, 5 years later, the use of unhealthful weight-control behaviors increased six times the risk for binge eating with loss of control, three times the risk for being overweight, and two to five times the risk for extreme weight-control behaviors such as the use of diet pills and self-induced vomiting. A similar result was found by Stice and colleagues (Stice et al. 2008): in a different longitudinal study fasting was the best predictor for the future onset, 5 years later, of binge eating and bulimia nervosa.

It is well known from epidemiological studies that childhood obesity has different ethnic, socioeconomic (compared with affluent white children, the poor Hispanic, white, and black children have 2.7, 1.9 and 3.2 times higher odds of obesity), and behavioral risk factors (Singh et al. 2008). Between the behavioral variables higher television viewing, and higher physical inactivity levels were all independently associated with higher obesity prevalence.

However, in a 4-year longitudinal study on 496 adolescent girls, Stice and colleagues (Stice et al. 2005) studied the psychological and behavioral risk factors able to predict the onset of obesity in adolescent girls. Their data show that participants who were on a weight-loss diet, or who used maladaptive compensatory behaviors for weight control at T1 of the study showed, 4 years later, an increased risk for obesity onset.

The Role of a Negative Body Experience in the Aetiology of Eating Disorders and Obesity

The present results have an important clinical implication: the evidence that youths practicing unhealthful weight-control behaviors are at higher risk for obesity and eating disorders implies that prevention and treatment interventions should also focus on the causes of these behaviors. In other words, why do adolescents decide to start such radical weight-control behaviors? In a recent letter to the *Women-health.com* site an adolescent girl wrote: "*I hate my body. No matter what I weigh I always look fat, how can I fix this? I am 5' 1' (156cms) and weigh 142 lbs (64.5 kg). My BMI is 26.1. In terms of getting back to a healthy weight, I only need to lose between 7 to 10 lbs (3–4 kg). But to look in the mirror, I look at myself and think that I'm extremely fat. My dietitian seems to think that my weight will normalise and by eating normally and exercising moderately that I should go back to a weight closer to 132 lbs (60 kg). However, even when I was that weight that I still looked horrendously overweight and disgusting*." (online: http://www.womens-health.com/boards/mental-health/32504-i-hate-my-body-no-matter-what-i-weigh-i-always-look-fat-how-can-i-fix.html).

The words of the girl clearly explain her behavior: she stopped eating properly because she does not like her body (Riva et al. 2000a, b). A study by Kostanski and Gullone (Kostanski and Gullone 1999) with a sample of 431 Australian pre-adolescent children (7–10 years) confirms this interpretation: pre-adolescents as young as 7 years of age are unsatisfied with their body appearance and deliberately engage in restrictive eating behaviors.

In general, between 50% and 80% of young women in developed countries want to be thinner and between 20% and 60% are dieting because they think they are fat and unattractive (Cash and Pruzinski 2004). Even normal-weight and underweight girls want to lose weight. These high percentages in the female population have led some authors to speak of the existence of a body experience "normative discontent" in this group (Rodin and Larson 1992). Indeed, men are usually less dissatisfied than women and may even show an increase in body satisfaction during adolescence. For girls, however, puberty only makes things worse. The normal physical changes – increase in weight and body fat, particularly on the hips and thighs, take them further from the cultural ideal of unnatural slimness.

Developing a Negative Body Representation

As we have just seen, a negative body experience during adolescence is an important predictor of eating disorders. Therefore, it is useful to identify the aspects related with its development. Personal, interpersonal and social factors must all be considered.

Personal factors include biological factors such as body mass index (BMI), sex and age, and psychological and personality characteristics. From early childhood, children are aware of the social preference for slender bodies and internalize the present aesthetic model of beauty, which is characterized by the idealization of an ever thinner female body. Likewise, children detect rejection of obese or overweight people. Consequently, overweight children show body dissatisfaction and express their desire to be thinner. Indeed, the BMI of girls correlates with reported body dissatisfaction. During adolescence, the feeling of dissatisfaction in girls increases; with the onset of puberty, they suffer substantial physical changes that involve an increase in their body volume and in the accumulation of fat in certain body parts. These changes do not conform to the ideal of thinness to which women aspire. By contrast, boys' dissatisfaction seems to fall during adolescence; as they gain height and volume, they come closer to the male aesthetic body model. Linda Smolak (2012) notes that differences between males and females with respect to dissatisfaction with one's own body representation and weight concerns are already present in children in elementary education.

Literature reports suggest that certain psychological and personality characteristics may be associated with an increased risk of developing a negative body representation. High levels of social anxiety and the tendency to compare with others may be associated with poor self-esteem in childhood and, consequently, with an increased risk of developing a negative body representation. As Cash and Pruzinski (2004) state, negative body image is correlated with low self-esteem, depression, anxiety, fear of negative evaluation and obsessive-compulsive tendencies.

With regard to **interpersonal factors**, parents and peers are the main contributors to the development of our body representations. Parents can influence in two ways: through comments made in relation to their children's appearance and the eating habits that they inculcate in them, and through the example they offer with their own eating habits and the attitudes they show towards the body. Studies have shown that the comments of parents are related to their children's body dissatisfaction (Cash and Pruzinski 2004; Kim 2009). However, there are no clear data about the influence of parental modeling, although it seems that girls are more affected than boys, especially by maternal modeling (Smolak 2012).

Social comparison with peers plays an important role in children's development. By means of social comparison, they realize the ideals of beauty associated with weight and body shape, and become aware of the extent to which they conform to these ideals or not. However, it is during adolescence when peer influence exerts more pressure, especially in girls. A phenomenon that deserves special attention is teasing. Research shows that there is a close relationship between suffering gibes about body size and shape and the body image that young people develop (Sweetingham and Waller 2008). People who have suffered some kind of sexual abuse during adolescence also tend to show a more negative body image because of the feelings of shame and the perceived loss of control over the body that are experienced in these situations (Cash and Pruzinski 2004).

More, the **socio-cultural and economic** environment also plays an important role in the development of our body representation. We have already mentioned the importance of the female aesthetic body model currently in vogue in Western societies. This model has progressively reduced the ideal body size to below the average weight of women (Dakanalis et al. 2012). In the case of men, the aesthetic model promotes physical fitness and an athletic body rather than thinness. Moreover, women more often receive pressure than men to fit a certain aesthetic model. Many studies have shown how this pressure is exerted by the mass media (Dakanalis and Riva 2013). The slender body ideal and associated body dissatisfaction have usually been ascribed to Western societies or developed countries. However, such a beauty ideal and body concerns are now spreading to different social, economic and cultural settings as part of the globalization of Western beliefs, attitudes and practices. Consequently, body dissatisfaction and weight concerns are now present in most societies (Dakanalis et al. 2013a, b).

From a Negative Body Representation to the Development of Obesity and Eating Disorders

A popular socio-cultural model – the "objectification theory" introduced by Fredrickson and Roberts (Fredrickson and Roberts 1997) identifies in a negative body representation a key factor in the aetiology of these disorders. Specifically, this theory suggests that our culture imposes a specific orientational model – self-objectification – defining women's behavioral and emotional responses (Calogero 2012; Calogero et al. 2010) At its simplest, the objectification theory holds that (Dakanalis and Riva 2013; Riva 2014): (1) there is an societal ideal of beauty underlying the key role of a thin body that is (2) transmitted via a variety of sociocultural channels. This ideal is then (3) internalized by individuals, so that (4) satisfaction and dissatisfaction with appearance will be a function of the extent to which individuals do (or do not) meet this ideal prescription. Different studies based on this theory have shown that exist strong links between self-objectification and eating disorder symptoms (Dakanalis et al. 2015, 2017; Monro and Huon 2006). Nevertheless, even if self-objectification is a key characteristic of our culture, only a small subset of all the female and male subjects exposed to idealized body models develops clinically diagnosable EDs (Thompson et al. 1999). Why?

A possible answer to this question is offered by the Allocentric Lock Hypothesis.

Recently, Riva and colleagues (Dakanalis et al. 2016; Gaudio and Riva 2013; Riva 2007, 2011, 2012; Riva et al. 2012; Riva and Gaudio 2012, 2018; Riva et al. 2015) have proposed the **allocentric lock hypothesis** as a synthesis of neurobiological, psychological and socio-cultural data about the etiology of both ED and obesity. The primary claim of the "*Allocentric Lock Hypothesis"* is that deficits in the integration of expected (from predictive coding) and experienced (from perception) bodily inputs are able to produce a disturbed body memory that does not only motivate severe dietary restrictions and other weight loss behaviors, but also may play a central part in initiation, persistence, and relapse of EDs. This perspective offers a powerful insight, according to which EDs subjects may indeed have a dysfunction in multisensory integration processes that does not allow them to modify their experience of the body even after a demanding diet or a significant weight loss (Riva 2018; Riva and Gaudio 2018).

The process linking the cultural pressure to be thin, to the allocentric lock induced by a multisensory integration deficit, to the development of an eating disorder is detailed in Fig. 7.1 and summarized below:

- Subjects in their social interactions develop a specific "body image" that defines the meaning of our objectified body. The content of the body image is related to cultural standard. For example, this may include "fat phobia" (fear of becoming fat) in Western countries, or "weight phobia" (fear of becoming mature) in Asian countries (Lee 1995).
- In Western countries, the value of the objectified body is defined more by observable body attributes (e.g., "How do I look?" – allocentric perspective), rather than by privileged, or nonobservable body attributes (e.g., 'What am I capable of?" "How do I feel?" – egocentric perspective).
- The endorsement and acceptance of appearance media ideals lead subjects to become aware of how their bodies looks and to evaluate themselves in terms of physical appearance. This evaluation becomes body surveillance, the tendency to be highly vigilant of one's appearance (Fitzsimmons and Bardone-Cone 2011).
- Subjects who experience one or more personal (e.g., "The new jeans were too tight") or social (e.g., teasing) situations in which they fail to meet physical appearance standards, then update the objectified body accordingly (van den Berg et al. 2007): e.g., "My body is fat". As demonstrated by different studies, including a recent meta-analysis (Makinen et al. 2012; Menzel et al. 2010),

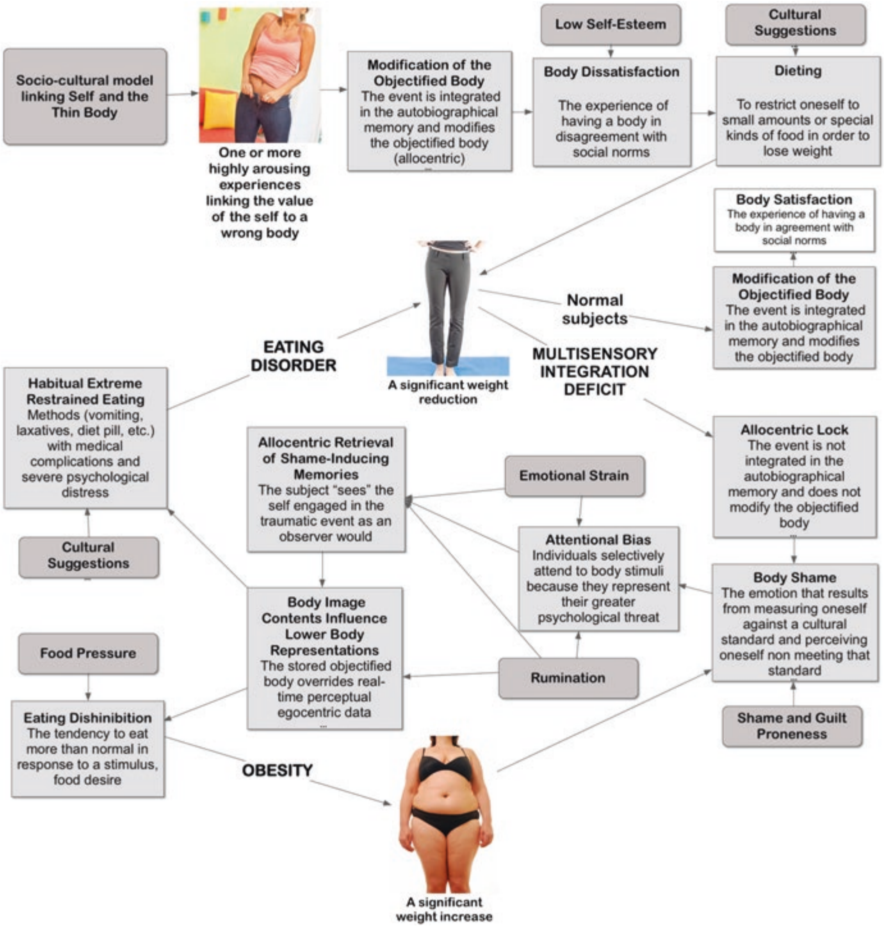

Fig. 7.1 The aetiology of eating disorders and obesity (Adapted from Riva 2014)

this produces body dissatisfaction, defined as displeasure with some aspect of one's appearance (Cash and Pruzinski 2004).

- Body dissatisfaction has a critical effect on eating behavior: subjects go on diet to improve the satisfaction with their body. According to the data collected by Ogden and colleagues from 8165 children and adolescents living in the United States (Ogden et al. 2008) about 62% of girls aged 12–19 report that they are trying to lose weight.
- Normally, after a successful diet, subjects experience a thinner body and again modify their objectified body accordingly (e.g., "I'm no more fat"). For a multisensory integration deficit (Riva and Gaudio 2018), however, subjects with eating disorders are locked into their negative objectified body: its content cannot updated even after a demanding diet and a significant weight loss.

- The impossibility of meeting societal standards transforms body dissatisfaction into body shame: the painful social emotion that can result from measuring oneself against a cultural standard and perceiving oneself as being judged and seen as inferior, defective or unattractive in the eyes of others (Dakanalis et al. 2013a, b; Pinto-Gouveia and Matos 2011).
- Body shame usually has two behavioral effects: subjects either start more radical dieting behaviors – such as the use of diet pills and self-induced vomiting – or, at the opposite, decide to stop any form of food control and start "disinhibited" eating behaviors (Van Strien et al. 2009). In particular, as samurai committed seppuku to remove shame, subjects are ready to use the most extreme weight reduction techniques – fasting, vomiting, laxatives, etc. – to achieve the same result.
- A variety of studies show that shame experiences are also recorded in autobiographical memory, influencing body image and self-relevant beliefs, inattentional and emotional processing (Pinto-Gouveia and Matos 2011). As demonstrated by numerous studies, in patients with eating disorders, the representation of the body included in the shame-inducing negative emotional event produces a priming effect on any body-related experience (Blechert et al. 2011; Goldfein et al. 2000): on one side, the tendency of our perception to be affected by our recurring thoughts produces an attentional bias on body related stimuli; on the other side, it draws the subject's attention to previously stored body image stimuli biasing egocentric perceptual data and the interpretation of future self-relevant events.

This situation potentially has three effects: experiential, cognitive and social (Riva 2014). The first, and probably most relevant consequence, is experiential: The permanent experience of a "wrong" body, totally independent by the shape or the size of the real body. In simpler words, these subjects cannot win: Whatever they will do to modify their real body, they will always be present in a virtual body (the objectified negative memory) that they hate. The second effect of the allocentric lock is cognitive: It reorganizes existing memories and produces a priming effect on any body related experience. The final consequence of the allocentric lock is social: Subjects attribute mental states to others by adopting an allocentric stance, striving towards static and sometimes unrealistic systems for understanding social relations.

The Use of Virtual Reality in the Study and Assessment of Weight-Related Disorders

To maximize the degree of control and internal validity, traditional experimental methods usually require participants to carry out tasks that are far removed from real-life activities. This means that the ecological validity of these tasks is questionable. On the other hand, studies based on field data, while having ecological validity, cannot control multiple confounding variables that may have an impact on observed results, so that their internal validity is reduced. Virtual Reality provides a better balance between internal and ecological validity, since VR simulations can be completely controlled for experimental purposes and, at the same time, allow subjects to carry out tasks that are identical to those performed in real life. For this reason VR has been used to study different features of weight-related disorders.

Virtual Reality and Body Image

A first use of VR technology in the field of weight-related disorders is in body image research: **to broaden our knowledge of the body image concept and to aid the evaluation of body image disturbances**.

Riva conducted the pioneering studies on the application of VR for the assessment and treatment of body image disturbances (Riva et al. 1997) as part of the European VREPAR Project (Virtual Reality Environments for the Psycho-neuro-physiological Assessment and Rehabilitation Project). The main purposes of this project were to study certain mental disorders and to develop new therapeutic techniques for their treatment and rehabilitation. Riva developed a software package for the assessment of body image disturbances, known as the BIVRS (Body Image Virtual Reality Scale; [Riva 1998a] and [Riva and Melis 1997a, b]). The BIVRS was a non-immersive, 3D graphical interface comprising nine figures, male and female, ranging from underweight to overweight. Participants were asked to choose the figures that best fit their self-perceived and their desired body size. Discrepancy between the two measures was an indicator of body image dissatisfaction. The BIVRS improved on traditional assessment methods based on silhouettes by adding the third dimension to the figures presented to the user: the increased realism of the figures made it easier for the participants to identify with them.

Perpiñá and colleagues went a step further with the development of an immersive VR-based application for the assessment of body image disturbance (Perpiñá et al. 2000). The assessment software consisted of a 3D human figure whose body parts could be modified using sliders. The main advantage of this application was that, as it is immersive, the modifiable figure was of a similar size to the user size and was placed in the same virtual position. Moreover, the software allows clinicians to assess several dimensions or indexes of body image (e.g., the perceived body, the desired body, the healthy body, etc.) and body weight (actual weight, subjective weight, healthy weight and desired weight), and all in different contexts.

To explore the concept of body image further, Gutiérrez-Maldonado and colleagues (Gutiérrez-Maldonado et al. 2010; Ferrer-Garcia and Gutiérrez Maldonado 2010) focused their attention on the study of body image instability in patients with anorexia and bulimia nervosa. Several studies have stressed that trait and state components coexist in the construct of body image (Etu and Gray 2010; Lattimore and Hutchinson 2010; Myers and Biocca 1992; Rudiger et al. 2007). According to the trait perspective, emotional and situational variables may produce changes in the way that people perceive and value their own body (Cash et al. 2002; Slade and

Brodie 1994; Smeets 1997; Thompson 1996). Continuing this line of research, Gutiérrez-Maldonado and colleagues (Gutiérrez-Maldonado et al. 2010; Ferrer-Garcia and Gutiérrez Maldonado 2010) used the ability of VR to reproduce everyday life environments in order to study whether body image disturbance in patients with eating disorders (ED) change depending on the situation.

The authors exposed 85 women with ED and 108 women without ED to different VR environments (kitchen and restaurant) containing different kinds of food (low-calorie versus high-calorie food) and in the presence or absence of other people (avatars). In accordance with the trait perspective, the authors found that ED patients showed a significantly higher over-estimation of body size after simulating eating high-calorie food than after simulating eating low-calorie food in the virtual environments. Likewise, ED patients reported significantly higher percentages of body dissatisfaction after the high-calorie food than after the low-calorie food simulation. In contrast, participants without ED showed similar body distortion and body dissatisfaction in both situations. For its part, the presence or absence of people in the virtual environments had no significant effect on body image.

Gutiérrez-Maldonado concluded that body image distortion and dissatisfaction change depending on the situation to which participants are exposed, provided this situation is emotionally significant for them. In his study, two variables were manipulated to induce an emotional response in participants: the kind of food and the presence of other people. As mentioned above, only food type proved to be an emotionally significant stimulus for patients with ED (one capable of producing changes in their body image), whereas the presence or absence of other people had no such effect.

The main interest of this study is that it provides evidence that body image distortion and dissatisfaction can be influenced by situational factors or, in other words, that body image disturbances act partially as a state. This assertion has important therapeutic implications. Indeed, one of the most difficult therapeutic goals for clinicians is to change the body image experience of ED patients (Rorty et al. 1993). Besides, treatment programs usually devote fewer sessions to this component than to disturbed eating behavior (Rosen and Ramírez 1998; Rosen 1997). However, by using different virtual scenarios representing a range of stressful real-life situations for ED patients, the inclusion of body image assessment could provide clear, therapist-independent information about the subjective view that patients have of their bodies, since their perception and judgments change depending on the situation they have been exposed to. This would offer patients with ED hard evidence that their body image is just a mental representation which may differ greatly from objective reality – which in itself would represent a starting point for accepting change.

Virtual Reality and Emotions

Virtual reality-based methods have also been used to assess the different responses of ED patients and healthy controls when exposed to certain stimuli and situations. Several studies show that exposure to food cues produces specific emotional and behavioral responses in ED patients (e.g., Fett et al. 2009; Schienle et al. 2009). It has been suggested that if VR environments could induce similar responses to real stimuli in patients with ED, this technology could be used as a valid exposure technique in the assessment and treatment of eating disorders (Ferrer-Garcia et al. 2009). Unlike conventional methods (e.g., "in vivo" exposure, exposure to photographs, exposure via guided imagination, and so on), VR exposes individuals to interactive three-dimensional environments that simulate real situations, thus offering high ecological validity as well as strict control over the variables. Furthermore, VR allows researchers and clinicians to include both distal (e.g., restaurant) and proximal cues (e.g., pizza).

To test the usefulness of VR for developing life-like virtual exposure environments capable of eliciting emotional responses in ED patients, Gutiérrez-Maldonado and colleagues designed a multi-stage research project (Gutiérrez-Maldonado et al. 2006; Ferrer-Garcia et al. 2009). Six virtual reality environments were developed using the information obtained from a survey of 68 patients with ED, who were asked about the situations and specific aspects of these situations that caused them discomfort related with body image. One hundred and eight healthy female students and 85 patients with a diagnosis of ED were exposed to the virtual environments (training room, kitchen with low-calorie food, kitchen with high-calorie food, restaurant with low-calorie food, restaurant with high-calorie food, and swimming pool). First, participants visited the virtual training room, a neutral situation in which they learned to use navigation keys and which served as a baseline, and the anxiety and depression experienced in this situation were assessed using the STAI-S (Spielberger et al. 1970) and the CDB (Pérez et al. 2004) respectively. Participants were then randomly exposed to the remaining virtual environments. In the intervals between the presentation of each environment, anxiety and depressed mood were assessed again.

Compared with healthy controls, patients with ED showed higher levels of anxiety and a more depressed mood after visiting all the virtual environments. The highest levels of anxiety and depressed mood were found after eating high-calorie food (in the kitchen and in the restaurant) and after visiting the swimming pool. On the other hand, healthy controls only showed increased anxiety (compared with the neutral room) in the swimming pool. Ferrer-Garcia et al. (2009) attributed this last result to the "normative discontent" in women (Rodin et al. 1984), according to which most women experience body image concerns in situations such as the swimming pool where the body is exposed and susceptible to social comparison.

In the same research line, Aimé and colleagues (Aimé et al. 2009) exposed 27 women to three virtual environments – the office (a neutral environment), the restaurant (with high- and low-calorie food), and the swimming pool – and measured anxiety before, during, and after immersions. Weight, shape, and food concerns, drive for thinness, and body dissatisfaction were also measured after immersions. The authors found that participants with elevated but subclinical concerns with their weight and shape (n = 10) showed significantly higher level of anxiety and weight concerns after visiting the restaurant and the swimming pool than visiting the neutral situation. On the other hand, participants who did not show concerns with their weight and shape (n = 17) showed no anxiety or concerns after visiting the restaurant and the swimming pool.

The results of these studies suggest that VR exposure is able to produce similar responses in ED patients and healthy controls to those elicited in real situations and that it could therefore be used for both evaluative and therapeutic purposes. However, despite their promising results, these studies did not directly compare VR exposure with in vivo exposure. To overcome this drawback, Gorini et al. (2010) assessed the emotional reactions of 10 AN patients, 10 BN patients, and 10 healthy controls to real food, VR food, and photographs of food. Authors found that real food and VR food produced comparable emotional reactions in ED patients and that this reaction was stronger than the one produced by photographs of food.

Perpiñá, Botella, Baños and colleagues also studied the ability of VR environments to elicit emotional, cognitive and behavioral responses in ED patients (Perpiñá et al. 2001; Perpiñá et al. 2013). This research group conducted a pioneering pilot study with a small sample composed of five patients with BN and four with BED, with the aim of analyzing the use of virtual environments to assess and treat binge eating episodes. Participants were exposed to a virtual kitchen, where they were asked to eat high-calorie food (e.g., pizza). The results showed that the virtual environment was able to provoke the undesirable features present in binge-eating episodes. Once a forbidden food had been eaten, patients reported anxiety, impulse to over-eat, and guilt feelings (from moderate to extreme). Furthermore, all the patients said they experienced a strong sense of reality in the virtual environment. Moreover, when augmented reality was added in a second VR exposure session (patients smelled a real hot pastry for the duration of the virtual eating process), scores on all measures increased.

More recently, Perpiñá et al. (2013) examined the ability of virtual environments to elicit sense of presence and judgment of reality in users. Twenty-two ED patients and 37 healthy eating controls were exposed to a non-immersive virtual environment, a kitchen in which participants had to eat a virtual pizza. Participants filled out the Reality Judgment and Presence Questionnaire (RJPQ) and the ITC-Sense of Presence Inventory (ITC-SOPI). The results showed that the VR environment induced a sense of presence and was felt to be real by both groups; however, the ED patients reported paying more attention and experiencing greater emotional involvement and dysphoria after virtual eating. The results suggest that the VR environments created were clinically meaningful to the ED patients.

Another interesting line of research has focused on the ability of VR environments to elicit food craving in ED patients and non-clinical samples. Ledoux and colleagues (Ledoux et al. 2013) assessed whether food-related cues delivered by VR induced greater food craving than neutral VR cues, photographic food cues, or real food in a sample of 60 normal-weight non-dieting women. The results showed that the food craving produced by VR was only marginally greater than craving elicited by neutral cues, not significantly different from picture cues, and significantly lower than real food. Ledoux suggested that these modest effects may have been due to the low quality of the VR system and/or measures of food craving (i.e., self-report and salivation). In fact, contrasting results were found by Ferrer-Garcia and colleagues, who also assessed the ability of different virtual environments to elicit craving for food in non-clinical samples (Ferrer-Garcia et al. 2013a, b; Ferrer-Garcia et al. 2015a, b). These authors reported that exposure to high-calorie food in virtual environments provoked significantly higher levels of food craving than low-calorie food virtual cues. In view of the evidence of the effectiveness of food-related VR environments to elicit food craving and emotional responses in ED patients, this research group started a new line of study assessing food craving in ED patients using VR-based exposure.

With this objective in mind, Pla-Sanjuanelo et al. (2017) developed a VR-based software for cue exposure therapy in patients with bulimia nervosa (BN) and binge eating disorder (BED). As a previous stage before using the software with therapeutic intent, these authors tested its ability to elicit anxiety and food craving in ED patients, and assessed differences with respect to the responses of healthy controls. Fifty-eight ED outpatients (33 BN and 25 BED) and 135 non-clinical participants were exposed to 10 craved virtual foods (e.g., chocolate) and a neutral cue (a stapler) in four experimental virtual environments (kitchen, dining room, bedroom, and cafeteria). After exposure to each VR scenario, food craving and anxiety were assessed. In both groups, craving and anxiety responses when exposed to the food-related virtual environments were significantly higher than in the neutral-cue virtual environment; however, craving and anxiety levels were significantly higher in the clinical group. Thus, these results supported the usefulness of VR for eliciting food craving in ED patients and its ability to discriminate between clinical and non-clinical participants.

Interestingly, an association has also been found between participants' eating behavior style (emotional, restrictive, or external; Van Strien et al. 1986) and food craving levels reported in the virtual environments (Ferrer-Garcia et al. 2015b; Ferrer-Garcia, Pla-Sanjuanelo et al. 2017). Analyzing the effect of eating style on the anxiety and food craving reported in the study by Pla-Sanjuanelo et al. (2017) mentioned above, Ferrer-Garcia et al. (Ferrer-Garcia et al. 2017a) found that, in the healthy group, external eating was the only predictor of cue-elicited craving and anxiety, whereas in participants with BN and BED external and emotional eating were the best predictors of cue-elicited craving and anxiety respectively. Based on these data, the authors suggested that VR-based cue-exposure therapy may be an ideal intervention for ED patients with an external eating style.

Finally, the potential usefulness of VR to elicit social comparison tendencies has also been investigated. Guitard and colleagues assessed the emotional impact of exposure to avatars with different body shapes in a virtual bar on 17 body shape-concerned participants, using physiological and self-reported measures (Guitard et al. 2011). Their results provided preliminary support for the hypothesis that social comparison in virtual environments produces emotional reactions in participants, especially when confronted with a thin-ideal stimulus.

In conclusion, the studies discussed in this section show that VR environments are able to produce responses similar to those observed in real world.

The Use of Virtual Reality in the Treatment of Weight-Related Disorders

As noted above, body image disturbance is one of the most difficult features of ED and obesity to modify. The cognitive-behavioral approach (Butters and Cash 1987) has proved to be effective for its treatment and is the most frequently used intervention. Alternatively, visual-motor therapy, whose main objective is to increase subjects' awareness of their own body by videotaping and subsequently viewing the different gestures and body movements, has also showed promising results (Wooley and Wooley 1985). Both kinds of intervention are useful, but body image disturbances are highly persistent (Vandereycken 1990; Vandereycken et al. 1988); in this context, VR offers an innovative and promising complement to traditional methods of intervention.

Virtual Reality in the Treatment of Body Image-Related Disturbances

Riva and colleagues (Riva and Melis 1997a, b; Riva et al. 1997) developed the first VR-based application for the treatment of body image disturbance in weight-related disorders: the VEBIM (Virtual Environment for Body Image Modification). The VEBIM consisted of five virtual reality environments or zones grouped into two parts. The first part (Zone 1: training room and balance; and Zone 2: kitchen and office) was developed so that users could acquire the minimum skills necessary to navigate and interact with the environment, and to identify which stimuli were able of eliciting disturbed eating behaviors. Three additional virtual areas (Zone 3: pictures of models; Zone 4: the mirror room; and Zone 5: the room of doors) were developed to modify the user's body image. During exposure to different environments the Socratic Method was used to help participants to challenge distorted thoughts about their body weight and shape, and to develop a more realistic perception of their own body image (Riva et al. 1998a, b).

The main problem facing therapists when treating body image disturbances is perhaps the lack of awareness that patients show about the real state of their bodies. Riva starts from the premise that body image is a cognitive bias (see also the paragraph on the Allocentric Lock Hypothesis) and, as such, it is barely accessible to consciousness. This fact hinders body image change, as users believe that biased information is real (Riva 2003). However, due to the intrinsic features of the technology the virtual experience gives users access to this unconscious information related with body schemata, where the latter refers to the model of their own body that individuals have developed and which serves as the basis for judging their movement and posture (Head 1926). It has been shown that common distortions and desynchronizations produced in VR systems can alter people's lived experience. Discrepancies between the signals arriving from the user's propioceptive system and the external signals from the virtual environment alter body perceptions and may have undesirable consequences such as discomfort or simulator sickness. However, these same effects can be used for therapeutic purposes, as they involve a greater awareness of the associated sensorimotor and perceptual processes. When a particular event or stimulus is discordant with body schemata information, such as occurs during the virtual experience, this information becomes conscious (Baars 1988). This, in turn, facilitates the process of changing a disturbed body image, since, according to Riva, body schema changes involve body image changes, as the objective of the self is to integrate and maintain the consistency of different body representations. Furthermore, VR experience may enhance cognitive-behavioural techniques: "Using VR the therapist can actually demonstrate that what looks like a perception does not really exist. This gets across the idea that a person can have a false perception. Once this has been understood, individual maladaptive assumptions can then be challenged more easily" (Riva et al. 1999, p. 78).

Riva (1998a; b; c; Riva and Melis 1997b) conducted some preliminary studies with non-clinical population to assess the VEBIM. In the first of these studies, exposure to VEBIM during no more than 10 mins produced changes on body image dissatisfaction (understood as the discrepancy between the perceived and the ideal body size). Specifically, body dissatisfaction levels were significantly lower after leaving the VEBIM than before entering. A controlled study was conducted subsequently in order to test the results obtained in the first one. Here, 48 women were randomly assigned to two groups: the experimental group, in which the VEBIM was administered, and the control group, without treatment. In line with the first study the experimental group showed a significant reduction in body image dissatisfaction after visiting the VEBIM compared with previous measures. The control group did not show any significant change across the two measures. Riva (1998c) also studied whether exposure to VEBIM produced psychophysiological changes in a sample of 47 males and 24 females. Blood pressure and heart rate were assessed. No differences were found between measures obtained before and after the virtual experience. Given the results of those preliminary studies, Riva and colleagues (Riva et al. 1998a, b, 1999) then administered these virtual environments to a 22-year-old woman with anorexia nervosa (purging type).

After eight treatment sessions, the participant had increased awareness of her own body. She had not yet looked in the mirror, but this was proposed as the next target. Altering her body representation allowed this patient to reduce significantly her level of body dissatisfaction. There was also a reduction in the avoidance behaviors and grooming habits associated with a negative body image. By the end of treatment, she showed a greater motivation for change and expressed her desire to continue with it.

In 2000, Riva and his team (Riva et al. 2000a, b, c) tested the efficacy of VR in modifying body image disturbances also in patients with obesity, BED and ED-NOS. Fifty-seven women who contacted the Weight Reduction Unit of the Istituto Auxologico Italiano were assessed before and after being treated by means of a brief VR therapy consisting of five fortnightly sessions. The measures used to assess body image disturbances showed a significant post-treatment improvement.

Furthermore, the authors note that this improvement led, in turn, to a reduction in disturbed behaviors related to food and social relationships.

The results of these studies allowed Riva and his team to develop the **Experiential Cognitive Therapy** (ECT), which uses an enhanced version of the VEBIM in combination with cognitive-behavioral treatment and psychoeducation (see Table 7.1). Since 2007 VEBIM has been included in NeuroVR 2 (http://www.neurovr.org, see Fig. 7.2) a free virtual reality platform based on open-source software (Riva et al. 2007, 2009, 2011).

ECT is a relatively short-term (8–12 weeks), patient-oriented approach that focuses on individual discovery. As in the case of Cognitive Behavioral Therapy, ECT uses a combination of nutritional, cognitive and behavioral procedures to help the patient identify and change the maintaining mechanisms in both obesity and

Table 7.1 The structure of the Experiential-Cognitive Therapy – ECT (Adapted from Riva et al. 2004, 2006)

Week 1	
Psychometric test (Test)	
Psychodiagnostic Interview	Preliminary group (Motivation to treatment and definition of rehabilitative protocol)
Session 1 VR Assessment + body image (virtual balance + sitting room)	Nutritional assessment
Weeks 2 and 3	
Session 2 VR Eating control + interpersonal reframe (kitchen + bathroom + bedroom)	Nutritional group (2/3 sessions)
Session 3 VR Body image (BIVRS)	Psychological Group (1 session)
Session 4 VR Eating control (supermarket)	Physical Activity
Weeks 4 and 5	
Session 5 VR Body image + interpersonal reframe (gymnasium)	Nutritional group (2/3sessions)
Session 6 VR Eating control + interpersonal reframe (pub)	Psychological group (1 session)
Session 7 VR Body image + interpersonal reframe (clothes shop)	Physical activity
Weeks 6 and 7	
Session 8 VR Eating control + interpersonal reframe (restaurant)	Nutritional group (2/3sessions)
Session 9 VR Body image + interpersonal reframe (swimming pool + beach)	Psychological group (1 session)
Session 10 VR Eating control + body image (kitchen + BIVRS + 9 doors room)	Physical activity
Week 8	
	Psychological support (2/3 sessions)
	Physical activity
	Final group (motivation to out-patient phase)
Psychometric tests (Re-test)	

eating disorders. However, ECT differs from the typical cognitive-behavioral approach in the VR body image rescripting protocol based on the Allocentric Lock hypothesis (see Table 7.2), in its focus on empowerment and in its focus on the negative emotions related to both body and eating.

Riva and colleagues have published several case studies (Riva et al. 2002; 2003) and controlled studies (Riva et al. 2001; 2002; 2003; 2006) about the application of ECT to different weigh-related disorders.

Table 7.2 *The VR body image rescripting protocol* (Adapted from Riva 2011)

Phase 1: Interview	During a clinical interview the patient is asked to relive the contents of the allocentric negative body image and the situation/s in which it was created and/or reinforced (e.g. being teased by my boyfriend at home) in as much detail as possible. The meaning of the experience for the patient was also elicited.
Phase 2: Development of the VR scene	The clinician reproduces the setting of the identified situation (e.g. the corridor of the classroom where my boyfriend teased me) using one of the different scenes available in the free NeuroVR software (http://www.neurovr2.org),
Phase 3: Allocentric Experience of the VR scene	The patient is asked to reexperience the event in VR from a first person perspective (the patient does not see his/her body in the scene) expressing and discussing his/her feelings. 
	The patient is then asked what was needed to happen change the feelings in a positive direction. The questions asked follow the Socratic approach, for example "What would need to happen for you to feel better? How does it look through the eyes of a third person? Is there anything you as a third person like to do? How do the other people respond?"
	The main cognitive techniques used in this phase, if needed, are: *Countering*: Once a list of distorted perceptions and cognitions is developed, the process of countering these thoughts and beliefs begins. In countering, the patient is taught to recognize the error in thinking, and substitute more appropriate perceptions and interpretations.
	Label Shifting: The patient first tries to identify the kinds of negative words she uses to interpret situations in her life, such as bad, terrible, obese, inferior, and hateful. The situations in which these labels are used are then listed. The patient and therapist replace each emotional label with two or more descriptive words.

(continued)

Table 7.2 (continued)

Phase 4: Egocentric Experience of the VR scene	The patient is asked to reexperience the event in VR from a third person perspective (the patient sees his/her body in the scene) intervening both to calm and reassuring his/her virtual avatar and to counter any negative evaluation. 
	The main cognitive techniques used in this phase, if needed, are: *Alternative Interpretation*: The patient learns to stop and consider other interpretations of a situation before proceeding to the decision-making stage. The patient develops a list of problem situations, evoked emotions, and interpretative beliefs. The therapist and patient discuss each interpretation and if possible identify the kind of objective data that would confirm one of them as correct.
	Deactivating the Illness Belief: The therapist first helps the client list her beliefs concerning weight and eating. The extent to which the illness model influences each belief is identified. The therapist then teaches the client a cognitive/behavioral approach to interpreting maladaptive eating behaviors and shows they can be understood from this framework.

In 2001, Riva and colleagues divided 28 obese women into two equal groups in order to compare the results obtained from the application of two different treatments: one based on ECT and another on the psycho-nutritional intervention of traditional cognitive-behavioral treatment (CBT). Both groups also took part in a parallel diet and exercise program. The results showed that treatment using ECT was more effective than CBT in improving body satisfaction, self-efficacy and motivation for change, as well as in reducing over-eating and reported anxiety. A later study by the same team (Riva et al. 2002) found similar results with 20 BED patients. Intervention based on ECT was more effective in the short term than was CBT in improving the overall psychological state of patients and, specifically, in increasing body satisfaction, self-efficacy and motivation for change. However, no differences were found as regards the reduction of binge eating behavior.

A year later Riva et al. (2003) randomly divided a sample of 36 women with binge eating disorder into three groups according to the type of treatment received: experiential cognitive therapy including VR (ECT group), cognitive-behavioral therapy alone (CBT group), and the nutritional psychoeducation group. At six-month follow-up 77% of people in the ECT group had stopped bingeing, compared with 56% and 22% in the CBT and nutritional psychoeducation groups, respectively. In 2006, Riva provided new evidence for the efficacy of ECT in the treatment of obesity (Riva et al. 2006). On this occasion the sample comprised 211 obese women (aged 18–50 and BMI over 40) without any other serious psychiatric disorder, and who had suffered at least one relapse after treatment for obesity. The women were randomly assigned to one of three groups: ECT, traditional CBT or nutritional psychoeducation. As in previous studies, the ECT group not only obtained better outcomes than the other two groups in terms of reduced body dissatisfaction and increased self-efficacy, but they also had fewer relapses both at six-month and twelve-month follow-up (Riva et al. 2012).

The advantage of ECT in these patients is that during the VR exposure they experience critical situations related to relapse in real life. In virtual environments, the user can face and learn to cope in such situation, which, in addition to allowing the body image disturbance to be treated, increases the user's sense of self-efficacy.

In a further study Cesa et al. (2013) compared within a controlled study the outcome of 90 obese (BMI>40) female patients with BED upon referral to an obesity rehabilitation center. As before, they were randomly assigned to three conditions: ECT, traditional CBT or nutritional psychoeducation. At start, upon completion of the inpatient treatment, and at 1-year follow-up, patients' weight, number of binge eating episodes during the previous month, and body satisfaction were assessed by self-report questionnaires and compared across conditions. The results showed that only ECT was effective at improving weight loss at 1-year follow-up. Conversely, control participants regained on average most of the weight they had lost during the inpatient program. Binge eating episodes decreased to zero during the inpatient program but were reported again in all the three groups at 1-year follow-up. However, a substantial regain was observed only in the group who received the nutritional psychoeducation alone, while both ECT and CBT were successful in maintaining a low rate of monthly binge eating episodes. In a final study (Gutiérrez-Maldonado et al. 2016b) 163 female morbidly obese inpatients (body mass index >40) were randomly assigned to three conditions: a standard behavioral inpatient program (SBP), SBP plus standard CBT, and ECT. Patients' weight, eating behavior, and body dissatisfaction were measured at the start and upon completion of the inpatient program. Weight was assessed also at one-year follow-up. All measures improved significantly at discharge from the inpatient program, and no significant difference was found among the conditions. However, odds ratios showed that patients in the ECT condition had a greater probability of maintaining or improving weight loss at one-year follow-up than SBP patients had (48% vs. 11%, $p = 0.004$) and, to a lesser extent, than CBT patients had (48% vs. 29%, $p = 0.08$). Indeed, only ECT was effective in further improving weight loss at one-year follow-up. On the contrary, participants who received only the inpatient program regained back, on average, most of the weight they had lost. Findings support the hypothesis that a VR module addressing the locked negative memory of the body may enhance the long-term efficacy of standard CBT.

Perpiñá et al. (1999), developed another application for the treatment of ED that was tested in a controlled study with a clinical sample (patients with AN and BN). With this objective, the researchers combined three treatment components:

- An adaptation of the body image disturbance treatment of Cash (1996) and Rosen (1997), consisting of psychoeducation, exposure, intervention on safety behaviors, cognitive restructuring and self-esteem related to the body. This cognitive-behavioral programme was developed for eight weekly group sessions of 3 h each.
- A VR component, applied in parallel to the body image treatment over six, weekly individual sessions of 1 h each.
- A relaxation component, again implemented in parallel to the treatment for body image disturbances over six, weekly individual sessions of 1 h each. This final component was added in order to balance the duration of therapy in both conditions, so that all the patients received the same number of hours of treatment.

Eighteen outpatients diagnosed with ED (anorexia nervosa or bulimia nervosa) were randomly assigned to two treatment conditions: the VR condition (cognitive-behavioral treatment + VR) and the standard treatment for body image disturbances (cognitive-behavioral treatment + relaxation). Thirteen of the eighteen patients completed treatment and a significant improvement was observed in all of them. However, those who were treated with the VR component showed a significantly greater improvement in specific body image variables (highest level of satisfaction with their body in social situations, fewer thoughts and negative attitudes towards the body, less afraid of their weight, and less fearful of achieving a healthy weight). It should also be noted that the dropout rate was lower in the VR group, indicating an increased motivation and adherence to treatment.

These results show that greater improvement was achieved with the addition of the VR component compared to the standard body image treatment alone. Given this, the researchers offered the patients in the standard treatment group the possibility of being treated with the VR component as well. The sample in this second study comprised twelve patients (seven with AN and five with BN). The results showed that the improvement achieved after completing the treatment was not only maintained after 12 months but actually increased (Perpiñá et al. 2004). Similarly, a case study by the same authors (Perpiñá et al. 2001) also reported an improvement in the ED patient's symptomatology at one-year follow-up. Salorio del Moral and colleagues (Salorio del Moral et al. 2004) published another case study in which they applied a ten-session treatment programme based on the treatment developed by Perpiñá and her team to an AN patient. The authors reported decreased body dissatisfaction, better interoceptive awareness, less perfectionism, and no tendency toward asceticism in the treated participant. Furthermore, at one-year follow-up the patient showed no drive for thinness, more body satisfaction and less interpersonal distrust, while perfectionism, asceticism and social insecurity were all absent.

In a further study, Marco et al. (2013) integrated this VR body image protocol within a Cognitive Behavioral Treatment (CBT) for eating disorders and compared it with the CBT alone in a sample of 34 ED patients. Results showed that the patients who received the VR component improved more than the group without this component. Furthermore, improvement was maintained in post-treatment and at one-year follow-up.

Perpiñá and colleagues (Perpiñá et al. 2001) conducted a study with a small sample of ED patients (five with BN and four with BE) with the aim of analyzing the use of virtual environments to assess and treat binge eating episodes. The virtual environment presented to participants was the kitchen area, where forbidden (high-calorie) and permitted (low-calorie) food could be found. Participants were then asked to eat the forbidden food, usually a pizza. While they carried out this task the experimenter suggested flavors and sensations. The results showed that the virtual environment were able to provoke the undesirable features present in binge-eating episodes. First, once a forbidden food had been eaten, patients reported anxiety, an impulse to overeat and guilt feelings (from moderate to extreme). Furthermore, all the patients said they experienced a strong sense of reality in the virtual environment. Secondly, introduction of the food smell during VR exposure led to an increase on all measures, indicating that augmented reality is useful for the purpose of helping participants to immerse themselves in the virtual situation and experience it more intensely. It should be remembered that the VR serves not only to re-create situations but also to help patients cope with mental representations of their fears.

Virtual reality technology has been also used to increase adherence to physical activity in obese individuals. Ruiz and colleagues (Ruiz et al. 2012) exposed 30 overweight and obese participant to three versions of a 3D avatar-based VR intervention to promote exercise: virtual representation of the self-exercising condition; virtual representation of other person exercising; and control condition. Results showed that only participants in the virtual representation of the self-group significantly increased their levels of physical activity after intervention.

Virtual Reality in the Treatment of Binge Eating-Related Disorders

Cognitive-behavioral therapy (CBT) is considered the treatment of choice for both BN and BED (Wilson et al. 2007) and was given the highest rating in the National Institute of Mental Health (2004) review of evidence-based treatments. However, an important percentage of BN and BED patients fail to respond by the end of the treatment and the effects tend to wane in the long term (Amianto et al. 2015; Berkman et al. 2007; Lampard and Sharbanee 2015; Wilson et al. 2010). Consequently, the addition of second-level treatment has been proposed in those cases where the first level (i.e., CBT) does not work (Wilson et al. 2007). Although there is some evidence that BN and BED patients who do not stop binge eating after CBT benefit from additional CBT sessions focusing on the specific problem areas identified at the end of the initial program (Eldredge et al. 1997), it has been suggested that second-level interventions targeting specific features associated with poor response may represent a better option (Dakanalis et al. 2016; Dakanalis et al. 2017; Halmi 2013).

In line with this approach, Gutiérrez-Maldonado and colleagues created a new treatment method based on cue exposure via virtual reality (Ferrer-Garcia et al. 2017a, b; Gutiérrez-Maldonado et al. 2016a, b; Pla-Sanjuanelo et al. 2007). The novelty of this proposal was the addition of VR to cue-exposure procedures, which have proved effective for the treatment of binge-related eating disorders in previous research (see Gutiérrez-Maldonado et al. 2013; and Koskina et al. 2013 for a review). This addition aims to increase the efficacy of cue exposure therapy (CET) by enhancing its ecological validity, while reducing the logistic complications associated with exposure to real cues (i.e. food).

Cue exposure therapy is based on classic conditioning theory. According to this model, the intake of food is considered the unconditioned stimulus and all stimuli associated with this action (e.g., the presence of palatable food, emotional states, the smell of food) are considered the conditioned stimuli. Once conditioning has been established, the presence of conditioned stimuli (e.g., sweets) elicits physiological responses (experienced as food craving) which in turn trigger binge episodes (Jansen et al. 1989; Jansen 1998). The main objective of CET is to extinguish food craving by breaking the bond between the conditioned stimuli and the food craving. Toro and Martínez-Mallén (Martínez-Mallén et al. 2007; Toro et al. 2003) proposed an alternative explanation of the CET rationale. According to them, anxiety, stress and negative mood are strongly associated with binge behavior. Episodes of excess intake at the onset of the disorder generate feelings of anxiety, shame and guilt. With time, exposure to cues related with binges produce anticipatory anxiety in BN and BED patients and it is this anxiety that leads to "bulimic hunger" (Martínez-Mallén et al. 2007). These two explanations are not mutually exclusive; in fact, BN and BED patients frequently report experiencing food craving associated with high levels of anxiety and negative mood (Pla-Sanjuanelo et al. 2015). As Martínez-Mallén et al. (2007) suggested, anxiety and food craving are experienced simultaneously in the presence of binge-related cues.

Although CET is considered an effective intervention for BN and BED (especially in cases in which CBT does not achieve good results; indeed, it has been proposed as a second line of treatment in these situations, Koskina et al. 2013), logistical difficulties and the time necessary for in vivo CET to work have hindered its development and implementation (Gutiérrez-Maldonado et al. 2013). To overcome these difficulties, Gutiérrez-Maldonado proposed using VR-based exposure for CET. VR technology has several benefits for exposure therapy: first, VR environments maintain good ecological validity even when exposure is conducted in the therapist's office and are therefore easy to generalize to real situations. Second, VR exposure allows the therapist to control all the parameters of the situation and to adapt the exposure environment to the specific needs of each patient at each stage of treatment. Third, using VR scenarios patients can be exposed not only to specific stimuli but to contextual cues related with the problem.

Gutiérrez-Maldonado and colleagues found that exposure to VR environments incorporating both specific stimuli (e.g., high calorie food) and contextual cues (e.g., kitchen) significantly reduces food craving and anxiety (Gutiérrez-Maldonado et al. 2016a, b; Pla-Sanjuanelo et al. 2016) in a non-clinical sample. Likewise, a case study showed that six sessions of VR-based CET were sufficient to extinguish episodes of binge-eating, and associated purging behaviors, in a BN patient who initially failed to successfully respond to CBT (Pla-Sanjuanelo et al. 2016).

On the basis of these results, a multicenter, randomized, parallel-group study was conducted at different hospitals (five sites) in three European cities in order to establish whether the addition of a six-session VR-CET second-level treatment, after a structured CBT program, achieved a better outcome than adding six more CBT sessions (A-CBT) in treatment-resistant patients aged over 18 with BN and BED (https://clinicaltrials.gov/ct2/show/NCT02237300). Exclusion criteria were suicidal ideation and severe mental disorder (psychosis or dementia). Sixty-four patients (35 BN and 29 BED) were randomly assigned to two experimental conditions: VR-CET and A-CBT. Frequency of binge and purge episodes, drive for thinness, bulimia symptoms, body dissatisfaction, food craving and anxiety were assessed both before starting second-level treatment and once it had finished.

Even though patients in both groups improved, VR-CET was significantly superior to A-CBT at the end of second-level treatment in terms of the proportion of participants who achieved abstinence from binge eating episodes: 17/32 (53%) of those treated with VR-CET, compared with 8/32 (25%) of those treated with A-CBT ($N = 32$) ($\chi^2 = 5.32$, $p = .02$). Amongst BN patients, VR-CET was also superior to A-CBT at the end of second-level treatment in terms of the percentage of participants that achieved abstinence from purging episodes (75% vs. 31%, [$\chi^2 = 6.56$, $p = 0.02$]). Consistent with these results, the VR-CET group showed a lower clinician-rated frequency of binge and purge episodes and a lower self-reported tendency to engage in episodes of uncontrollable overeating (assessed by the bulimia scale on the EDI-3) than the A-CBT group at the end of second-level treatment, although there were no significant differences between groups at the pre-randomization/pre-test phase (Ferrer-Garcia et al. 2017a). Furthermore, good outcomes were maintained at 6-month follow-up. The authors conclude that the results highlighted the superiority of VR-CET over A-CBT. This software can be downloaded for free at http://www.ub.edu/vrpsylab/foodcraving/

Conclusions

During the last decade virtual reality (VR) emerged as a technology that is especially suitable for the study, assessment and treatment of weight related disorders (Riva 2017; Riva et al. 2016a, b; Wiederhold et al. 2016). Taking into account the results obtained to date in the studies reviewed, several conclusions can be drawn (Gutiérrez-Maldonado et al. 2016a, b). Even if It has been recognized that the field had in the past very few methodologically strong studies, the situation is quite different now. Three different randomized, controlled trials (Cesa et al. 2013; G.M. Manzoni et al. 2016; Marco et al. 2013) have shown at one-year follow-up that VR had a higher efficacy than the gold standard in the field, i.e., cognitive behavioral therapy (CBT).

More, this chapter also outlined the potential of virtual reality in the study of weight-related disorders. This approach is currently used for the assessment of body image distortions, emotional responses and social comparison skills in clinical and subclinical subjects.

First, VR can be used to improve our knowledge about the body image concept. For example, different studies explored whether perceptual distortions in body image and body dissatisfaction changed depending on the situation.

Second, VR can be used to evaluate the emotional responses produced by food exposure. In fact, real food and VR food produce comparable emotional reactions – anxiety, food craving, impulse to over-eat, and guilt feelings – in ED patients and this reaction was stronger than the one produced by photographs of food.

Third, it is also possible to use the potential of virtual reality (VR) to elicit social comparison tendencies induced by subjects with different weight and body sizes. The available studies suggest that more negative stereotyping and less visual contact are produced by the interaction with overweight/obese subjects.

In conclusion, VR is a powerful tool for studying, assessing and treating weight related disorders. Nevertheless, future research and clinical practice are still required for transforming virtual reality in a real tool for researchers and clinicians.

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Chapter 8
Virtual Reality Distraction to Help Control Acute Pain during Medical Procedures

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Introduction

The Problem: Uncontrolled Pain

Uncontrolled pain is a widespread problem in medicine. Both military and civilian advisory committees have called for large improvements in pain control. The treatment of severely burn-injured patients is one of the most intensely painful processes

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in medicine. Few injuries involve more painful and numerous procedures than severe burns. In the United States, each year, an estimated 700,000 people visit the emergency room for treatment of burns. Of these, 45,000 have burns significant enough to require inpatient hospitalization (American Burn Association: Burn Incidence and Treatment in the US 2007). In order to prevent infection and promote healing, patients with severe burns typically must have their bandages removed, and have their wounds cleaned daily for weeks or even months. During cleaning/debridement, foreign materials and dead tissue are removed from the open wound, antiseptic ointments are applied, and the wound is re-dressed/re-bandaged. These wound care sessions allow caregivers to look at the wound and monitor healing progress. Surgeons may need to surgically remove damaged skin and transplant fresh skin from another part of the body, e.g., the patient's own unburned thigh to their burned hands. Once the graft takes hold on the burn site, staples or other adhesive devices that have been temporarily holding the transplanted skin in place must be removed. Wound care sessions involving staple removal from healing skin grafts are often especially painful. Furthermore, the site where the healthy skin was "harvested" from a non-joint area is now an additional painful raw wound that must also be kept clean. While most patients report only mild pain when lying still (termed "resting pain"), most patients with burn injuries report severe pain during burn wound care (Hoffman et al. 2008a; Perry et al. 1981; Ptacek et al. 2000).

Under-medication contributes to severe pain (Melzack 1990). Repeated administration of opioids often results in gradually reduced analgesic effects, a phenomenon known as tolerance. With frequent medications over days, weeks or months, escalating doses of opioid analgesics are often needed to achieve the same analgesic effect. And over time, daily use of opioids is frequently accompanied by physical dependence, the need for continued drug use to prevent physical and emotional withdrawal symptoms (Berger and Whistler 2010). Even maximal opioid doses often fail to control all pain (Cherny et al. 2001; Shang and Gan 2003). Opioid side effects can include nausea, excessive sedation, cognitive dysfunction, constipation, and other concerns, and become increasingly problematic with higher dose levels (Cherny et al. 2001), limiting what dose is considered appropriate. In addition to numerous wound cleaning procedures, burn patients must also endure weeks or months of daily physical therapy exercises both as inpatients and after discharge as outpatients. Hand burns are very common. After healing, patients who sustain burns in vulnerable joints such as fingers may find it challenging to move their fingers enough to grasp objects or type on a computer. To counteract the tendency of healing burned skin to harden, contract, and lose its elasticity, frequent physical therapy is conducted to help retain full use of their injured limbs. This is especially important for burn wounds that cross joints such as fingers, elbows, shoulders and knees. Physical therapy is essential for maximizing functionality and can also help minimize the number of skin grafts needed to surgically release skin that has contracted during healing. But pain can interfere with compliance (Ward 1998). Adjunctive nonpharmacologic techniques, including use of hypnosis (Montgomery et al. 2000; Patterson 2001, 2010; Patterson and Jensen 2003) and related cognitive behavioral approaches may be used in addition to traditional pain medications to help reduce severe procedural pain. There are numerous studies reporting evidence that conventional distraction such as music can help reduce pain (Fernandez and Turk 1989; Klassen et al. 2008). However, the benefits of trying to distract burn patients using "music alone" has produced mixed results (van der Heijden et al. 2018) and a much stronger, more robust adjunctive non-pharmacologic analgesic is needed.

Immersive Virtual Reality Pain Distraction

Interdisciplinary research teams are exploring ways to use emerging computer technologies to help address this important medical problem of how to better control acute procedural pain. Immersive virtual reality (VR) visually isolates patients from the "real world." The helmet typically used to deliver VR blocks the patients' view of the hospital room and substitutes computer-generated images via small computer screens and lenses positioned near the patient's eyes. Noise canceling earphones block/replace hospital noises with sound effects and relaxing background music from the virtual world. The goal of immersive VR is to give patients the illusion that they are inside the 3D computer-generated world, as if the virtual world is a place they are visiting. In theory, while health care professionals are conducting invasive procedures on the patient, instead of cognitively remaining in the painful real world, the patient is allowed to perceptually escape into a pleasant alternative 3D virtual world.

The logic for how VR works is as follows. Pain requires attention (Eccleston 2001; Eccleston and Crombez 1999). Humans have limited attentional capacity (Kahneman 1973). Interacting with virtual reality uses a substantial amount of the patient's limited controlled attentional resources. For example, VR has been found to reduce performance on a divided attention task (Hoffman et al. 2003a). Consequently, when in VR, the patient has less attention available to process incoming signals from pain receptors. As a result, patients report less pain while in VR, they spend less time thinking about their pain during VR, and often report having more fun during wound care while in VR compared to wound care with no VR (Hoffman et al. 2008a; Hoffman 2004, 1998; Hoffman et al. 2000a).

The first immersive VR software designed for pain control was named SnowWorld (www.vrpain.com). In SnowWorld, patients interact with snowmen, igloos, penguins, woolly mammoths and flying fish by throwing snowballs. Patients aim with a computer mouse (or sometimes via head tracking) and left click the mouse to throw snowballs. The virtual objects respond in various ways when hit by snowballs: Snowmen shatter in 3D with sound effects, and mammoths trumpet angrily, with Paul Simon songs from the album Graceland playing in the background.

In the series of preliminary studies with patients undergoing painful medical procedures, patients report feeling 35–50% less pain while in VR with immersive VR (standard medications + VR) compared to treatment as usual (standard medications alone + no VR). VR analgesia has been demonstrated in burn patients both during wound care (Hoffman et al. 2008a, 2000a, 2004a; van Twillert et al. 2007) and during physical therapy (Carrougher et al. 2009; Hoffman et al. 2000b; Soltani et al. 2018; Schmitt et al. 2011; Sharar et al. 2007). In one study comparing burn patients aged

6–65 years old during physical therapy, age was not a significant factor in how much VR reduced pain. VR was effective regardless of age (Sharar et al. 2007). Using an interactive projector-dome virtual reality system (Khadra et al. 2018), researchers have recently shown preliminary evidence of VR analgesia during wound care, in very young children (range = 2 months to 10 years, mean = 2.2 years old).

Is VR Analgesia Effective for Patients Experiencing Severely Intense Pain?

Previous pain researchers have theorized that distraction will be less effective at reducing severe pain intensity levels compared to reducing mild to moderate pain intensities. For example, (McCaul and Malott 1984) proposed that "stimulus intensity is an important determinant of whether and when a distraction will occur. In other words, as a painful stimulus reaches some intense level, it will begin to attract attention and impede the effectiveness of the distraction" (p. 518). According to these researchers, distraction should become less effective during severe and higher pain intensity. In other words, McCaul and Mallot predict that distraction will fail exactly when an effective treatment is needed the most. Other researchers have argued that distraction will be less effective if the pain is perceived as very threatening (affective factors), for instance in high pain catastrophizers who have trouble disengaging their attention from pain (Crombez et al. 1998).

To explore whether VR can reduce severe and higher pain, patients received VR during burn wound debridement in a hydrotherapy tank, where some of the most painful burn wound care is conducted (Hoffman et al. 2008a). Eleven patients were studied using a custom fiberoptic water-friendly VR system that can safely be used in water. Each patient spent a portion of their wound debridement with no distraction and spent an equivalent portion of wound care in VR during the same wound care session (within-subject design, condition order randomized). After each condition, patients completed 3 subjective pain ratings using 0–10 labeled Graphic Rating Scales with respect to the preceding portion of wound care. Such pain rating scales have been shown to be valid through their strong associations with other measures of pain intensity, and through their ability to detect treatment effects (Jensen 2003). These queries were designed to assess the cognitive component of pain (amount of time spent thinking about pain), the affective component of pain (unpleasantness), and the sensory/intensity component of pain (worst pain). Affective and sensory pain are two separately measurable and sometimes differentially influenced components of the pain experience (Gracely et al. 1978). (Gracely et al. 1978) have shown ratio scale measures such as the labeled Graphic Rating Scales (GRS) to be highly reliable. In addition, a single GRS rating of "fun" during wound care was measured, as a surrogate measure of positive affect.

Overall, patients ($n = 11$) reported a large, statistically significant and clinically meaningful reduction in pain during VR (Hoffman et al. 2008a). The six patients who reported the highest pain intensity during "No VR" (worst pain >7.6, n = 6) reported a 41% reduction in pain intensity (worst pain) during VR. Although other VR analgesia studies have commonly included burn patients experiencing severely intense pain, this was the first study to analyze VR analgesia in a subgroup of burn patients who were all experiencing severe pain intensity. Although preliminary, these results suggest that immersive VR can be an effective adjunctive nonpharmacologic pain reduction technique, even for burn patients experiencing severe pain during wound care.

The Relationship between the Immersiveness of the VR System and Analgesic Effectiveness

In our systematic studies of VR distraction, our team has used the concept of immersion as a theoretical framework to guide our investigations of what makes VR effective for reducing pain. Slater and Wilbur 1997 define immersion as an objective, quantifiable description of what a particular VR system can provide to a participant. Immersion is different from the subjective psychological illusion of going into the virtual world, known as presence. According to (Slater and Wilbur 1997), presence is a psychological state of consciousness and is reliant on subjective measures (asking users to rate on a scale from 1 to 10 how much they felt like they went into the computer-generated world as if it was a place they visited). In contrast, immersiveness is objectively measurable (e.g., using trigonometry to calculate the “field of view” or amount of peripheral vision stimulated by a VR helmet’s displays).

In several laboratory studies exploring the relationship between immersion and analgesic effectiveness, healthy volunteers received brief thermal pain stimuli at carefully controlled temperatures, and rated how painful they found the stimuli. These studies found that highly immersive VR systems are more effective at reducing pain than less immersive VR systems (Hoffman et al. 2006a, 2004b; Wender et al. 2009; Dahlquist et al. 2007) and as described next, the difference in amount of analgesia achieved with a highly immersive VR system can be considerable.

In one laboratory study, high technology VR goggles increased the patient’s peripheral vision in the virtual world, and this manipulation increased how much VR reduced pain. Researchers (Hoffman et al. 2006a) randomly assigned participants (healthy volunteers) to either a low technology VR helmet group (n = 28), a high technology VR helmet group (n = 26) or to a No VR group (n = 23). To help minimize demand characteristics, both the subjects and the research assistant collecting the experimental pain ratings remained unaware that helmet quality was being manipulated. Compared to the group that received the low technology VR helmet (35 degrees field of view diagonal), the high technology VR goggles group (60 degrees field of view diagonal) reported 34% more reduction in worst pain, 46% more reduction in pain unpleasantness, 29% more reduction in time spent thinking about pain, and 32% more fun during the pain stimulus during VR. Sixty five percent of participants in the high technology VR goggles group showed a clinically meaningful reduction in pain intensity during virtual reality, compared to only 29% for the low technology VR helmet group. These results suggest that helmet quality (i.e., goggle size/field of view/amount of peripheral vision looking into VR) is an especially important factor for achieving clinically meaningful reductions in pain intensity, and the study design helps reduce the likelihood that VR analgesia is due to an artifact such as demand characteristics.

In a related study (Wender et al. 2009 see also Dahlquist et al., 2007), instead of manipulating helmet quality, the objective immersiveness of the VR system was manipulated via interactivity, i.e., whether participants interacted with the virtual world or not. Twenty-one participants (healthy volunteers) were randomly assigned to one of two treatment groups. All participants individually glided through the virtual world SnowWorld, but one group could look around and interact with the virtual world via a trackball, and the other group could not interact with the virtual world (no trackball). Afterwards, each participant provided subjective 0–10 pain ratings.

The more-immersive-VR group who interacted with the virtual world via a trackball showed significantly more pain reduction than the less-immersive-VR group who received non-interactive VR with no track ball (Wender et al., 2009; see also Dahlquist et al., 2007). Compared to the non-interactive VR group, participants in the interactive VR group showed 75% more reduction in pain unpleasantness ($p < .005$) and 74% more reduction in worst pain ($p < .005$) and 32% more reduction in time spent thinking about pain ($p = .01$). Interactivity increased the objective immersiveness of the VR system, and as predicted, increased the analgesic effectiveness. In summary, so far, high technology VR helmet quality (wide field of view goggles), and interactivity (playing with a mouse-like trackball or other input device) have been isolated as especially important factors contributing to VR analgesia.

Using fMRI Brain Scans to Measure Pain-Related Brain Activity

What is going on in people's brains when they feel pain, and how are those patterns of brain activity altered (if at all) when participants go into immersive virtual reality and experience large reductions in how much pain they feel? To explore these topics, Hoffman and colleagues (Hoffman et al. 2004c, 2006b) measured the objective physiological neural correlates of VR analgesia. Custom fiberoptic magnet-friendly VR goggles (Hoffman et al. 2003b) were designed and built that allowed participants to experience the illusion of going inside the computer generated world while simultaneously assessing neural activity using fMRI brain scans. A thermal pain stimulator was attached to the healthy volunteer's foot. Participants received 30 s of thermal stimulation at a painful but tolerable temperature pre-approved by each participant, then 30 s of a non-painful stimulus with lukewarm temperature, and this cycle of "pain on/pain off" was repeated a total of six times over a 6 min fMRI brain scan.

During half of the brain scan, the control condition, participants looked at a fixation cross and saw no VR, and heard no music and no VR sound effects. During the other half of their fMRI brain scan they went into the 3D computer-generated world, and interacted with the virtual world by throwing snowballs at snowmen, igloos, robots and penguins, which responded with 3D visual and 3D sound effects when hit. The treatment order was randomized such that approximately half of the participants received immersive virtual reality for 3 min followed immediately by "no VR' for 3 min or vice versa. Immediately after the 6 min fMRI brain scan, subjects rated how much pain they had experienced during VR and during no VR, on 10 point rating scales. The subjective pain ratings replicated previous results, i.e., participants reported feeling moderate to severe pain during the pain stimuli with no VR, and subjects reported much less pain when in VR. In addition to reporting less subjective pain, objective measures of the neural correlates of pain showed large (50% or greater) statistically significant reductions in pain-related brain activity in all five regions of the brain studied (the anterior cingulate cortex, insula, thalamus, the primary and the secondary somatosensory cortex (Hoffman et al. 2004c).

A second recent laboratory fMRI brain scan study involving 9 healthy volunteer participants (also using a within-subjects design) compared and contrasted VR analgesia vs. systemic opioid analgesia, both via subjective pain ratings as well as objective measures of brain activity patterns. Thermal pain stimuli were applied to the patient's foot during fMRI (Hoffman et al. 2007). Results showed that when used alone, VR and opioid analgesia each reduced both pain ratings and pain-related brain activity. Furthermore, adding immersive VR to opioids resulted in significantly more reduction in pain ratings than opioids alone, and patterns of pain-related brain activity were consistent with subjective analgesic reports.

Improving pain/sedation/anxiety management is one of the top two research and development priorities for combat trauma care and battlefield surgical care (Martin et al., 2019). The U.S. military is applying a multimodal (pharmacologic plus psychological) approach to pain control of patients with combat-related trauma injuries (Maani et al., 2008). Encouraged by the small but growing literature on VR analgesia in civilian burn patients, military researchers are beginning to explore the use of VR analgesia in patients with combat-related burn injuries, such as U.S. troops severely burned in Iraq and Afghanistan during terrorist roadside bomb attacks on humvee convoys (Maani et al. 2008; 2011a; 2011b). A custom "robot-like Magula arm" allows the soldiers to use the immersive VR world without the discomfort of wearing a VR helmet on their head. Instead, the patient looks into goggles suspended/positioned in front of the patient. In addition to making the goggles weightless, the robot-like arm reduces or eliminates contact between the patient and the equipment (making the goggles easier to clean/sterilize), and makes VR available to patients with bandaged face and head burns.

Using graphic pain rating scales, each of the two U.S. soldiers rated their pain during VR vs. no VR (order randomized) (Maani et al., 2011b). Both patients were severely burned in separate incidents when their humvees were attacked by terrorists using improvised explosive devices in Iraq (a roadside bomb for Patient 1 and a rocket propelled grenade for Patient 2). Both patients were evacuated from Iraq to a military burn trauma center in the United States. Averaged across the two patients, worst pain dropped from severe pain intensity (mean = 7.5/10) to moderate pain intensity (4.5/10). Pain ratings of "Time spent thinking about pain" dropped from 100% of the time during no VR to 08% of the time during VR, and "pain unpleasantness" ratings dropped from "moderate" (mean = 6.5/10) to "mild" (mean = 2.4/10). The patients rated wound care as "no fun at all" (0/10) during no VR but "pretty fun" (8/10) during VR.

A small within-subjects controlled study with twelve patients has since replicated these results showing VR analgesia in soldiers during wound cleaning of combat-related burn injuries (Maani et al. 2011a). Each patient (n = 12) received standard pain medication alone during some of their wound care, and pain medications + VR during equivalent portions of the same wound care session (treatment order randomized). Soldiers with combat-related burn injuries reported significantly lower pain during wound debridement with VR, than without VR, and patients with the highest pain ratings during No VR (worst pain greater than or equal to 7 out of 10, i.e., "severe" or higher worst pain intensity ratings) reported unusually large reductions in procedural pain during VR (see also Hoffman et al., 2008b), contrary to previous concerns that distraction would only work for mild or moderate pain but not for severe or higher pain intensities (Eccleston and Crombez, 1999).

These preliminary results (Maani et al. 2011a, b, 2008) suggest that immersive VR has feasibility as a potential adjunctive nonpharmacologic analgesic for military patients with combat-related burn injuries. Larger controlled military studies on VR analgesia are warranted and needed.

Studies Exploring the Use of VR Analgesia for Blunt Force Trauma, Dental Fears, Venipuncture, Claustrophobia, Cerebral Palsy, Cancer, and Urological Endoscopy Patients

Because burn wounds are unusually painful injuries, techniques that are effective for reducing pain in burn patients are also likely to be effective in treating procedural pain in other patient populations besides burns. Consistent with this notion, preliminary case studies have found that VR reduced pain during physical therapy in a non-burn blunt force trauma injury (a pedestrian who was hit by a semi-truck, undergoing physical therapy in the trauma unit) (Hoffman et al. 2008b). VR reduced pain and fear in patients during dental/periodontal procedures (Furman et al. 2009; Hoffman et al. 2001; Atzori et al. 2018a), and VR reduced fear/anxiety in a claustrophobic patient during a mock brain scan (Garcia-Palacios et al. 2007). VR has reduced pain during a urological procedure in an older man receiving endoscopic transurethral microwave thermotherapy ablation of the prostate (Wright et al. 2005), and in pediatric cerebral palsy patients during painful physical therapy rehabilitation after single event multilevel surgery to increase ambulation (Steele et al. 2003). Other research has shown the predicted pattern that VR reduced discomfort during subcutaneous vascular port access and venipuncture in children and adolescents (Gershon et al. 2004; Windich-Biermeier et al. 2007; Gold et al. 2006; Gold and Mahrer 2018; Atzori et al. 2018b), and women receiving chemotherapy (Schneider et al. 2004). A growing number of researchers using a variety of distraction software have also found evidence that VR reduces clinical and laboratory pain (Hoffman et al. 2006a; Das et al. 2005; Malloy and Milling 2010; Garrett et al. 2014; Hoffman et al. 2014; Morris et al. 2009) or itching (Liebovici et al. 2009).

Future Directions: Repeated Use of Virtual Reality Pain Distraction

Opioid narcotic analgesics are highly effective initially, but often require gradually higher and higher doses with repeated use, a limitation known as habituation/tolerance. There is currently little data on whether VR distraction continues to work when used repeatedly. To address this topic, a preliminary study recently explored whether VR continues to be effective when used for longer, clinically relevant treatment durations, for 5 days in a row. Four children with large severe burns ranging in size from 45% to 82% Total Body Surface Area (TBSA), with average 64.5% TBSA, were studied for 10 days each. Occupational and physical therapists orchestrated passive range of motion exercises with each patient for 5 days during VR compared to similar treatment for 5 days without VR. Treatment order was randomized. Some patients received 5 days of physical therapy with VR vs. 5 days with no VR, and others received 5 days of no VR followed by 5 days of Yes VR. Results showed large reductions in worst pain intensity (approximately 45% reduction in worst pain), pain unpleasantness, and time spent thinking about pain, and more fun during VR compared to no VR during the 25 min VR treatments per day, for 5 days in a row per patient (Flores et al., 2008). There was no diminishment in VR analgesic effectiveness over the 5 day period, and equivalent range of motion was achieved with VR as compared to standard care without VR.

Larger, multisite studies using VR for longer treatment durations on multiple days are needed to determine the clinical value of VR for everyday burn care, and to explore whether there are any long term benefits to repeatedly using virtual reality pain distraction. Better control of pain during repeated medical procedures could potentially improve long term physiological and/or psychological outcome (Flores et al. 2008; Hoffman et al. 2011). In addition to reduced procedural pain during VR, we predict that for patients who show VR analgesia, frequent use of adjunctive VR analgesia for acute procedural pain control can potentially reduce opioid dose levels (McSherry et al. 2018; Kipping et al. 2012), improved functionality (range of motion), and may improve sleep. We further predict that better control of acute pain via VR distraction has potential to reduce a burn patients likelihood of developing PTSD and/or chronic pain.

Future Directions: VR Hardware and Software Tailored to the Needs of Burn Patients

To date, researchers have been able to design and build several unique pieces of research equipment specifically tailored to the custom needs of burn patients. For example, a custom fiber-optic VR helmet was developed that could be safely worn by burn patients sitting in a tub of water known as a hydrotank/scrubtank (Hoffman et al. 2004a). Similarly, the first two fMRI neuroimaging studies on VR analgesia (Hoffman et al. 2004c, 2007) required researchers to design and build the first pair of custom wide field of view magnet-friendly fiberoptic "photonic" VR goggles (only light, no electricity, reaches the participants) (Hoffman et al. 2003b). These early devices worked very well for early research purposes. New display technologies may allow the creation of much smaller and lighter weight water- and magnet-friendly VR goggles.

Laboratory studies suggest that participants who show only modest VR analgesia using a less immersive VR system are likely to show larger reductions in pain if a more immersive VR system is used (Hoffman, Seibel et al., 2006). Sony, Oculus Rift VR and HTC VIVE VR goggles with 100 degree field of view are now available to mainstream consumers, and the industry is currently selling over a million new mass produced low cost, high tech VR helmets, per year, greatly increasing the affordability/accessibility of VR goggles potentially suitable for immersive virtual reality pain distraction. Perhaps most tellingly, several major mainstream video game companies have begun creating software specifically tailored to being used in the VR goggles. Furthermore, VR Worldbuilding software packages such as Unity3d and WorldViz, are making it increasingly easy for worldbuilders to design and create their own custom VR worlds, making it easier to tailor VR worlds to the patient's needs.

Despite the encouraging preliminary results, much stronger VR analgesia systems are greatly needed to increase the amount of pain reduction experienced by burn patients during medical procedures. Many burn patients need a stronger "dose" of virtual reality distraction than is currently available. For example, a patient whose pain drops from a 10 during No VR to an 8 during VR. More rugged, less expensive, more portable, water-friendly, easily cleaned plug and play VR systems are needed. Future VR analgesia systems will capitalize on new display technologies, more sophisticated virtual worlds, and a growing understanding of how to make VR even more distracting.

Because of the pervasive prevalence of excessive pain during medical procedures (Garrett et al. 2014), further improvement/development of VR equipment hardware and software tailored to the needs of patients receiving VR during medical procedures is recommended (Hoffman et al. 2011). Development of effective new non-pharmacologic analgesia techniques is a national priority (Keefe et al. 2018), and VR provides a new direction for adjunctive non-drug behavioral pain management (Keefe et al. 2012).

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Chapter 9
Using Virtual Reality with Child Sexual Offenders: Assessing Deviant Sexual Interests

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Sexual Interests and Sexual Offending Against Children

In the area of sexual offending, the presence of deviant sexual interests is a central feature of both clinical and theoretical understandings. At the theoretical level, many influential theories of sexual offending consider the presence of deviant sexual interests as a key element in explaining both sexual offending behaviors onset and reoffending (Finkelhor 1984; Hall and Hirschman 1992; McGuire et al. 1965; Singer 1984; Ward and Beech 2006; Ward and Siegert 2002).

The Integrated Theory of Sexual Offending (ITSO) (Ward and Beech 2006), which incorporate and articulate most of the notions suggested in other theories, has gained considerable popularity over the past decade. According to the ITSO,

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sexual offending results from the constant interactions of three types of factors: (1) biological factors, (2) ecological factors and (3) neuropsychological factors. Clinical indications of deviant sexual behaviors, including deviant sexual interests, are thought to result from these factors' dynamic interaction. Precisely, ITSO highlights how interactions between biological and ecological vulnerabilities may impact neuropsychological functions directly linked to action and behaviors, through three systems: (a) motivation and emotion, (b) perception and memory, and (c) action selection and inhibition. In sum, the way all components interact with each other and translate into behavior is highly specific to each offender and represent risk factors.

In addition to factors that are specific to the individual, ITSO suggests that deviant sexual behaviors are fundamentally situated. Precisely, sex offending would result from the actualization of individual risk factors by contextual and ecological triggers. Thus, both individual predispositions and precise environmental conditions need to be present in order for sexual deviant behavior to take place. Therefore, it becomes essential to not only understand the risk factors but also determine how they emerge and interact in a specific situation in order for a person to commit a sexual assault.

Understanding sex offending through ITSO has concrete implications on a practical level. First, sexual interests assessment requires that the necessary ecological conditions be present to trigger sexual arousal. Second, the assessment procedure should identify risk factors by combining measures on different dimensions of sexual interests. Finally, the procedure should provide information on how sex offenders regulate their continuous interactions with a given environment in the light of their specific risk factors (Benbouriche et al. 2014; Carver and Scheier 2011; Kingston et al. 2012; Ward et al. 1998).

In clinical settings, the presence of deviant sexual interests is the cornerstone of decision making surrounding diagnosis, treatment and supervision recommendations. Actually, one of the essential criteria of the diagnostic category is the presence of «any intense and persistent sexual interest other than sexual interest in genital stimulation or preparatory fondling with phenotypically normal, physically mature,

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consenting human partners» (American Psychiatric Association 2013, p. 685). In addition, a robust body of research argues that the presence of deviant sexual interests is one of the most important risk factors linked to sexual recidivism (Hanson and Bussière 1998; Hanson and Morton-Bourgon 2005). That being said, the Risk-Need-Responsivity intervention model, an empirically validated treatment models for offenders, highlight the importance of targeting risk factors specifically associated to offending (Andrews and Bonta 2010; Andrews et al. 2011; Hanson et al. 2009). Therefore, the accurate assessment and characterization of deviant sexual interests bear significant importance when working with child sexual offenders.

Sexual Interests Assessment

Several sources of information are taken into consideration when conducting deviant sexual interests assessment, such as clinical interviews and self-administered questionnaires. Although essential to the assessment process, these sources of information are contingent to the participant's willingness to remain trustful throughout the assessment process, which can be a challenge when dealing with clients facing legal repercussions and social stigma. Furthermore, it requires a certain level of insight and self-awareness from the individual, who needs to remember, acknowledge and share specific details on sexual interests while being completely removed from the environmental context in which they occur.

In order to obtain objective data on sexual interests, many specialized clinics use penile plethysmography. Penile plethysmography is an assessment method that measures changes in penile circumference, or volume, during the presentation of stimuli generally containing age- and coercion-related elements (Marshall and Fernandez 2003b). To date, sex offender's assessment methods relying on penile plethysmography have received vast empirical support (Harris et al. 1994; Howes 1998; Malcolm et al. 1993; Quinsey and Chaplin 1988a, b). Overall, these methods allow to discriminate child sex offenders from nonoffenders (Harris et al. 1994; Howes 1998; Serin et al. 1994). Results from the procedure are also specifically linked to sexual recidivism (Hanson and Bussière 1998; Hanson and Morton-Bourgon 2005).

Penile plethysmography assessments have relied on either visual or audio stimuli presentation; each of these modalities having their advantages and weaknesses. Visual stimuli consist of a series of pictures depicting individuals from different genders and age groups. Despite being valid (Proulx 1989), these stimuli can hardly be standardized, and the presentation of stimuli depicting actual children and adults to elicit sexual arousal have raised ethical and legal concerns (Card and Olsen 1996). Given the constraints, visual stimuli were progressively forgone in favor of the auditory modality. The auditory modality consists of a series of narrated scenarios describing interactions between an adult and either another adult or child while they are involved in varying degrees of physical and sexual coercion. One concern surrounding auditory stimuli is their limited ability to reproduce the ecological conditions that trigger deviant sexual arousal responses in real life situations (Blader and Marshall 1989; Marshall et al. 1999). In fact, many influential researchers acknowledge that improvements to the ecological validity of the assessment procedure are in order (Haynes 2001; Konopasky and Konopasky 2000; Marshall and Fernandez 2003a; O'Donohue and Letourneau 1992).

Whether using auditory or visual stimuli, another concern surrounding the penile plethysmography procedure is its vulnerability to voluntary control of the erectile response by participants (Golde et al. 2000; Howes 1998; Howitt 1995; Lalumière and Earls 1992; Looman et al. 1998; Mahoney and Strassberg 1991). Over the years, researchers have tried to develop methods and protocols to address this issue (Golde et al. 2000; Henson and Rubin 1971; Laws and Rubin 1969; Mahoney and Strassberg 1991; Malcolm et al. 1985; Marshall 2004; Proulx et al. 1993; Quinsey and Chaplin 1988b), but none have proven to be entirely satisfactory in detecting or preventing voluntary control of the erectile responses.

In sum, penile plethysmography is a valuable tool, and one of the only method to objectively assess sexual interests. However, the procedure could benefit from some improvements surrounding the ecological validity of its stimuli as well as its vulnerability to result tempering. Furthermore, the ecologically situated understanding of sexual aggression offered by influential theories imply the development of methods, for both clinical and research purposes, that allow the simulation of clinically significant environments (Barbaree and Marshall 1991; Beauregard et al. 2012; Bouffard 2002, 2011; Exum and Zachowics 2014; Gannon 2009; Spokes et al. 2014; Ward 2009).

Possible Contributions of Virtual Reality

It can be expected that virtual reality's ability to generate specific environments, virtual characters, and provide high experimental control may help overcome some limitations in the assessment of deviant sexual interests. Indeed, virtual reality provides assessment conditions that closely respect the ecological properties of real-life circumstances. This is of paramount importance given the fact that precise environmental conditions need to be present in order for individual risk factors to be triggered and sexual deviant behavior to take place (Ward and Beech 2006). Virtual reality also appears to be a relevant method to grasp and understand the underlying mechanisms involved in sexual offending.

Possible Contribution of Eye-Tracking

One of the instruments that also provide new perspectives on sexual functioning and more specifically on the mechanisms surrounding sexual interests is eye-tracking. This device, which can easily be combined with immersive technologies, allows gaze recognition and grants access to the visual information retrieval process through an infrared camera pointed at the fovea. Research based on such technologies suggests that visual attention is kept for longer periods on stimuli in resonance with sexual preferences, and that specific eye movement patterns are related to sexual interests (Alexander and Charles 2009; Dixson et al. 2011; Fromberger et al. 2012a; Hall et al. 2011; Lykins et al. 2006; 2008; Rupp and Wallen 2007).

Furthermore, eye-tracking research has uncovered that cognitive processes modulate eye movements (Engbert and Kliegl 2003; Hafed and Clark 2002; Laubrock et al. 2005; Yarbus 1965, 1967). Specifically, studies have shown that exploration patterns for the same image change according to participants' objective during the stimuli presentation (Yarbus 1965, 1967). Considering the important role cognitive strategies play in the control of the erectile response (de Jong 2009; Henson and Rubin 1971; Laws and Holmen 1978; Laws and Rubin 1969), the identification of interfering cognitive processes responsible for erectile inhibition during plethysmographic assessment could significantly improving the internal validity of the instrument. Thus, it could prove relevant to combine eye-tracking with immersive technologies for sexual interests assessments.

While virtual reality (Glantz et al. 2003; Gregg and Tarrier 2007) and eye-tracking (Rayner 1998; Rosch and Vogel-Walcutt 2013) have been used for several years to study an array of biological and behavioral phenomena, the uses of these methods with sexual offenders is fairly recent. To our knowledge, no literature review has so far been conducted on the use of virtual reality and eye-tracking to assess child sexual offenders.

A search was conducted on PsycINFO using the following words: sexual offenders OR sex offenders OR sex offenses OR pedophilia AND virtual reality OR (eye-tracking OR fixation OR gaze) on April 1st, 2016. Conference proceedings, and paper sessions retrieved online were also considered. All studies included had to pertain specifically to sexual interests assessment with child sex offenders, provide quantitative results and clearly emphasize on methodological choices surrounding stimuli and physiological indicators. In the next section, a narrative review of eight studies using virtual reality (with or without eye-tracking) for sexual interests assessments will be conducted. Studies will be sorted according to whether they essentially addressed procedure validation or combined physiological indicators.

Validation Studies

Since the early 2000, Renaud et al. (2002) have developed a research program based on virtual reality and eye-tracking for the assessment of deviant sexual interests. First, a series of animated 3D stimuli was developed and standardized. In contrast to other series of modified images used for sexual interests assessment (Dombert et al. 2013; Fromberger et al. 2015), these stimuli are animated. Movements performed by all characters were generated by motion capture system and express nonsexual neutral affects. Physiological properties of the stimuli were given particular attention and all accurately represent the morphological characteristics associated with Tanner's development stages (1978). In total, nine animated computer-generated stimuli (ACGS) representing both genders through various stages of development were created, as well as a neutral stimulus.

A first study aimed to establish face validity for the ACGS (Goyette et al. 2008). One hundred and forty undergraduate students (mean age = 22.3 years) were presented with all nine ACGS. Each stimulus was presented for 90 s. For each stimulus, participants had to indicate perceived age as well as rate the stimulus overall realism and ability to generate sexual arousal.

Average perceived age was significantly different according to developmental stages: children (7.63 years-old), prepubertal (11.79 years-old), puberty (15.92 year-old), adult (23.78 year-old). Statistically equivalent means were obtained in a subsequent study conducted with sex offenders (Goyette et al. 2011). Sexual arousal ratings for ACGS fluctuated according to participant's sexual orientation, with significantly greater sexual arousal reported to the sexually preferred adult ACGS than all other stimuli. Reported magnitude of sexual arousal to the sexually preferred ACGS was low to moderate. In addition, the mean overall realism rating for the ACGS was 5.39 (SD = 1.94) on a scale ranging from 1 (not at all realistic) to 10 (similar to a human).

Results suggest satisfactory face validity for all ACGS. Findings also highlight the necessity to consider realism and graphic quality as important variables in the context of human sexuality, specifically when performing sexual interests assessment. In fact, levels of realism and graphic quality required for sexual interests assessment remains an important issue to consider when developing tasks and virtual environment.

To that effect, Fromberger et al. (2015) made an attempt to determine the optimal level of immersive technological necessary to generate sexual arousal. Essentially, Fromberger and colleagues conducted a series of studies combining eye-tracking and visual reaction time to assess sexual interests (2012a, 2012b, 2013, 2015). Visual reaction time is an assessment method, which consists of inconspicuously recording the time a participant spends exploring the sexual attributes of a stimulus, while he is asked to perform an associated task, such as assessing stimuli attractiveness. A body of research suggests that visual reaction time is associated with sexual interests and is longer when an observer is exposed to a category of sexual stimuli corresponding to his sexual interests (Abel et al. 1994; Lykins et al. 2008).

For this particular study (Fromberger et al. 2015), twenty-five heterosexual males and twenty homosexual males from the community were presented with 20 fixed computer-generated stimuli representing nude adults from both genders modeled and designed at the University of Göttingen. Stimuli presentation took place in three different immersive conditions: (1) monoscopic flat-screen with no head-tracking, (2) stereoscopic head-mounted display and head-tracking, and (3) stereoscopic head-mounted display with head-tracking and turnable view. While participants were requested to evaluate the level of attractiveness and realism of the stimuli, visual reaction time was used as a measure of sexual interest. Subjective ratings of attractiveness and realism, visual reaction time as well feeling of presence were gathered for analysis.

Overall, results suggest that the two stereoscopic conditions generated significantly higher subjective ratings of stimuli realism, sexual attractiveness and feeling of presence than the monoscopic condition. Level of immersion did not however have an impact on the capacity to identify preferred sexual stimuli, as viewing time was invariably longer when exploring stimuli corresponding to sexual interests in all viewing condition. Findings also suggest differential scanning patterns when participants were allowed to turn around the stimuli. In this particular condition, participants circulated significantly more often around the stimuli corresponding to their sexual preference. Thereby, level of interactivity appears to be an important variable to consider when assessing sexual interests.

These results suggest that stereoscopic technologies perform better on subjective measures associated with sexual attractiveness, realism and presence than monoscopic technologies, while level of immersion seems to have little impact on objective measures allowing sexual interests assessment. Findings in regards to scanning patterns and body positioning also emphasize the relevance of focusing on psychophysiological indicators other than erectile response when assessing sexual interests.

A third study focused on establishing the validity of virtual reality and ACGS as a presentation modality for the plethysmographic procedure. Specifically, Trottier et al. (2014b) aimed to establish the immersive procedure's discriminant validity as well as its diagnostic accuracy. For this research, 22 child sex offenders and 42 non-deviant male participants were recruited and presented with five ACGS developed by Renaud et al. (2002) on a stereoscopic head-mounted display. For each trial, erectile responses were standardized in order to minimize inter-individual variability inherent to penile response (Blanchard et al. 2001). Deviant differentials, an index of relative preference between normative and deviant stimuli, were also calculated (Harris et al. 1992; Seto et al. 2004, 2006).

Results suggest that stereoscopic presentation of ACGS yielded significant erectile responses representative of sexual interests that allowed group discrimination. Precisely, child sex offenders had greater sexual arousal to children stimuli than adult stimuli, whereas the control group had greater sexual arousal to adult stimuli than children stimuli. Results pertaining to diagnostic accuracy were obtained through Receiver Operating Characteristic (ROC) analysis. ROC analyzes establish the ability of a test to discriminate between two groups (Streiner and Cairney 2007). The Area Under the Curve (AUC) represents, in this particular instance, the probability that the stimuli modality used will produce a higher deviance differential for a randomly selected sex offender than for a randomly selected control individual. The AUC values can range from 0 to 1. A value of 0.5 indicates a diagnostic capacity at the level of chance whereas higher values indicate better performance (Streiner and Cairney 2007). ACGS yielded a significantly greater diagnostic accuracy (AUC = .90) than chance. Similar diagnostic accuracy (AUC = .85) was obtained in a research using the same protocol on a flat panel display (Goyette 2012). Thus, stereoscopic presentation of ACGS appears to be a valid presentation modality for penile plethysmography assessment, with satisfactory discriminant validity and classification accuracy.

Overall, the published literature provides empirical support for the use of monoscopic and stereoscopic technologies as well as the presentation of computer-generated stimuli for sexual interests assessment. It now becomes appropriate to question the possibility of combining virtual reality to other instruments, such as eye-tracking, to obtain additional information regarding sexual interests.

Studies Using Combined Physiological Indicators

A total of five studies were found to combine virtual reality and eye-tracking for sexual interests assessment. The objective of the first study was to determine if certain eye-movement patterns recorded during the monoscopic exploration of ACGS could be linked to sexual interest towards children (Goyette et al. 2010). Twenty-two child sex offenders and 36 adult males from the community were presented with the nine ACGS developed by Renaud et al. (2002) on a flat panel display. Eye-movement data was recorded using an infrared camera measuring corneal reflection that was installed on a motorized tray and subsequently standardized.

For data analysis, three mutually exclusive body areas of identical dimensions were circumscribed: the head, chest, and genital area (including hips). The creation of distinct body areas allowed considering fixations and saccades in relation to the spatiotemporal changes in and between the identified body areas. Fixation number and duration as well gaze directional changes between areas of references were considered for analysis.

Results suggest that ocular dynamics associated with sexual interest are characterized by shorter mean fixation duration, greater time spent exploring the genital area, greater number of fixations in the genital area as well as a greater number of gaze transitions toward the chest and genital areas. These ocular behaviors were found in child sex offenders when exploring children stimuli and in men of the community when exploring adult stimuli. Similar results were obtained in a research using the same protocol with the stereoscopic presentation of the ACGS (Trottier et al. 2014a). Findings support eye-tracking technologies ability to provide relevant information pertaining to sexual interests, which allow group discrimination according to sexual offending history.

Fromberger et al. (2012a, 2013) also studied eye movements for sexual interests assessment. Specifically, two studies based on the same research protocol were conducted using monoscopic presentation of fixed computer-generated stimuli, originating from the Not Real People set of stimuli (Mokros et al. 2011). The selected subset consists of 128 computer-modified photographs of naked and clothed people representing both genders and two developmental stages: stage 1 and 2 (pre-pubescent) and stage 4 and 5 (pubescent and post-pubescent). Both studies were conducted on the same sample composed of 22 child sex offenders, 8 sex offenders of adult women and 52 men from the general population.

The protocol consisted in presenting a pair of stimuli for 5000 ms and then asking which of the stimulus is most attractive. Each set of two stimuli was composed of people from the same gender, but different developmental stages. Eye movements were recorded during stimuli presentation. Following this task, participants were asked to assess subjective sexual arousal for each stimulus at their own pace while viewing time was recorded without their knowledge.

In the first study using this protocol, Fromberger et al. (2013) wanted to test the assumption that stimuli in resonance with sexual interests are automatically selected by the viewer and will retain focal attention. Results obtained were in line with the assumption, with child sex offenders recording shorter entry time on child stimuli, whereas men from the community and sexual offenders of adult women, recorded shorter entry time on adult stimuli.

Findings are also coherent with results from the second study (Fromberger et al. 2012a), in which the authors compared the initial orientation, relative fixation time and viewing time according to group. In fact, findings suggest that initial orientation, which represents automatic attentional mechanisms, was faster for child sex offenders when facing children stimuli compared to sex offenders of adult women and men of the community. Similarly, for child sex offenders, relative fixation duration was significantly longer when facing children stimuli and shorter when viewing adult stimuli in comparison with offenders of adult women and men from the community.

Furthermore, the ability of initial orientation and relative fixation time to classify men accurately according to sexual preference towards adult or children was assessed with ROC analysis. Classification capacity for initial orientation (AUC = .90), relative fixing time (AUC = .83), and visual reaction time (AUC = .76) all recorded good stability and perform significantly better than chance. All three variables' classification accuracy were statistically equivalent. Findings from both researches bring further support to the use of eye-tracking technologies for sexual interests assessment.

Trottier et al. (2014c) conducted a study aiming to address penile plethysmography's vulnerability to faking attempts by participants. Based on eye-movement analysis, this research evaluated the possibility of detecting the use of cognitive strategies to exert voluntary control on the erectile response during the plethysmographic assessment. Since, it is established that cognitive processes modulate eye-movement (Engbert and Kliegl 2003; Hafed and Clark 2002; Laubrock et al. 2005; Yarbus 1965, 1967), it was hypothesized that faking attempts resulting from the use of a cognitive strategy would be detected.

To test that hypothesis, the eye movements and erectile responses of 20 men were recorded during the stereoscopic presentation of ACGS. Men had to explore stimuli in three distinct viewing conditions: (1) Free visual exploration of a stimulus corresponding to sexual interest, (2) Free exploration of a neutral stimulus, and (3) Exploration of a stimulus corresponding to sexual interest while attempting to suppress erectile response. In the third condition, participants were specifically asked to try to inhibit their erectile response by thinking of a disgusting image previously shown to them. For analysis, areas of interest were computed into three zones: (1) the erogenous zone, which regrouped the chest and genital areas, (2) the non-erogenous zone, which regrouped the head and feet areas, and (3) the exterior zone.

Results suggest that when attempts are made to suppress the erectile response to a stimulus corresponding to sexual interest, eye movement patterns are significantly different compared to the free visual exploration of either a sexually preferred stimulus or a neutral stimulus. Exploration patterns associated with erectile suppression are characterized by subdued stimuli exploration, long and infrequent fixations, and avoidance of the erogenous zone. Thereby, the combination of eye-tracking and immersive technologies allowed the identification of gaze pattern specific to the presence of cognitive strategies used for erectile inhibition. The identification of interfering cognitive processes responsible for erectile inhibition during plethysmographic assessment could significantly improve the internal validity of the assessment process.

Finally, a single-case study was conducted to establish the feasibility of immersive "role playing" with a sex offender (Renaud et al. 2009). The scene was designed based on the participant's sexual offending history and created by certified clinicians. A clinician enacted the 5 min real-time interaction with the offender in distinct rooms. A child female ACGS was presented to him through a stereoscopic head-mounted display. A speech recognition system allowed to modulate the lip movements of the animated female child character according to the words used by the clinician in charge. The ACGS was animated through a joystick, which further allowed manipulations of both body movements and facial expressions. Erectile responses were also recorded in real time throughout the role play and allowed the clinician to modulated verbal interactions, body movements and facial expressions of the ACGS.

As the role play unfolded, the participant recorded significant erectile tumescence in response to the ACGS's movements, became increasingly involved in the verbal exchange with the character and expressed cognitive distortions related to sexual offending. Role play allows the direct observation of many risk factor indicators as they unfold in real time such as cognitive distortions, social skills, affect regulation and decision-making skills. It then becomes possible to not only identify the presence of deviant sexual interests but also to understand how individual risk factors emerge and interact in a specific situation towards the commission of a sexual assault. These observations are all the more promising for assessment and treatment purposes when considering the recent development of idiosyncratic ACGS (Dennis et al. 2014).

Discussion

Some general findings emerge from these different studies. First, the introduction of virtual humans, whether animated (Renaud et al. 2002) or static (Dombert et al. 2013; Fromberger et al. 2015; Mokros et al. 2011), is an important progression for sexual interest assessment. In addition to being standardizable, they allow accurate group discrimination and diagnostic accuracy (Fromberger et al. 2012a, 2013;

Goyette 2012; Goyette et al. 2010; Trottier et al. 2014b) and their ability to elicit physical or attentional responses linked to sexual interests is maintained throughout immersive conditions (Fromberger et al. 2015). Thus, it appears all immersive conditions allow sufficient ecological validity for individual risk factors to be triggered and sexual deviant arousal to take place (Goyette et al. 2010; Fromberger et al. 2012a, 2013; Renaud et al. 2009; Trottier et al. 2014a, 2014b), which is paramount for both our clinical (Andrews and Bonta 2010; Andrews et al. 2011; Hanson et al. 2009) and theoretical (Ward and Beech 2006) understanding of the phenomenon. This conclusion supports the implementation of immersive technologies and ACGS as new modalities of assessments in clinical and research settings.

Furthermore, the use of visual stimuli for the penile plethysmographic procedure facilitates the inclusion of additional devices, such as eye-tracking, towards an integrated sexual interests assessment. In that sense, it is becoming evident that many ocular variables are associated with sexual interests (Fromberger et al. 2012a, 2013, 2015; Goyette et al. 2010; Trottier et al. 2014a, 2014c) and that eye-tracking not only allows a direct access to these exploration patterns but also to underlying attentional and cognitive processes directly involved in the sexual arousal process or its inhibition (Engbert and Kliegl 2003; Fromberger et al. 2012a, 2013; Hafed and Clark 2002; Laubrock et al. 2005; Trottier et al. 2014c; Yarbus 1965, 1967). Beyond sexual interests assessment, the combined use of eye-tracking and virtual reality could contribute greatly to our understanding of sexual abuse by granting us access to the perceptual-motor mechanisms as well as the attentional, self-regulation and decision-making processes associated with sexual arousal and sexual offending behaviours.

However, much more empirical and clinical research is needed. Eye-tracking applications are very recent in sexual interest assessment. Although an important and necessary starting point, most research protocols to date have been based on exploratory experimental or quasi-experimental designs. Often, working assumptions, selected ocular indicators, and data analysis strategies implemented were also exploratory. Most research protocols have limited the participant's mobility in the virtual space and focused on tracking head movements (3 degrees of freedom). Since increasing interactivity between the participant and the ACGS has proven to enhance subjective ratings of realism and sexual arousal (Fromberger et al. 2015), tracking 6 degree of freedom and allowing the individual to move across the virtual environment and around the ACGS could further improve the procedure's ecological validity and our understanding of approach behaviors leading to sexual offending.

The use of virtual reality and eye-tracking remains a complex endeavor that requires proper training in the handling of the instruments as well as in software operation. Furthermore, the staggering number of raw data emerging from each trial requires various transformations before it can be analysed and interpreted. These challenges are further increased by the use of several instruments simultaneously. Now equipped with more than a decade worth of insight, integrating skills and knowledge from different areas through the composition of multidisciplinary teams should be a priority.

Future research efforts should be devoted to the development of assessments and treatments protocols supported by virtual reality and eye-tracking to appreciate the full potential of these novel tools in the field of sexual aggression. In this regard, the flexibility of the stimuli in terms of physical appearance and emotional expression could allow the development of assessment protocol targeting adult rape perpetrators as well as other types of paraphilia and paraphilic disorders (Hogue and Perkins 2011; Perkins and Hogue 2011). Moreover, the possibility to use idiosyncratic characters and environments allow the reproduction of risk situations that are specific to the individual and pave the way to the use of virtual reality for broader assessments and even treatments of sexual offenders (Renaud et al. 2009). It could, for example, be possible to produce a virtual situation in which a participant has to move across a public setting such as a schoolyard or a public swimming pool filled with child ACGS.

On one hand, these protocols could be used in combination with traditional cognitive-behavioral intervention strategies such as roleplay (Renaud et al. 2009) to promote the use of self-regulation processes. Such a procedure could possibly be integrated into treatment programs and allow patients to consolidate their knowledge in dealing with their risk situations in a controlled environment with the assistance of a therapist. It could also allow the therapist to adjust the difficulty of the situation, stop the process at any time to identify cognitive distortions and propose more adapted thoughts or to assist a client having problems with its self-regulation. On the other hand, use of such role plays as part of a post-treatment assessment procedure could help make decisions in terms of recommendations for monitoring conditions or further treatment, by allowing in-vivo access to a client's abilities to apply behavioral skills acquired during treatment.

If such applications seem particularly attractive, virtual reality and eye-tracking in sexual offending are still mostly restricted to the assessment of deviant sexual interests. While more proof-of-concept and clinical randomized trials, are required, other aspects need to be addressed. Environments should be able to offer much more dynamical features than those currently available and to take into account a given patient's reactions. This idea refers directly to notions of interactivity and coupling in virtual environments (Bevacqua et al. 2014).

If the general aim of virtual reality is to simulate an environment closer to reality, a critical feature remains feedback loops by which any action leads to retroaction in a continuous manner. For example, virtual environments should be able to take into account and to evolve according to specific reactions. Imagine an interaction with a virtual character. If a sexual response is detected above a given threshold during a given amount of time, virtual character could morph into a facial expression of fear or disgust. Clinically relevant information could be found in patient's following reactions to this dynamic and continuous "update", directly related to self-regulation processes.

In sum, virtual reality and eye-tracking appear to be promising methods towards the resolution of some of the issues hindering penile plethysmography and a better understanding of the interacting factors related to sexual aggression as they may unfold in natural settings.

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Chapter 10
Using Innovative Technologies as Therapeutic and Educational Tools for Children with Autism Spectrum Disorder

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Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder diagnosed on the basis of deficits in social interaction and communication, and with narrow interests and repetitive behavior (American Psychiatric Association (APA) 2013).

Children with ASD initiate or respond to fewer socially acceptable interactions, have fewer social interactions and spend more time playing alone compared to their peers (Koegel et al. 2001; Hilton et al. 2008). They typically exhibit severe attention (Courchesne et al. 1994; Pierce et al. 1997) and language (Rutter 1978) deficits as well as difficulties in tasks requiring social (Pierce and Schreibman 1995), and affective (Hobson et al. 1988) competencies. According to the "theory of mind", children with ASD have difficulty in the ability to attribute to others' mental states and predict social behaviors. Therefore they have problems in inferring others' emotions, desires, and intentions which their abilities for social interactions (Baron-Cohen 2000).

Although those children with ASD who are cognitively able have social deficits and repetitive and restricted behaviors and interests, they differ from other children with ASD by the relative preservation of their linguistic and cognitive development (Volkmar and Lord 2007). Thus, they tend to function well in literal contexts but have difficulty using language in a social settings (Klin et al. 2005).

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Many of the children with ASD, and specifically those with HFASD, are able to use language skills in order to communicate and are independent in activities of daily living such as self-care and organization in the classroom. They are often integrated into regular school and classroom settings. Nonetheless, they show signs of difficulty in their everyday behavior, particularly in the areas of social communication and social interaction (APA 2013), which limits their ability to participate in many of the activities that are required within school and community settings.

ASD is a life-long disability. Many of the social-communication deficits that are prevalent in children with ASD linger into adolescence and adulthood, and have long-term adverse effects on the participation of adults with ASD in everyday lives. Indeed adults with ASD who exhibit deficits in social competence have difficulty achieving independence in adulthood (Howlin et al. 2004), maintaining employment (Szatmari et al. 1989), and creating and maintaining meaningful relationships (Howlin et al. 2004). Individuals with ASD are thus often frustrated by their difficulty in coping with life's challenges, and experience loss of self-esteem, anxiety, and even depression (Howlin et al. 2004). There is an overall reduction in their quality of life (Gal et al. 2015).

A number of social competence interventions have proven successful at increasing social and communicative skills for individuals with ASD in various studies, mostly adapting the principles and techniques of cognitive behavioral therapy (CBT). These interventions highlighted the interplay between how children think, feel, and behave in social situations to help them engage in more effective interactions with peers as well as to enhance their socio-cognitive understanding of social constructs and processes (e.g. Bauminger-Zviely et al. 2013; Lopata et al. 2010; Solomon et al. 2004).

As a tool of interest for this population, innovative technologies may be used in order to address difficulties, enhance strengths and prepare those with ASD for better participation within everyday activities including work leisure and recreation. The value of computer-based activities as therapeutic and educational tools for people with ASD has been noted for many years since they are usually highly motivated by such tasks (Hart 2005; Grynszpan et al. 2005). Focusing on a computer screen, where only necessary and relevant information are provided, may help people with ASD reduce distractions from extraneous sensory stimuli. Furthermore, computer programs are generally free from social demands and can provide consistent and predictable responses (Moore 1998; Murray 1997). Third, the safety of a clearly defined task appears to help people with ASD concentrate on this activity (Murray 1997).

All these affordances make computer-based interventions beneficial for people with ASD who usually present increased responsiveness to environmental stimuli when events are more predictable (Ferrara and Hill 1980). Nevertheless, the responses from some professionals and parents to technology have been mixed due to the fear of increased social withdrawal (Panyan 1984; Bernard-Opitz et al. 1990).

The range of computer-based technologies used as therapeutic and educational tools for children and adults with ASD has greatly increased over the past two decades. This chapter presents an overview of these technologies with a focus on the enhancement of social and communication skills and participation for children and adolescents with ASD. We specifically focus on video modeling, Shared Interactive

Surfaces, virtual reality and robotics. Our purpose is not to provide an exhaustive review of all the available technologies, rather to use a selected sample of technologies to illustrate their use to enhance social competence, communication and other skills that present the base for participation in those with ASD.

Innovative Technologies for People with ASD

One of the major determinants of participation in leisure and recreation is individual preferences or interests (Searle and Jackson 1985). The increasing availability of computer-based activities has improved the convenience and accessibility of a much wider range of activities, thus encouraging both self-development and participation in educational, vocational and recreational pursuits, This leads to greater opportunities for social interaction at home, school and community settings (Garton and Pratt 1991).

In recent years, a growing number of technologies have been developed with the aim of helping people with ASD improve their social and communication skills. These include applications to enhance emotional expression (Silver and Oakes 2001), to learn vocabulary (Moore and Calvert 2000), and to improve social problem solving (Bernard-Opitz et al. 2001) and functional daily activities (Josman et al. 2008). These technologies provide learning activities based on multimodal computer interfaces (Bernard-Opitz et al. 2001; Bosseler and Massaro 2003), videomodeling (Dowrick 1999), virtual reality (SikLányi and Tilinger 2004; Parsons et al. 2006), robotics (Dautenhahn 1999) and Shared Interactive Surfaces (Gal et al. 2005, 2009).

Video Modeling and Video Self-Modeling

Modeling, also referred to as observational learning, is a tool that has received much attention in the literature since it was introduced over 40 years ago by Bandura and Menlove (1968) as an intervention for enhancing language, affective responses and social skills. They specifically noted the tendency of children to use observation of others to acquire new skills, rather than basing skill acquisition primarily on their own personal experiences. Advances in videotaping, recording and playback during the past two decades have extended the practice of modeling to include its use to teach a wide variety of skills. Video modeling (VM) is a technique that involves demonstration of desired behaviors through video representations. A video modeling intervention typically involves an individual watching a video demonstration of an adaptive behavior, and then imitating it. VM can be used with peers, siblings or adults who model the desired behaviors.

Video self-modeling (VSM) is a specific application of VM that encourages individuals to imitate targeted behaviors by observing themselves successfully performing them (Dowrick 1999). VSM interventions typically fall within two categories:

positive self-review (PSR) and video feed-forward (Dowrick 1999). In the case of PSR, individuals watch themselves effectively engage in an everyday behavior or skill that they do not frequently use (although it is present in their behavioral repertoire). Watching the performance of these behaviours appears to increase their frequency of use. In the case of video feed-forward, individuals observe themselves successfully performing skills that are somewhat beyond their current capability, using “hidden support” such as cues from an adult that are then edited out of the final version of the recorded segment (Bellini and Akullian 2007). Watching themselves perform the task without cues appears to increase self-esteem and to encourage independent performance of the behavior.

Video modeling and video self-modeling have been used across diverse disciplines and populations to teach a wide variety of skills including motor behaviors, social skills, communication, self- monitoring, functional skills, vocational skills, athletic performance, emotional regulation and play behaviors. Nikopoulos and Keenan (2004) examined the effects of a VM intervention on social initiation and play behaviors in three children with ASD. Each child watched a videotape showing a typically developing peer, and then engaged with an adult in a simple, single toy social interactive play session. Social initiation and reciprocal play skills were enhanced following the intervention, and maintained at both one and three months afterwards. The effect of VM intervention on play behavior in preschool children with ASD was also tested by D’Ateno et al. (2003) and MacDonald et al. (2005). In both cases VM led to rapid acquisition of both scripted verbal statements and scripted motor actions during play, but the interventions did not generalize by leading to unscripted play behaviors.

Charlop-Christy and Daneshvar (2003) used VM to enhance perspective taking (the ability to understand mental states of others in order to explain or predict behavior) for children with ASD. Cihak et al. (2012) used a videotaped “Social Stories” intervention to decrease attention-seeking and task-avoidance behaviors in four middle school students with ASD. The intervention was effective only when the Social Stories were related to specific behaviors that illustrated task-engagement behaviors but not when the viewed Social Stories did not match these specific behaviors. This finding suggests the need to match a video-modelled behavior to individual’s interests and abilities.

Wert and Neisworth (2003) showed the effectiveness of VSM in teaching four young children with ASD to make spontaneous verbal requests in school settings. Buggy et al. (1999) showed that VSM led to a marked improvement in the acquisition and maintenance of play-related verbal responses in school aged children with ASD (although only minimal maintenance effects were observed).

For many years video modeling was carried out with a television and videotape recorder (Coyle and Cole 2004; Mechling 2005). In the past decade, digital recording and playback techniques have greatly enhanced the ease with which VM and VSM are used. Cihak and Schrader (2008) used a laptop computer system to show adolescent students with ASD video clips of themselves (VSM) as they independently and adaptively performed targeted vocational tasks in their work setting. This technique provided them with greater support since they could simply replay the video recordings for review. Cihak et al. (2008) demonstrated the effectiveness of video modeling to facilitate independent transitions during vocational training for students with severe disabilities.

Ayres and Langone (2005) suggested that video modeling is particularly useful when the video is digitally implemented since it can be more easily integrated into software-based applications. A recent example of such integration is CONTACT (Conflict Orientation Negotiation Training Among Children and Teens), a multi-user, collaborative application designed to identify, classify and treat conflict resolution skills within a technology-supported, constructivist learning environment, is based on the COSPATIAL No-Problem authoring application (http://cospatial.fbk.eu/) with new content related to conflict resolution scenarios. It incorporates VM and VSM within the computerized application aimed at enhancing adolescents' negotiation strategies for social conflicts. "Simu-Voc"is another recent video modeling and video self- modeling application that targets adolescents and young adults with HFASD, aimed at enhancing prevocational skills, such as preparation for a job interview (Rosen et al. 2017). According to studies that aimed at examining the usability and sensitivity of CONTACT and Simu-Voc, they both appear to be a feasible, user friendly and sensitive application for querying adolescents' responses to conflict (Hochhauser et al. 2016; Rosen et al. 2017).

In summary, video modeling and video self-modeling have been demonstrated to be effective intervention strategies for addressing social communication skills, and functional skills for children and adolescents with ASD. Due to its overall effectiveness and accessibility, this tool is widely used in various ways in education and clinical settings. However, further research is needed to determine the extent to which the behaviors taught with these techniques generalize to everyday behaviors and improved participation in daily tasks. Indeed, it appears that although the children in the above cited studies learned the targeted skill behaviors only, and, in many cases, maintained them, they were unable to engage in similar behaviors in other situations that were not directly taught through VM (e.g., MacDonald et al. 2005; Cihak et al. 2012).

Shared Interactive Surfaces

The term Shared Interactive Surfaces (SIS) describes devices that are specifically designed to allow simultaneous interaction by multiple users on the same interface (Zancanaro 2012). Generally, this technology is characterized by large displays that can be placed in horizontal (also called 'tabletop' devices) or vertical (also called 'wall displays') orientations. SIS represent a shift from a one-user-one-computer paradigm and have become a focus of research investigating the benefit that they can provide in the support of collaborative activities (Müller-Tomfeld 2010).

Shared Interactive Surfaces are characterized by the number of simultaneous touches that they can handle and by the possibility of distinguishing different users. The number of simultaneous touches is an important variable to support complex usage such as working together with others or gesturing. Standard touchscreens allow just one touch at a time while some of the larger displays allow multi touches at one point of time. Identifying touches made by different users, at present available only on the DiamondTouch table (Dietz and Leigh 2001), means that the interface is capable of identifying who is touching where. This leads to novel design possibilities such as assigning the playing of one game piece to one child which another cannot manipulate (and vice-versa); in order to obtain a successful result they would have to play in a collaborative way.

In general, an important benefit offered by SIS is the direct manipulation of digital objects through touch. Although accuracy of touch on a tabletop interface is inferior to mouse interaction (Forlines et al. 2007), several studies suggest that for collaborative tasks a direct touch interface is more effective than the use of multiple pointing devices, in particular for achieving higher levels of awareness, fluidity of interactions and spatial memory (Ha et al. 2006; Hornecker et al. 2008; Antle et al. 2009; Müller-Tomfeld 2012).

Direct manipulation is particularly useful for children who may have difficulties in their motor coordination ability (Piper et al. 2006; Hourcade et al. 2012). A further advantage of these devices is that they are large enough to allow multiple users to collaborate without crowding, in contrast to computer monitors or tablets (like iPads and Android tablets), which are not big enough to allow equivalent visual perspectives and interaction by more than one or two people. These features, together with well-designed activities, can make SIS an ideal platform to enhance social skills in children.

Several studies have investigated the potential benefit of SIS for children with ASD, specifically focusing on enhancing social interaction (Hourcade et al. 2012; Giusti et al. 2011; Zancanaro et al. 2011; Piper et al. 2006, Ben-Sasson et al. 2013). Some of these applications are co-located interfaces on a tabletop device that include sets of rules that structure the interaction to make collaboration more effective. Piper et al. (2006) described an application for the use of groups of four children with Asperger's Syndrome. The system included a computer-enforced turn-taking mechanism, forcing the participants to vote unanimously in order to proceed with the game. In the studies conducted by Gal et al. (2005, 2009), pairs of children with High Functioning ASD were involved in the collaborative narration of a story using an application named "StoryTable"(Zancanaro et al. 2007), using the multi-user capability of the DiamondTouch. The StoryTable provides virtual environments where users can manipulate objects and characters within the context of a specific story background. It enables the production and recording of joint narratives, and requires joint touch of the icons in various stages of the story telling. These joint touches are referred to as "enforced collaboration", that is, a computer-supported interaction paradigm wherein participants are required to carry out joint actions on digital objects during a common activity (Cappelletti et al. 2004). Enforced collaboration was found to be effective in various interaction contexts such as collaborative storytelling among primary school children (Zancanaro et al. 2007).

The same paradigm, when used with children with ASD, had a positive effect on social interaction among children with High Functioning ASD (Gal et al. 2005, 2009).

There were significantly higher rates of positive social behaviors and collaborative play, and lower rates of negative social interaction following the intervention. Improvement was maintained when tested 3 weeks later via the non-technological tasks, suggesting generalization of the social skills learned during the intervention.

The Collaborative Puzzle Game, also developed for the DiamondTouch, differs from the StoryTable in that it required visuo-spatial abilities rather than narrative skills. Pairs of children jointly select and drag individual puzzle pieces to collaboratively complete a puzzle (Battocchi et al. 2008 2010; Ben-Sasson et al. 2013). Results of the CPG studies indicated that enforced collaboration is associated with a positive effect on collaboration, reflected by an increased rate of simultaneous activity by the two players (Battocchi et al. 2010). Winoto and Tang (2017) discussed a similar approach while investigating variations in the type of play and collaboration levels. Their results suggest an impact on joint attention for children with all levels of ASD.

In other studies, the enforced collaboration paradigm has been combined with CBT as an intervention technique for enhancing social cooperation of children with high functioning ASD (Giusti et al. 2011; Wass and Porayska-Pomsta 2014, Bauminger-Zviely et al. 2013). One application (Join-In, Giusti et al. 2011) consists of three social stories each associated with a game that encoded a different collaboration dimension achieving a common goal: doing things together, sharing objects and playing different roles. A second application (No-Problem) consists of situations that teach the concept of social conversation and social interaction. Pairs of children with High Functioning ASD were able to use the CBT role play technique (via video modelling and video self modelling) to practice the learned social concepts. A 6 week intervention using these two applications led to improvement in the socio-cognitive area with children providing more active social solutions to social problems and revealing more appropriate understanding of collaboration and social conversation after intervention (Bauminger-Zviely et al. 2013). The multi-user capability of DiamondTouch allowed embedding of the social rules in the operations of the interface thus making them more acceptable to the children (as already noted by Piper et al. 2006). Furthermore, the support provided by the system may enhance a facilitator's management of interaction flow to increase its effectiveness during social competence training (Zancanaro et al. 2011).

In a companion study, Eden et al. (2011) compared two versions of No-Problem to train social conversation skills based on the CBT approach: one for DiamondTouch and one for a standard computer equipped with three mice (each of which each controlled its own cursor). Although the majority of children preferred using the tabletop, they reported equivalent amounts of competence, perceived choice, and felt minimal tension when using either interface. This result provides support for the use of a smaller and less expensive platform in locations (e.g., schools) that do not have access to the more expensive tabletop equipment.

Hourcade et al. (2012) developed a suite of simple applications for a multi-touch tablet (smaller and cheaper than the larger tables). Their observations suggest that these activities increased pro-social behaviors such as collaboration and coordination, enhanced appreciation for social activities and provided children with novel forms of expression. They also noted that using the computer with others appears to make the computer itself becoming the recipient of the participants' focus thus reducing the anxiety of initiating social interaction.

Overall, these studies provide evidence of the potential benefit of SIS technology, in particular in educational and rehabilitation programs in which collaborative behaviors and social skills, such as shared attention for objects, negotiation and imitative behaviors are the main focus. Although the findings presented above were obtained primarily with multi-user devices, similar results might be achieved with smaller and cheaper hardware. For example, we note the recent use of tablets to study these behaviors (Escobedo et al. 2012; Hourcade et al. 2012; Fage et al. 2016).

Virtual Reality

Virtual reality (VR) is defined as the use of interactive simulations created with computer hardware and software to present users with opportunities to perform in virtual environments (VEs) that appear, sound and, occasionally, feel similar to real world objects and events (Sheridan 1992; Rizzo et al. 1997; Weiss and Jessel 1998). The use of VR as an educational and rehabilitation tool is based on a number of unique attributes of this technology including the use of ecologically-valid experiential tasks that are motivating, challenging, yet safe (Rizzo et al. 2002; Schultheis and Rizzo 2001). Importantly, the automated nature of stimulus delivery within VEs enables a therapist to focus on the clients' performance, to observe whether they are using effective strategies, and document all results. Clinicians and teachers use VR to achieve a variety of objectives by varying task complexity, type and amount of feedback, and the extent of independent activity. All of these attributes have been noted to be of particularly relevance for people with ASD (Strickland et al. 1996; Trepagnier 1999; Parsons and Cobb 2011).

In a pioneering study, Strickland et al. (1996) used a desktop virtual environment viewed while wearing a Head mounted display (HMD) to teach two children with ASD, aged 7.5 and 9 years, to cross a street. She found that both participants succeeded in adjusting to the HMD (which was much heavier than those currently used) and in concentrating on the task. They both learned to navigate within the virtual environment, and to locate and approach objects that moved. Only one of the two learned to stop when he reached the object, which constituted the goal of this task. Although the initial results were encouraging, the implications of the study are limited due to the small number of participants and concerns related to the use of an HMD with this population.

Cobb et al. (2002) used a computer desktop system to explore the suitability of a virtual coffee house to support learning of social communication skills for teenagers with Asperger's syndrome. The rationale behind this study was that, if social scenarios could realistically be replicated within virtual environments, the limited personal interaction afforded by the computer interface would be inherently more attractive to these youth and therefore provide a safe and supportive environment for learning (Parsons et al. 2000). The environments represented typical social situations that would be familiar to most users with the objective of supporting social interaction behavior specific to two tasks: lining up to enter a coffee house and finding somewhere to sit. This required users to control the movement of their avatar (virtual person whose actions represent that of the user) in the virtual coffee house, to respond appropriately to other avatars, and to make decisions about when they should communicate with others and what they should say. Observations of how educators used the virtual environment to support teaching of these specific skills in the classroom showed that they used the virtual environment as a visual prompt to promote discussion about what happened in the social scenario and why characters behaved as they did (Neale et al. 2002).

Teachers reported that the virtual environment helped students to discuss their anxieties in dealing with these situations (Neale et al. 2002). Examinations of the navigation patterns of participants in the virtual coffee house, documenting how much time they spent at specific locations (e.g., near or far from virtual people) and whether their behavior was appropriate (e.g., did they sit at a free table in the café or one that was already occupied) showed that people with ASD knew how to respond to the virtual setting in a non-literal manner, attributing to the avatars 'people-like' behavior (Parsons 2001). Moreover, the virtual environments were used and understood appropriately by young people with ASD and were effective in supporting learning about social skills (Parsons et al. 2004, 2005, 2006; Mitchell et al. 2007).

Another street crossing environment was used by children and youth with ASD to examine whether they were able to learn street-crossing skills with the aid of the simple, desktop environment (not displayed nor controlled by an HMD), and whether the simulation helped them to improve their pedestrian behavior in a real road street-crossing setting (Josman et al. 2008). The findings demonstrated that the research and control groups (both children with ASD) differed in their initial ability to successfully cross the virtual street, but no significant differences were found between groups in measures related to appropriate pedestrian behavior (e.g., number of times looked to the left and right). This finding is similar to that of Parsons et al. (2004, 2005) who found no differences between youth with ASD and youth who are typically developing on all measures in their virtual pedestrian and coffee shop simulations.

Cassell (2004) and colleagues (Cassell and Bickmore 2003; Ryokai et al. 2003) developed the novel "Virtual Peer", a life-sized, animated character that resembles the children with whom it interacts. Virtual peers appear to give children with ASD opportunities to repeatedly rehearse both verbal and nonverbal interaction skills. They also appear to empower children, offering the ability to be manipulated by their users, and to encourage the creation and practice of dialog and sharing behaviors. In an extended series of studies, the virtual peer approach was shown to successfully develop peer social interaction skills via a collaborative storytelling task interaction (Tartaro 2011). A recent study examined the feasibility of enhancing social skills, social cognition, and social functioning via VR-based social cognition training intervention (Kandalaft et al. 2013). Eight adults with high-functioning autism, aged 18–26 years, completed 10 sessions over a period of 5 weeks. The avatars were edited to graphically represent the participants and coaches. Following training, there were significant increases on social cognitive measures of theory of mind and emotion recognition, as well as in real life social and occupational functioning.

Two collaborative 3-D interactive virtual environments were developed as part of the COSPATIAL project (Parsons and Cobb 2014). They could navigated in real-time, enabling pairs of users to interact with each other within the VE. The assets of a collaborative VE approach included encouragement of verbal and spoken communication while providing the children with naturalistic responses. For example, Block Challenge (Cobb et al. 2010) is a two-player problem-solving game where each child aims to achieve different but interdependent objectives (related to building a tower of blocks comprised of different colored patterns). Although the players are fully aware of their own patterns, they do not have information about the other player's target pattern. Thus, they need to communicate to determine which block colors to share on the other side. Although the technology used by Parson and Cobb (2014) differs greatly than the collaborative tabletop paradigm used by Bauminger-Zviely et al. (2013), both appeared to encourage social interaction and conversation. In another recent study, Strickland et al. (2013) evaluated the effectiveness of JobTIPS, an internet accessed training program that included Theory of Mind-based guidance, video models, visual supports, and virtual reality practice sessions in teaching appropriate job interview skills to individuals with high functioning ASD. Their results suggested significant improvement in the job interviewing skills of those who completed the program when compared to a contrast group who did not receive such training.

Fernández-Herrero et al. (2018) carried out a bibliometric study of the use of VR as an educational tool for children with HFASD. They identified six domains of social or emotional skills research showing the predominance of research on social skills relative to emotional skills; individual interactions were much more prevalent than collaborative paradigms, and desktop technology greatly surpassed the use of immersive VR. About 7% of the cited papers are literature reviews or meta-analyses.

In addition to the sub-domain of improving competence in social skills, issues related to child safety and motor and cognitive skills are gaining in frequency of citations with an increasing focus on practical skills.

In summary, although the research support is mainly from studies with small numbers of subjects, there is a consensus that VR appears to be an effective way to improve the social abilities of children with ASD and to give them opportunities to learn skills that transfer to daily life abilities (Parsons and Cobb 2011). The simpler virtual environments may be run on inexpensive computers; however, there is still a lack of widely available software for clinical and educational use.

Robotics

A robot is an electro-mechanical device that uses microprocessor technology and information received from one or more sensors to manipulate objects within its immediate environment (Preising et al. 1991). In order to create a device that is readily comprehended by users their appearance, design and function is often based on a human model (humanoid). Robots in rehabilitation are used as prosthetic or orthotic devices to replace or assist function, as a therapeutic intervention to augment and facilitate exercise or to provide social assistance that serve to motivate, encourage and monitor social interactions or exercise. The latter option is the one used for ASD.

To date the literature on applications of robotics for ASD is not extensive, and these have typically aimed at motivating and monitoring play and social interactions. Weir and Emanuel (1976) reported the use of a primitive LOGO robot learning environment to promote positive communication in a young child with ASD. This robot was not autonomous and the child did not physically interact with it. Two early interactive robotic systems, KISMET (Breazeal 2003) and the ROBOTA dolls (Billard 2003) were both humanoid in design, being able to generate expressive social interactions with others. Their purpose was to encourage the development of social relationships between a robot and a human via imitation, speech and gestures. Work by Robins et al. (2005) focused on studying the way children with ASD play with robots. This longitudinal study demonstrated that children responded positively to robots when exposed over a number of therapeutic play sessions. However, no adaptive technology was used; the robots were built and programmed to interact in fixed, completely predictable ways. Scassellati (2005) investigated the use of robots for diagnosis and treatment of ASD. He focused on the use of a non-sensing robot which could execute scripted actions but could not sense nor respond dynamically to the individuals. He concluded that there is much potential in the use of robotics with this population because the robots engage these children very easily. Robots as interactive playmates for children with ASD have also been developed (e.g., Montemayor et al. 2000).

The AURORA robot was a major step forward in using a non-humanoid, autonomous mobile robot to encourage children with ASD to become more engaged in interactions known to be important in human social behavior (e.g., eye-contact, joint-attention, imitation) (Dautenhahn 1999). Children were encouraged to interact with the robot in whatever position and manner they preferred (e.g., lying on the floor or standing; touching or watching from a distance). The AURORA robot is deliberately non-humanoid robot in an effort to avoid the difficulty that children with ASD have in interpreting facial expressions and other social cues in social interactions. This robot aims to provide highly predictive motor and social responses. Initial results using the AURORA robot showed that most children responded positively and had great interest in interacting with it. A comparative study of the AURORA robot with a passive, non-robotic toy demonstrated that the children had more interest in interactions with the robot than with the inanimate toy (Werry and Dautenhahn 2007).

Moreover, the children showed less autistic and repetitive behavior when playing with the robot.

Feil-Seifer and Mataric (2008) designed the Behavior-Based Behavior Intervention Architecture (B3IA) as an autonomous robot capable of sensing the actions of children and understanding their approximate meaning in a given social context, of acting autonomously within specific interaction scenarios, and of reacting to both the immediately sensed situation and to the interplay of interaction over time. The B3IA robot observes the behavior of the child via sensors in the environment and/or worn by the child. The researchers suggested that a child who interacts with a contingent robot (one that responds explicitly to his behavior) will exhibit more positive social behavior than when interacting with a robot that responds randomly. For example, when the child pushes one button, the contingent robot blows bubbles while turning in place. When the child does not push one of the buttons, the robot does nothing. Sensors on the child enable the robot to respond in a truly contingent manner.

As summarized by a recent systematic review of Autism and Social Robotics (Pennisi et al. 2016), children with ASD often performed better with a robot partner compared to a peer or adult; they tended to show reduced repetitive and stereotyped behaviors and, social robots appeared to improve spontaneous language during therapy sessions in some cases. Socially assistive robots may thus provide therapists and researchers an additional means to promote interaction. Nevertheless, research in this area is still sparse, especially those using high level methodological designs. Due to small sample sizes, the effect of variables such as the child's gender, intelligence quotient, and age on the outcome of therapy has not been sufficiently explored. Nor has the transfer of any beneficial effects beyond the robotic session been sufficiently documented.

The technology, to date, is somewhat expensive for regular clinical or home use. Since the robots are customized units used in specific research studies, it will likely take additional development until they are available to the community at large. To this end, recent work by Barakova et al. (2013) proposed a participatory design process (based on reusability, modularity, affordances for natural interaction and the ease of use) to facilitate programming of robots that can encourage social skills behaviors for children with ASD. Pilot results on their TiViPE based robot control platform provide support for this usage (Barakova et al. 2013).

Discussion

The literature indicates a great potential for wider clinical and educational use of various technologies for children with ASD. It provides support for the suitability of technologies such as video modelling, SIS, VR and robotics to achieve various therapeutic and educational goals. The main objectives currently addressed by these technologies include those related to social, communication, emotional, play, and daily activity skills.

Table 10.1 Potential to achieve therapeutic/educational goals via the use of the technologies reviewed in this paper: video modeling, Shared Interactive Surfaces, virtual reality and robotics. A three point scale is used where three stars indicate that the technology has been shown to have considerable potential down to a single star indicating a paucity of evidence

	Video modeling	Shared Interactive Surfaces	Virtual reality	Robotics
Social skills	***	***	***	*
Communication	**	*	**	*
Emotional skills	***	*	*	*
Play skills	***	**	**	**
Functional activities	*	*	***	*

As reviewed above and summarized in Table 10.1, the various technologies differ in the evidence accumulated to show their ability to help children with ASD improve in the targeted skills. A three-point scale is used in Table 10.1, where three stars indicate that the technology has been shown to have considerable potential down to a single star indicating a paucity of evidence. Video modelling is currently considered to be the strongest of the available technologies in terms of evidence. Research has demonstrated its strong potential in the areas of communication, social and emotional skills but there is less evidence for its abilities concerning communication and functional activities. SIS is a relatively new area of research and has mainly focused on applications of social skills, for which it has been shown to have great potential. Virtual reality has, to date, mainly addressed social skills and functional activities (e.g., street crossing) and, to a lesser extent, communication and play skills. Although robotic technologies have been available for decades, their use for children with ASD is relatively recent and is still at an initial stage of development for clinical aims.

Parents and educators have expressed various concerns regarding the use of technology for those with ASD (Moore et al. 2000). One such major concern addresses the fear that technology may further increase social withdrawal of children who are prone to social isolation to start with. In an effort to alleviate this concern, many of the technologies are used with two or more children at the same time which may present an asset to a teacher who often needs educational tools that meet the needs of larger groups.

Researchers and clinicians have also identified various advantages that technology provides for children with ASD who appear to be nurtured by technology-oriented learning and to show improvements in many of the ASD core symptoms following technology based interventions (e.g., Dautenhahn and Weery 2004; Gal et al. 2009). The strong preference and interest that children with ASD express in technological applications, as well of the evidences of improvement in various skills following technological interventions, suggest that the use of technological based interventions have a great potential for improving participation of children and adults with ASD. As some evidence suggest, not only the direct interaction of individuals with their social and physical environments improves during such interventions but some of the interventions also have the potential to generalization, therefore improving one's involvement in life situations. Some of the interventions have the potential to a very narrow generalization only, that is generalization of the very same behavior as the specific one that was directly taught within daily life. Others have a potential to a wider generalization, namely expanding one's own repertoire of positive social communication behaviors following the innovative technology intervention.

It is important to emphasize that not only the second has the potential to affect one's participation. For some children with ASD, who have very limited repertoire of positive social behaviors, for example, the addition and exploitation of even a small new skill or positive social behavior may have a huge impact on the child's participation. Participation in the everyday occupations of life is a vital part of human development and life experience. There is a circular relationship between task achieving and participation: Not only that acquisition of new tasks may affect participation, but participation and involvement in new situation may also serve to help the individual acquiring skills and competencies, connect with others and our communities, and find purpose and meaning in life (Law 2002). Expanding the repertoire of behaviors through technologies may serve, therefore to a very meaningful change in one's life.

Nevertheless, although the literature indicates many advantages of using technology for children with ASD and its potential to improve their participation, technology has, to date, addressed only some of the key clinical challenges. This review has shown that the main applications of technology are in social interactions, play and language skills, and only a few applications address emotional issues, and daily activity skills.

Moreover, despite advances in research, clinical observation and surveys reveal that only the most basic types of technology, such as simple educational software, the Internet and videotaping, are currently in use in educational settings In contrast, VR, SIS, video modeling and robotics, are used less frequently. Teachers who work with children with ASD are often not even aware of the potential of such technologies as educational tools, and do not have the financial or technical resources to adopt them.

This gap between the potential of technological applications and their actual use can be attributed to a number of practical limitations. First, the devices are often not available to teachers, clinicians and parents due to their relatively high cost and need for technical support. Moreover, many are currently available only as research prototypes that need further development prior to adoption for everyday use. These devices, in particular, are often complex to operate since they have not yet been designed and implemented with the end user in mind.

To summarize, although the literature abounds with studies regarding the benefits of the use of technology for those with ASD, parents and clinicians remain at a loss regarding the feasibility, viability and effectiveness of technological devices. Indeed, there is an urgent need to bridge the gap between developing technological innovations and their actual use for children and adolescents with ASD, making technology more accessible for the potential use with ASD, and bringing it, when appropriate, closer to each child's individualized intervention program. In addition, such programs should provide specific guidelines to teachers as social mediators to enable them to address the type and level of facilitation, and environmental arrangement that will enhance the advantages of technology but minimize its disadvantages such as social withdrawal and perseveration. Future research, development and marketing must address these highly important goals.

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Chapter 11
A Review of Virtual Classroom Environments for Neuropsychological Assessment

Thomas D. Parsons and Albert "Skip" Rizzo

Introduction

Although traditional neuropsychological assessment approaches provide highly systematic control and delivery of performance challenges, they have also been criticized as limited in the area of ecological validity (Parsons 2015; Rizzo et al. 2004). By ecological validity, neuropsychologists mean the degree of relevance or similarity that a test or training system has relative to the real world, and in its value for predicting or improving daily functioning (Wilson et al. 1998; Chaytor et al. 2006). Adherents of this view challenge the usefulness of constrained paper-and-pencil tests and analog tasks for addressing the complex integrated functioning that is required for successful performance in the real world. Computer-based neuropsychological assessments offer a number of advantages over traditional paper-and-pencil testing: increased standardization of administration; increased accuracy of timing presentation and response latencies; ease of administration and data collection; and reliable and randomized presentation of stimuli for repeat administrations (Parsey and Schmitter-Edgecombe 2013; Parsons et al. 2018; Schatz and Browndyke 2002). However, these assessments usually take place in a highly controlled laboratory setting that does little to mimic the real world, and therefore have also been criticized as lacking ecological validity. This problem may be particularly salient in

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the assessment of individuals with neurodevelopmental disorders impacting fronto-striatal function, particularly attention-deficit hyperactivity disorder (ADHD).

Currently approaches to assessment of ADHD rely on converging lines of evidence from behavioral rating scales, paper-and-pencil cognitive assessments, and computerized measures of attention (e.g., continuous performance tasks). An unfortunate limitation to this approach is the dearth of generalizability to activities of daily living. A possible answer to the problems of ecological validity in assessment of ADHD is to immerse the participant in a virtual classroom environment. Work has been done to develop a virtual classroom that assesses executive functioning (Rizzo et al. 2006). These virtual environments have been found to offer significant advantages to more traditional methods of diagnosis and observation.

The plan of this chapter will be as follows: In Sect. 11.1, current approaches to the assessment of ADHD will be discussed. Section 11.2 will describe the use of virtual environments for the assessment of neurodevelopmental disorders. Next, in Sect. 11.3, the Virtual Classroom will be introduced. Finally, in Sect. 11.4, research conducted using the Virtual Classroom will be presented.

Attention-Deficit Hyperactivity Disorder

The neurodevelopmental disorder known as ADHD is a heterogeneous disorder of unknown etiology, which is comprised of difficulties with sustained attention, distractibility, impulse control, and hyperactivity (Biederman 2005). Researchers have proposed that ADHD arises from a core deficit in inhibitory control, resulting in multidimensional deficits in executive functioning (Barkley 1997, 2000; Scheres et al. 2004). Individuals with ADHD may have difficulty organizing behaviors, solving problems, and shifting mental sets (Schachar et al. 2000). Due to the heterogeneity of his disorder, reaching a consensus on diagnosis has proven to be challenging.

Traditional assessment of ADHD utilizes clinician-administered and self-report rating scales, including the Conner's Adult ADHD Rating Scales (Conners et al. 1999) and ADHD Rating Scale-IV (DuPaul et al. 1998). These scales, though psychometrically sound, have limited predictive validity (Lahey et al. 2006) and treatment utility (Scotti et al. 1996). Although these scales may provide insight into an individual's behavior in one or more domain, malingering and reporter bias is always a concern (Abikoff et al. 1993; Sayal and Taylor 2005). Further, structured interviews are time-consuming for both the parent and the clinician, yielding them less practical and cost-effective. Additionally, when assessing behavior changes over time, structured interviews may lose validity after the initial interview.

More recently, research has examined the assessment of executive functions in children with ADHD. The hypothesis of executive dysfunction in children with ADHD has been supported in a number of studies (Barkley et al. 1992; Grodzinsky and Barkley 1999; Schachar et al. 2000; Scheres et al. 2004). Measures that have been shown to differentiate children with ADHD from typically developing children include: the Stroop task (Barkley et al. 1992; Nigg 1999), Controlled Oral Word Association Test (Grodzinsky and Diamond 1992), and Picture Arrangement from the Wechsler Intelligence Scale for Children-III (Pineda et al. 1998). While these tests are highly validated and provide adequate predictive validity, they have also been criticized as limited in the area of ecological validity (Chaytor et al. 2006; Farias et al. 2003; Gioia and Isquith 2004; Odhuba et al. 2005; Plehn et al. 2004; Ready et al. 2001; Silver 2000). Testing usually takes place in a quiet, well-controlled environment with little if any of the distractions that are common in the real world. This lack of ecological validity may weaken predictions about real-world functioning.

Assessment of executive functioning is a principal objective of neuropsychological evaluations. These executive functions are accomplished by the supervisory attentional system and accomplish functions such as: selective attention, inhibitory control, planning, problem solving, and some aspects of short-term memory (Baddeley 1996; Baddeley and Hitch 1974; Norman and Shallice 1986; Burgess and Simons 2005; Diamond 2013). Some theories of executive functions and attentional processing consider executive functioning to be unitary construct, while others consider attentional processing to be a system of independent networks (Raz and Buhle 2006). Given that attention deficits are the basis of many pathological disorders in children and adults, it is important to understand the different facets of attentional processes as well as the anatomical sites at which they are carried out. Because deficits in executive functioning underlie many disorders, including ADHD (Rothbart and Bates 2006), it is essential to understand all aspects of executive functions as well as the underlying anatomical sites at which they are accomplished. Because different disorders result in different patterns of attentional deficits, it is imperative to be able to differentiate different attentional processes (Posner and Rothbart 2007). Novel assessments of attention are needed that can enhance ability to differentiate specific attentional processes, because different pathologies show different patterns of attentional deficits (Chaytor and Schmitter-Edgecombe 2007; Posner and Rothbart 2007).

Posner and Rothbart (2007) proposed an attention network theory, in which the human attentional system is subdivided into three functionally and anatomically independent networks: alerting, orienting, and executive attention (see also Fan et al. 2012; Posner and Petersen 1990). The Attention Network Task (ANT) is a computerized assessment of attention that was developed by Posner and colleagues to measure the three aspects of the attention network (Fan et al. 2002). The ANT combines cued detection (Posner 1980) with a flanker-type paradigm (Eriksen and Eriksen 1974) and allows for the behavioral assessment of attentional dimensions of alerting, orienting, and executive function via specific reaction time (RT) patterns (Fan et al. 2002). The ANT has been argued to hold particular promise for assessment of attention deficits in ADHD. A number of studies using the ANT have shown specific deficiencies in the alerting and executive control substystems (Johnson et al. 2008; Abbes et al. 2009). It is important to note that Adólfsdóttir et al. (2008) have argued that the ANT's main contribution to ADHD assessment is its accuracy and variability measures rather than measures of the three attention subsystems.

The ANT is also purported to be useful in distinguishing between subtypes of ADHD (Lundervold et al. 2007; Oberlin et al. 2005).

Other computer-based measures of ADHD have been developed that offer a number of advantages over traditional comprehensive self-report measures, including: enhanced cost and time effectiveness and improved usability for administrators (Nichols and Waschbusch 2004). One of the most used computerized assessments of ADHD is the Continuous Performance Test (CPT). CPT tests require participants to remain vigilant to a specific stimulus in a continuous stream of distractors (Eliason and Richman 1987). Individuals with ADHD find this protocol long and tedious, and thus it has been shown to differentiate between typically developing children and children with ADHD by assessing arousal, activation and effort (Rapport et al. 2000; Nichols and Waschbusch 2004; Corkum and Siegel 1993).

While computer-based measures are more advanced in the area of stimulus presentation and response measurement, responding to continuously presented symbols on an otherwise blank computer screen lacks the complexity individuals face in the real world. Although these neuropsychological measures have been found to have adequate predictive value, their ecological validity may diminish predictions about real-world functioning. Traditional neurocognitive measures may not replicate the diverse environment in which persons with ADHD and other neurodevelopmental disorders live. Additionally, standard neurocognitive batteries tend to examine isolated components of neuropsychological ability, which may not accurately reflect the distinct cognitive domains found in neurocognitive disorders (Dodrill 1999; Wilson 1993). Although today's neuropsychological assessment procedures are widely used, neuropsychologists have been slow to adjust to the impact of technology on their profession. While there are some computer-based neuropsychological measures (see discussion above) that offer a number of advantages over the traditional paper-and-pencil testing, the ecological validity of these computer-based neuropsychological measures is less emphasized. Only a handful of neuropsychological measures have been developed with the specific intention of tapping into everyday behaviors like interacting with a teacher and peers in a virtual school setting, navigating one's community, grocery shopping, and other activities of daily living. Of those that have been developed, even fewer make use of advances in computer technology. In summary, current diagnosis of ADHD relies on an accumulation of clinical interviews, behavior rating scales, and computerized neuropsychological tests. These instruments each lack the essential component of ecological validity necessary to make predictions about real-world functioning. Additionally, because of the heterogeneity and different presentations of this disorder, comprehensive assessment is necessary for a diagnosis of ADHD.

Assessment of Neurodevelopmental Disorders using Virtual Environments

One viable approach is to capitalize on advances in virtual reality (VR) technology. Virtual environments can provide platforms for child attention assessment and intervention that are sufficiently rich in terms of ecologically validity, while also providing scientifically rigorous control, manipulation and bio-behavioral data recording options (Rizzo et al. 1998a, b; Rizzo and Schultheis 2002; Rizzo et al. 2012, 2006). Virtual Reality is a form of human–computer interface that allows the user to "interact" with and become "immersed" in a computer-generated environment (Bohil et al. 2011; Parsons 2015; Schultheis et al. 2002). VR paradigms also allow for the sophisticated, objective, real-time measure of participants' behaviors (e.g. visual attention) and training outcomes (Rizzo and Kim 2005). Recent cost reductions in VR technologies have led to the development of more accessible, usable and clinically relevant VR applications that can be used to address a wide range of physical and cognitive ailments and conditions (Parsons et al. 2009; Rizzo et al. 1997; Rizzo and Buckwalter 1997a, b; Rizzo 2005; Schultheis and Rizzo 2001).

Virtual environment applications that focus on treatment of cognitive (Rose et al. 2005) and affective disorders (Parsons and Rizzo 2008a; Powers and Emmelkamp 2008) as well as assessment of component cognitive processes (see Neguţ et al. 2016a, b for recent meta-analyses) are now being developed and tested. Examples of recent (past 10 years) virtual reality assessments used in neuropsychological studies include: attention (Law et al. 2006; Parsons et al. 2007; Rizzo et al. 2006) spatial abilities (Beck et al. 2010; Foerster et al. 2016), episodic memory (Parsons and Rizzo 2008b; Plancher et al. 2010, 2012, 2013), prospective memory (Knight and Titov 2009), spatial memory (Goodrich-Hunsaker and Hopkins 2010; Zakzanis et al. 2009), executive functions (Armstrong et al. 2013; Denmark et al. 2017; Jovanovski et al. 2012a, b; Parsons et al. 2013; Parsons and Courtney 2014; Renison et al. 2012); and activities of daily living (Besnard et al. 2016). The increased ecological validity of neurocognitive batteries that include assessment using virtual scenarios may aid differential diagnosis and treatment planning. Within a virtual world, it is possible to systematically present cognitive tasks targeting neuropsychological performance beyond what are currently available using traditional methods (Parsons and Phillips 2016; Rizzo and Kim 2005). Reliability of neuropsychological assessment can be enhanced in virtual worlds by better control of the perceptual environment, more consistent stimulus presentation, and more precise and accurate scoring. Virtual environments may also improve the validity of neurocognitive measurements via the increased quantification of discrete behavioral responses, allowing for the identification of more specific cognitive domains (Gaggioli et al. 2009). Virtual environments could allow for neurocognition to be tested in situations that are more ecologically valid. Participants can be evaluated in an environment that simulates the real world, not a contrived testing environment (Gorini et al. 2008). Further, it offers the potential to have ecologically valid computer-based neuropsychological assessments that will move beyond traditional clinic or laboratory borders.

To review, a possible solution to problems of ecological validity in traditional assessment is to utilize technological advances in virtual reality. Advantages of virtual reality computerized testing include the following: (1) enhanced ecological validity by "immersing" the individual into an environment; (2) ability to present and control ecologically valid distractions; (3) ability to objectively record behavioral data; and (4) enhanced reliability increased control over the perceptual world and stimulus presentation. Thus far, a number of virtual environments have been tested on a number of clinical and non-clinical populations.

Assessment of Neurodevelopmental Disorders using Virtual Environments

An optimal ecologically valid approach to diagnosis and treatment of individuals with neurodevelopmental disorders may be to use VR methods to simulate classroom social-educational environments under controlled conditions (Parsons 2014). Impairments in attention are a common and debilitating occurrence in a number of clinical populations. Clinical populations affected by attention deficits include individuals with ADHD, traumatic brain injury, autism spectrum disorders, and a host of other neurodevelopmental and neurodegenerative disorders. Using VR with these populations may be particularly practical due to increased control over the procedure and fewer extraneous distractions.

The Virtual Classroom project represents a joint venture between the University of Southern California and Digital Media Works in Canada (Rizzo et al. 2006). The Virtual Classroom was designed for the study, assessment, and rehabilitation of cognitive and functional processes, particularly in clinical populations with central nervous system (CNS) dysfunction. The vision of this project saw the Classroom as way to advance the scientific study of typical cognitive and behavioral processes as well as to improve the capacity to understand, measure, and treat impairments in this clinical populations. Initially, the Virtual Classroom project focused on the assessment of attention in individuals with ADHD. Due to the heterogeneous nature of the disorder, reaching a consensus on the proper diagnosis and treatment of the disorder has proven to be difficult. Currently, assessment focuses on a number of behavior checklists given to parents and teachers. Diagnosis is made from converging evidence based on these scales. Such scales are vulnerable to a number of errors, such as reporter bias, and so may be inconsistent. Thus, the VR Classroom aims to be a reliable and objective measure of attention functioning in ADHD (Rizzo et al. 2006).

The VR Classroom employs a head-mounted display (HMD) with which individuals view the environment. HMDs are able to occlude extraneous distraction and focus the participant's attention within the VR environment where presentation of distracting auditory and visual stimuli is tightly controlled. In this way, VR is able to identify precisely when individuals make errors due to distraction, and what type of distraction precluded the error. In addition, it is possible to use a number of tracking devices on the head, arms, and legs to track movements besides head movements as a concurrent index of hyperactivity symptoms. Hence, the Virtual Classroom is able to objectively assess not only cognitive abnormalities in ADHD, but also behavioral abnormalities, effectively integrating information traditionally only available from cognitive measures and behavioral rating scales administered separately (Rizzo et al. 2006).

The Virtual Classroom utilizes a continuous performance task paradigm (CPT) commonly used in the assessment of ADHD. Participants are instructed to view a series of letters presented continuously on a blackboard. They are asked to respond via a mouse click only after they view the letter “X” preceded by the letter “A.” Emphasis is placed on speed and accuracy. Individuals with ADHD have generally been shown to make more omission errors (failing to respond to a target) and commission errors (responding to a non-target) on CPT tests. Omission error are considered indicative of inattention while commission errors are indicative of hyperactivity (Nichols and Waschbusch 2004). In the high distraction task, external interference control is also assessed. To begin the task, the participant is immersed in the classroom, and seated in a desk near the center of the classroom with a view of other children, a teacher, and a window, among other things. After instructions are communicated to participants via computer speakers, the task begins. The participants are instructed to respond via a mouse click to each target (the letter “X” preceded by the letter “A”) and to withhold a mouse click for all non-targets. The Virtual Classroom presents distractors in various areas of the classroom. Audio-visual distractors include a school bus driving by, an SUV driving by, a book dropping to the floor, children passing notes, a child raising his hand, the teacher answering the classroom door, and the principal entering the room. Visual distractors include a paper plane flying through the room. Audio distractors include the sound of paper crumpling, a pencil hitting the floor, an airplane passing overhead, a voice from the intercom, the bell ringing, a sneeze and a cough. These distractors are dispersed throughout the left, center, and middle of the classroom. An important feature of the Virtual Classroom is its ability to mimic the complexity of the real world in a controlled environment. Individuals are immersed in this environment and are surrounded by desks, children, a teacher, and a white board much like they would be in a real-world classroom. Additionally, auditory and visual distractors, much like those that would be present in the real world can be enabled or disabled, allowing the researcher to manipulate the complexity of the environment. This ability to manipulate complexity in a virtual environment allows neuropsychologists to generalize results of these standard tests to an individual’s real-world functioning.

The Virtual Classroom for ADHD

As mentioned above, current approaches to assessment of ADHD rely on converging lines of evidence from behavioral rating scales, paper-and-pencil cognitive assessments, and computerized measures of attention (e.g., continuous performance tasks). These approaches are limited in their generalizability to activities of daily living. A possible answer to the problems of ecological validity in assessment of ADHD is to immerse the participant in a virtual classroom environment. Work has been done to develop a virtual classroom that assesses executive functioning (Rizzo et al. 2006). These virtual environments have been found to offer significant advantages to more traditional methods of diagnosis and observation.

In an initial clinical trial of the Virtual Classroom, Parsons et al. (2007) compared performance of ten children with ADHD with ten typically developing children. In this study, children with ADHD performed differently from typically developing children in a number of different ways: (1) children with ADHD made more commission and omission errors (2) children with ADHD exhibited more overall body movement; and (3) children with ADHD were more impacted by distracting stimuli. Additionally, performance measures in the VR Classroom were significantly correlated with traditional measures and behavior checklists (Parsons et al. 2007). Thus, the Virtual Classroom was able to assess not only attentional abnormalities but also behavioral abnormalities concurrently.

Another study of ADHD using the Virtual Classroom focused on distractibility in ADHD. Nineteen adolescent boys with ADHD and sixteen age-matched typically developing adolescents were compared on performance in the Virtual Classroom CPT with and without real-world distractors and on a traditional CPT without distractors. The Virtual Classroom was able to distinguish between ADHD and control groups more so than the traditional CPT, with adolescents with ADHD committing more commission errors and overall errors. Additionally, the Virtual Classroom was more specific, correctly identifying 87.5% of controls, compared to only 68.8% in the standard CPT. Additionally, ecologically valid distractors presented in the task seemed to have a greater impact on the adolescents with ADHD compared to those without. Adam et al. attributed poorer performance in the ADHD group to these distractions, explaining the adolescents with ADHD were less able to cope with the novelty of the situation than those in the control group (2009).

Pollak et al. investigated the use of the Virtual Classroom in assessing the effect of methylphenidate (MPH), a drug used in the treatment of ADHD. Twenty-seven children with ADHD completed the Virtual Classroom CPT, the traditional CPT, and the Test of Variables of Attention (TOVA). These children were divided into MPH and non-MPH (placebo) groups. Ingestion of MPH decreased omission errors in all measures; however, compared to the TOVA and traditional CPT, ingestion of MPH reduced omission errors in the Virtual Classroom to a greater degree. These results suggest the Virtual Classroom may be more sensitive to attention deficits than traditional measures. Additionally, children rated the Virtual Classroom to be more enjoyable than either the TOVA or the traditional CPT (2010). See Table 11.1 for some examples of recent studies using this Virtual Classroom.

The Virtual Classroom Extended

The Virtual Classroom has also been used in study assessing attention in adolescents with sports concussions. Twenty-five sports-concussed adolescents were compared with twenty-five non-sports-concussed adolescents in the Virtual Classroom and on a traditional CPT task. The Virtual Classroom proved to have greater sensitivity in detecting subtle attention deficits due to the sports concussion

Table 11.1 Recent virtual classroom studies

Study	Sample	Research design and traditional tests	Results
Adams et al. (2009)	Sample included 35 boys ages 8–14 years. 19 participants with ADHD were compared to 16 age-matched controls.	Research Design: Comparison of participant performance on the Continuous Performance Test with and without the Virtual Classroom.	Findings revealed greater specificity for Virtual Classroom CPT.
		Traditional tests included: Behavior Assessment System for Children (BASC)	While differences between the two groups were not significant, a significant trend was observed for correct target identification and commission errors.
		VIGIL continuous performance test	
Bioulac et al. (2012)	Sample included 36 boys ages 7–10 years. 20 participants with ADHD were compared to 16 age-matched controls.	Research Design: ADHD and controls children were first tested with the traditional computerized CPT. After 10 min they were tested with the virtual CPT.	Findings revealed that ADHD participants showed a significant performance decrement, as well as a decrease in the number of correct hits. They were also slower with increased reaction time.
		Traditional tests included: Continuous Performance Test (CPT II).	Findings also revealed that ADHD children performed worse than controls on both the Virtual Classroom CPT and the traditional computerized CPT.
		Conners' parents rating scale	
		Child behavior check list	
		State Trait Inventory Anxiety Inventory	
Gilboa et al. (2011)	Sample included 54. 29 with Neurofibromatosis type 1 (NF1). 69% female; mean age 12.2). 25 controls 72% female; mean age = 12.2).	Research Design: Comparison of Virtual CPT and the traditional tests. Cross sectional design.	Findings revealed significant differences between the NF1 and controls on omission errors and commission errors in the Virtual Classroom CPT.
		Traditional tests included: Conners' parent rating scales —revised:	Poorer performance was found in NF1 children.
			Significant correlations were found between number of targets correctly identified, the number of commission errors, and reaction time.

(continued)

Table 11.1 (continued)

Study	Sample	Research design and traditional tests	Results
Gilboa et al. (2015)	Sample included 76. 41 children ages 8–16 with acquired brain injury. 35 age- and gender-matched controls.	Research Design: Cross-sectional design.	Findings revealed significant between group differences for number of targets correctly identified in the Virtual Classroom CPT.
		Traditional tests included: Test of everyday attention for children	Furthermore, 45% of the children with ABI suffered marked deficits in sustained attention on the Virtual Classroom CPT.
		Wechsler abbreviated scale of intelligence (Matrix reasoning and vocabulary)	
		Conners parent rating scales—revised	Attentional performance was found to be related to age, age at injury/ diagnosis and treatment.
Lalonde et al. (2013)	Sample included 38 adolescents ages 13–17 years.	Research Design: Descriptive/correlational study of a Virtual Classroom Stroop task. Convergence validity study.	Findings revealed that the Virtual classroom Stroop task correlated with D-KEFS and BRIEF.
			Performance on the Virtual Classroom Stroop task was correlated with paper–pencil Stroop task.
		Traditional tests included: Delis–Kaplan executive function system (Trail making, tower, twenty questions, verbal fluency, color-word interference)	VR classroom Stroop more accurately reflected everyday behavioral functioning.
		Behavior rating inventory of executive function	
		Child behavior checklist	
Nolin et al. (2009)	Sample included 8 children with acquired brain injury, ages 8–12 years.	Research Design: Repeated measures comparisons.	Findings revealed no difference between the Virtual Classroom CPT and the traditional computerized CPT on total of omissions.
		Traditional tests included: VIGIL continuous performance test	Significantly more commissions and longer reaction times in the Virtual Classroom CPT.
Nolin et al. (2012)	Sample included 50 participants. There were 25 sports-concussed and 25 matched control adolescents.	Research Design: Comparison of the traditional CPT and Virtual CPT was	Findings revealed that the Virtual Classroom CPT showed greater sensitivity to the subtle effects of sports concussion.
		counterbalanced across participants.	It is important to note that the sports concussion group reported more symptoms of cybersickness than the control group.
		Traditional tests included: VIGIL continuous performance test	

Parsons et al. (2007)	Sample included 20 participants with 10 boys diagnosed with ADHD and 10 matched controls.	Research Design: Intergroup comparison of participants with ADHD and normal controls.	Findings revealed ADHD group exhibited more omission errors, commission errors, and overall body movement in the Virtual Classroom CPT.
		Traditional tests included: SWAN Behavior Checklist	ADHD group was more impacted by distraction in the Virtual Classroom CPT.
		Conners' CPT II	Virtual classroom CPT was correlated with traditional ADHD assessment tools, behavior checklist, and traditional computerized CPT.
		Stroop	
		Trail making tests	
		NEPSY (Visual attention, design fluency, verbal fluency)	
		WISC-III (Digit Span, coding, arithmetic, vocabulary)	
		Judgement of line orientation	
Parsons and Carlew (2016)	Two Studies reported—Study #1: Sample included 50 undergraduate students (mean	Research Design: Two studies: Normative study and a clinical study	Findings revealed that the Virtual Classroom Stroop task was correlated with traditional tasks and elicited an interference effect similar to those found in classic Stroop tasks.
		Study #1: Normative study comparing Virtual Stroop to traditional tasks.	During the distraction condition of the Virtual Classroom Stroop the ASD group performance declined.
	age = 20.37; 78% female).	Study #2: Cross sectional design.	
	Study #2: Sample included 8 students with high functioning autism (mean age = 22.88) and 10 matched controls.	Traditional tests included: Wechsler test of adult reading	
		Delis-Kaplan executive functioning system: Color word interference test	
		Stroop task from automated neuropsychological assessment metrics	
		Wechsler abbreviated scale of intelligence- Second edition	
Pollak et al. (2009)	Sample included 37 boys ages 9–17 years, with (n = 20) and without ADHD (n = 17).	Research Design: Crossover design comparing Virtual Classroom on regular computer screen.	Findings revealed ADHD group performed less well on all CPT tasks.
			Virtual classroom CPT showed effect sizes similar to the TOVA.
		Traditional tests included: Test of Variables of Attention – TOVA	Self-reported preference for Virtual CPT.
		Short feedback questionnaire	

(continued)

Table 11.1 (continued)

Study	Sample	Research design and traditional tests	Results
Pollak et al. (2010)	Sample included 27 16 boys and 11 girls, with clinical diagnosis of ADHD.	Research Design: Double-blind, placebo-controlled, crossover design.	Findings revealed that metilphenidate (MPH) reduced omission errors to a greater extent on the Virtual classroom CPT compared to the no Virtual classroom CPT and the TOVA, and decreased other CPT measures on all types of CPT to a similar degree.
		Traditional tests included: Test of Variables of Attention – TOVA	Children rated the Virtual Classroom CPT as more enjoyable compared to the other types of CPT.

than did the traditional CPT, detecting a significantly higher number of head movements and commission errors in the adolescents with a sports concussion than in those without (Nolin et al. 2012).

Gilboa et al. utilized the Virtual Classroom to assess attention deficits in children with Neurofibromatosis type 1 (NFI), an inherited neurological disorder with symptoms including attention deficits (2011). NF1 is highly comorbid with ADHD, with 30–50% of individuals meeting diagnostic criteria for both (Keyhan et al. 2006). Twenty-nine children with NF1 and 25 typically developing children completed the Virtual Classroom CPT and the Conners' Parent Rating Scales-Revised: Long (CPRS = R:L; Conners 1997), a questionnaire used to assess ADHD. Children with NF1 performed significantly poorer than typically developing children making more commission and omission errors. Additionally, significant correlations between the rating scale and performance on the Virtual Classroom were observed (Gilboa et al. 2011).

Researchers at the University of Victoria have developed a version of the VR Classroom capable of measuring interference control via the Stroop task. The Stroop task is widely used and well-replicated task which requires participants to inhibit a prepotent response to read the name of a color and name the conflicting ink color it is printed in. In a validity study, the VR Classroom Stroop task elicited similar "interference effects" to the traditional Stroop task. Reaction times to the VR Classroom Stroop were slower overall, possibly due to the increased processing demand. Nevertheless, the VR Classroom Stroop proved to be a valid assessment of interference control (Rizzo et al. 2006). Recently, Parsons and Carlew (2016) applied the Virtual Classroom Stroop task to compare performances between persons with autism spectrum disorder and typically developing participants. While significant differences were not observed between persons with autism spectrum disorder and neurotypical participants on the paper-and-pencil and computerized Stroop tasks, persons with autism spectrum disorder performed significantly worse on the Virtual Classroom Stroop task when distractors were present. These findings suggest the potential of the Virtual Classroom Stroop task to distinguish between prepotent response inhibition (non-distraction condition) and resistance to distractor inhibition (distraction condition) in participants with high functioning autism.

In sum, research suggests the Virtual Classroom is an ecologically valid, highly specific, and enjoyable assessment of attention deficits in multiple populations. Performance on the Virtual Classroom has been correlated with many other well-validated measures of attention including the CPT, TOVA, and behavioral rating scales. Future research should assess a broad range of populations. Additionally, the Virtual Classroom has been expanded beyond the CPT to include a Stroop task. Further development of the Virtual Classroom seeks to expand the clinical utility of the Virtual Classroom beyond executive assessment to rehabilitation and therapy.

Conclusions

This chapter reviewed the ways in which previous research has most often relied on paper-and-pencil and computerized psychometric tests of executive functions. Again, although these approaches provide highly systematic controlled and delivery of performance challenges, they have also been criticized as limited in the area of ecological validity. A possible answer to the problems of ecological validity in assessment of executive functioning is to immerse the child in a virtual classroom environment.

Virtual reality technology is able to replicate real world environments and present standardized neuropsychological tasks within those environments. Additionally, controlled presentation of real-world distractions is possible. These capabilities enhance ecological validity by immersing individuals in a controlled environment that mimics their every-day life to complete neuropsychological assessments. It follows that the results of these assessments are more generalizable and more closely representative of an individual's real world functioning.

The Virtual Classroom was initially developed as an assessment of attention functioning in ADHD. A number of preliminary studies have confirmed its utility for this purpose. The Virtual Classroom is able to distinguish children with ADHD from normal controls on the basis their performance on a CPT test embedded within the environment as well as from behavioral data. Additionally, participants reported enjoying the Virtual Classroom more than the standard CPT.

The Virtual Classroom has been expanded for use in different populations, and also has been expanded to include different neuropsychological task (e.g. the Stroop task). Because initial success has been obtained in these studies, use of the Virtual Classroom should be explored in other populations as well. One possible population in which the Virtual Classroom may be particularly useful is individuals with autism spectrum disorder (ASD). Due to the high overlap between symptoms ADHD and ASD, reliable and specific diagnosis is crucial. Special considerations should be made due to the sensory issues of many individuals with ASD. Consequently, future research in virtual reality technology should investigate a less invasive method of presenting the virtual environment than HMDs.

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Chapter 12
Developmental and Learning Disabilities

P. J. Standen and David J. Brown

Introduction

People with developmental disabilities are usually one of the last groups to benefit from advances in technology yet special education was quick to adopt information technology even providing exemplars for mainstream education (Lilley 2004). Educational virtual environments were being developed in special schools and adult training centres when virtual reality was still a novel technology in education (Standen and Brown 2004, 2005, 2006). Virtual environments had many characteristics that suited them perfectly to applications for people with developmental disabilities. This explains why they were so readily adopted. However, technology has moved on rapidly since those days with information technology providing smaller, cheaper and mobile solutions. People with developmental disabilities are still collaborating with researchers in the development of novel applications using the most recent technology. This chapter will review the work on new technologies that have been developed for first of all training and education and secondly for therapy and rehabilitation.

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Dealing with the Terminology

The term "developmental disability" or "disabilities" is used in the United States and Canada to refer to a diverse group of severe chronic conditions that are due to mental and physical impairments. According to the Center for Disease Control and Prevention (http://www.cdc.gov/ncbddd/dd/), people with developmental disabilities have problems with major life activities such as language, mobility, learning, self-help, and independent living. While most are associated with pre or perinatal incidents, developmental disabilities can begin anytime during development up to 18 years of age and usually last throughout a person's lifetime. A small proportion are the result of chromosomal or genetic abnormalities but other likely explanations are brain injury or infection before, during or after birth; extreme prematurity; poor intrauterine environment resulting from poor maternal diet, substance abuse or smoking during pregnancy. For most no cause will be identified. Because of the vulnerability of the nervous system during development, these causative factors can result in complex impairments. Most of this group will experience intellectual disabilities (ID) but other major conditions that may co-exist with ID are cerebral palsy, sensory impairments and autistic spectrum disorders. Because the majority of people in this group can be considered to have intellectual disabilities, both terms have been used interchangeably in this chapter.

Developmental disabilities are estimated to affect between 1 and 2% of the population in most western countries, although the accuracy of this is hard to determine. In the UK it is estimated that only 21.6% of people with intellectual disabilities are known to services (Emerson et al. 2011). What is known is that the number of people with intellectual disabilities is increasing. Emerson and Hatton (2008), examining UK figures, conclude that there will be sustained growth in the need for social care services for adults with intellectual disabilities over the period 2009–2026. They estimate that support will need to be provided to between an additional 47,000 (34%)–113,000 (82%) adults over the next 10 years. They identify three demographic changes driving this increase: decreasing mortality among people with intellectual disabilities, especially in older age ranges and among children with severe and complex needs; the impact of changes in fertility over the past two decades in the general population and the ageing of the 'baby boomers', among whom there appears to be an increased incidence of intellectual disabilities. Silverman et al. (1998) have projected that in the United States the number of adults over the age of 65 with intellectual disabilities could reach between 700,000 and 4,000,000 people by 2030. Combine these predictions with other changes in western society such as an increase in lone parent families, increasing rates of maternal employment and an increase in the percentage of older people with intellectual disabilities whose parents are likely to have died or be very frail, and there is a predicted reduced capacity of informal support networks to provide care. At the same time current policy in Europe and North America is designed to enable people with intellectual disabilities to have as much choice and control as possible over their lives, be involved in their communities and to make a valued contribution to the world at work. Consequently there is a real need to find new ways of supporting people with intellectual or developmental disabilities.

A Quick Jog Through the History of Changing Technology

The rapid changes seen recently in information technology need to be appreciated to understand the role virtual reality and associated technologies have played in the lives of people with developmental disabilities. Back in the 1990s, the implications of the demographic and policy changes described above were not so urgent. There was optimism in education both mainstream and special education and the growth in information technology contributed to this. One of the first developments in which people with developmental disabilities played a significant role was the use of virtual environments in order to learn a skill. Virtual environments are usually described as computer generated three dimensional environments that can be explored and interacted with in real time. Computers were already being adopted as an aid to learning in mainstream education and were seen by some educators as having the potential to revolutionise special education. Their interactivity would encourage active involvement in learning and give the experience of control over the learning process. Learners could work at their own pace. They could make as many mistakes as they wanted without irritating others and the computer would not tire of the learner attempting the same task over and over again, nor get impatient because they are slow or engrossed in particular details.

In addition to these advantages of computer supported education and training, desk top virtual environments were seen as possessing characteristics that made them particularly appropriate for people with developmental disabilities (Cromby et al. 1996). Because virtual environments could portray real world scenarios they created the opportunity for people with developmental disabilities to learn skills by making mistakes but without suffering the real, humiliating or dangerous consequences of their errors. People with developmental disabilities are often denied real-world experiences which might promote their further development because their carers are apprehensive of the consequences of allowing them to do things on their own. Accompanied visits to a real environment sufficient to learn a skill may be impossible to arrange. However, in the virtual environment they can go where they like even if they have a mobility problem. Virtual worlds can be manipulated in ways the real world cannot be. In the real world, the learner can be provided with “scaffolding” (for example, human support, or self-help manuals) because the world itself cannot be changed. As the learner becomes familiar with elements of the task the scaffolding or training support is removed little by little. Finally, when the task is completely learned, all scaffolding will have been removed and the learner is doing the job without assistance. In a virtual environment, however, worlds can be constructed in any way the designer or teacher requires. A simple world could be constructed first, for example and as the user becomes more familiar with the tasks, more complex worlds can be substituted. For people with no or limited grasp of language, virtual environments have another advantage: rules and abstract concepts can be conveyed without the use of language or other symbol systems. According to Bricken (1991) virtual environments have their own ‘natural semantics’ in that the qualities of objects can be discovered by interacting with them. For example, when crossing the road in a virtual environment, the learner does not have to grasp the conditional statement: 'If you cross when the light is red you may get hit by a car.' They can learn what happens if they cross at the wrong time by experiencing the virtual version of the consequences. Virtual environments can thus be used to facilitate concept attainment through practical activity.

There was a flurry of publications describing the creation and evaluation of virtual environments for people with developmental disabilities (for reviews see Standen and Brown 2004, 2005, 2006) but as with other applications of virtual reality, it fell out of favour. When considering the more widespread application of virtual reality Rizzo (2002) writes that the "expectation-to-delivery" ratio was imbalanced and "the real thing never quite lived up to expectations generated by initial media hype" (p567). One of the reasons for the failure of virtual reality to deliver was that the state of technology at the time was not sufficiently advanced (Barry and Phillips 2002). Intentions were way ahead of the technology available but in the mid 1990s computing power took off and although this permitted more sophisticated virtual environments, the games market drove developments in more realistic depictions of environments and people. Mobile phones appeared, shrank in size and became ubiquitous.

Many of the early applications of information technology for people with developmental disabilities depended on desktop computers. While there is still a role for this mode of delivery in education and entertainment especially for the low cost experience of three dimensional virtual environments, advances in technology have meant that the inevitable progression in miniaturisation has allowed individuals to carry their computing power around with them. This has resulted in the use of laptops, notebooks and personal digital assistants (PDAs). Lower cost smart phones are available with media player, camera, high-resolution touchscreen, web browser, GPS navigation, Wi-Fi and mobile broadband access. People with developmental disabilities recognise the significance of this particular technology and the status it carries with their peers so find them highly desirable. While handheld devices can pose serious challenges for some learners with disabilities especially if they have poor vision or dexterity, these devices are already being employed in applications for people with developmental disabilities. The games industry has also had an influence through either the use of off the shelf products such as Nintendo's Wii, Microsoft's Kinect or through making possible low cost methods of data capture through for example infra red or to capture EEG to control a computer. The recent appearance of commercially available, lightweight, head mounted devices ushers in an era of new possibilities for the use of immersive VR with people with developmental disabilities. Early testing has proved promising but only for those with more mild disabilities. Freina and Canessa (2015) designed an educational game for children with mild intellectual impairment after conducting a small pilot into the acceptability of an HMD for these participants. Nine intellectually impaired young adults tried to wear the Oculus Rift while walking around a virtual town. Only two showed distress and took it off before the end of the session. The rest "managed to wear it without major distress". Gelsomini et al. (2016) tried out their system with 5 children described as having either minor forms of intellectual and developmental disability or medium-functioning autism. One of the therapists involved in the study reported that the immersion was a pleasant experience for every child.

All the studies reviewed here demonstrate the wide range of applications for which the technology has been utilised and will be grouped according to their aim rather than the technology employed: training and learning new skills to promote independence and employment and rehabilitation and therapy.

Training and Learning New Skills to Promote Independence and Employment

One of the largest drivers for the early work using three dimensional environments was the need to provide a more effective way of supporting the acquisition of skills to support independence and employment. Because they could depict real world environments, virtual environments lent themselves perfectly to the acquisition of such skills. As an example, one of the first studies to evaluate the use of VE to teach skills for daily living used a small randomised control study and found that school aged students with intellectual disabilities could learn to find items from a pictorial shopping list and take them to the check out in the virtual supermarket and that the skills learnt in a virtual supermarket would transfer to the real world (Standen et al. 1998). Much of the earlier work has been reviewed elsewhere so the reader is directed to already published reviews of this work (Standen and Brown 2004, 2005, 2006). More recent work can be grouped into either vocational training and employment skills or the promotion of what are normally described as classroom skills such as mathematical skills. However, sometimes it is difficult to describe studies as falling exclusively into one of these categories.

One of the few recent references to the use of a virtual environment for one of these purposes was reported by Loup-Escande et al. (2012) who described an environment that was designed to teach washing dishes. Their study did not evaluate the effectiveness of this as an intervention for promoting employability skills but instead compared two interaction techniques, a mouse and a touchscreen, for performing the task in a virtual environment by individuals with intellectual disabilities. They found that the touchscreen allowed better performance and was more acceptable than the mouse.

A second application of a 3D simulation was used in a European wide project (Sik Lányi et al. 2012) that developed a virtual learning environment (VLE) with computer games to teach employment skills to young people with intellectual disabilities and additional sensory impairments. The advantages of employing games in education and training are dealt with in another volume (ref to our chapter in David and Eva's book) and will not be described here. However, the characteristics of games thought to promote learning were the motivation behind the project. The games were designed to help users learn how to prepare themselves for work and deal with everyday situations at work, including money management and travelling independently. The games were Flash based but the VLE included a 3D Work Tour that simulated the first days at work allowing the user to run through a generic office layout that included workspaces and restroom as well as avatars representing line managers and colleagues. This 3D work tour was implemented by 'modding' the source engine that was used to produce the Half Life 2 game. Included also was a 3D virtual supermarket designed to help teach students about money management skills. The difference between this environment and those described in earlier studies is that it is highly structured to promote skill acquisition, rather than to allow learning through discovery. When the user enters the supermarket they receive a virtual wallet, shopping list and shopping trolley. The task is to buy all the items on the list and tender the correct money. The user receives feedback from the cashier and the cash register. No full evaluations of this VLE have yet been published.

Savidis et al. (2007) designed two computer games for people with intellectual disabilities in Crete to help their users acquire employment skills. The games were based on the classic space invaders and pong arcade games but were produced in an accessible and highly configurable format. They were included in a software package that also included two training applications. The first was designed to train people with intellectual disabilities for the role of cashier management in a typical canteen. The second was a multimedia sewing tutorial application to learn to complete typical sewing tasks with a real sewing machine. The authors hoped that by supplementing the training applications with the two games they would not only motivate the learners but improve their basic kinaesthetic skills, orientation capabilities, short term strategic thinking, decision making and self esteem. Exposing learners to the games as well as the two training applications was intended to have an amplifying effect and support faster learning cycles. The small number of cases studies they report gave encouragement to this approach but interestingly the authors concluded that the way to ensure motivation to play a game over and over again would be to make the computer game mimic the characteristics of board games that are played by whole families or other "restricted social groups" (p 415).

The potential of serious games for people with developmental disabilities will be dealt with in more detail in the other volume but it is worth highlighting briefly here two further examples of how games can be employed to support the learning of skills. Brown et al. (2011) observed an improvement in the understanding of fractions in school aged students with intellectual disabilities when compared to a control group after several sessions playing the Tetris like game described in Standen et al. (2009b). This game was delivered on a conventional desktop computer. Although designed for low-achieving mainstream students, it is also worth drawing attention to a study reported by Pareto (2012) on a game designed specifically to improve mathematical skills through graphical intuitive representation. She created an augmented reality version of a card and board game where mathematical concepts are represented graphically. The augmented reality version involved interactive whiteboards and 3D cubes which players had to move to form the answer to the questions. Additionally players had to work in collaborative pairs. The evaluation included students with intellectual disabilities and showed gains in their mathematical understanding, strategic thinking and communication.

Collaborative learning lends itself readily to the new technologies available. While improvements in communication were not the primary aim in the study by Pareto (2012), Battocchi et al. (2010) deliberately set out to see whether collaborative game playing could be successfully employed to enhance social interaction in young people with autism. They used a collaborative puzzle game with boys with Autistic Spectrum Disorder (ASD) and those with typical development. This table-top game promotes collaboration since, in order to be moved, digital puzzle pieces must be touched and dragged simultaneously by the two players. Actions on digital objects can be performed only through the simultaneous touch of two or more users. For children with ASD, the game was effective in triggering behaviours associated with co-ordination of the task and negotiation.

These two studies have highlighted the importance of social and communication skills in promoting independence. Mobile devices also have a role to play here as their characteristics can be used to support communication. Rodríguez-Fórtiz et al. (2009) developed an augmentative and alternative communication application for mobile devices to enable students with severe communication disorders to participate in instructional activities alongside their non-disabled peers. Van der Meer et al. (2011) have been using the iPod as a communication device for individuals with developmental disabilities who lack speech. They successfully taught two of their three participants to request snacks and toys by selecting graphic symbols on an iPod Touch.

While previous examples have described the acquisition of quite complex behaviours, it is often something simple that can enable someone to become more independent. One of the first uses proposed for mobile devices was in prompting individuals to complete everyday tasks. The pioneers here were Vanderheiden and Cress (1992) who proposed a device called the Companion which, in the days before miniaturized mobile phones, they described as a pocket computer incorporating a real time clock, speech synthesis and a GPS link, which people with intellectual disabilities could use to help them live more independently. As well as a navigation device it could remind the user to carry out tasks in the right sequence and thus help them perform in jobs which would otherwise be beyond them. With modern, less expensive devices this approach has been resurrected particularly for young people with autism. As part of a programme to improve employability, Burke et al. (2010) adapted a standard iPhone application to provide performance cues to teach fire safety to six young adults on the Autism Spectrum. The cues were displayed on an iPod which assistants controlled using an iPhone. Although a small study, results suggested that this system was more effective than behavioural skills training alone and it received high satisfaction ratings from both learners and their parents.

A more ambitious approach was adopted by Gentry et al. (2010) who trained 22 young people with autism to enter appointments, medication schedules, homework assignments, home chore schedules and other items from paper-based calendars to a PDA, appending a reminder alarm. At the end of an 8 week period they all appeared to be entering new appointments adequately although there was great variation in the number of appointments within the group. While there was no control group, at 8 weeks, performance on a self-assessment of occupational performance (the Canadian Occupational Performance Measure (COPM)) was statistically significantly improved from baseline. It is not clear what the level of cognitive ability of this group was: they were described as having a diagnosis of autism and exhibiting difficulties in performing everyday tasks due to cognitive-behavioral problems. However, participants reported that the device had improved their independence in performing functional activities and this suggests that such an approach would be worth exploring for those with a greater degree of intellectual disability.

It was with the intention of helping this particular group that Brown et al. (2010) developed RouteMate. Based on the Android Operating System from Google, it exploits the mobile phone's location tracking to help people with intellectual disabilities plan and rehearse new routes and then to carry these out independently in a safe manner. Mobile route guidance systems are in common use by vehicle drivers and have formed the basis of systems used in research projects to aid route following (eg Lemoncello et al. 2010). However, although such systems obviously reduce the mental load for drivers, their use suppresses the development of cognitive or mental maps. These are important for users with disabilities as conventional route guidance does not help when the traveller gets lost and wants to get back on track or just wants to get back to the starting point (Lindström 2007). Consequently RouteMate was designed to promote route learning rather than provide route guidance and thus facilitate the development of cognitive maps.

Because of its ability to locate the position of the user, the device can track the user's performance on previously trained routes and can indicate significant divergence from the planned route in terms of time or distance. This has two advantages. First of all, this can trigger an alarm to the user and then offer advice for correction. However, it can also automatically text the user's GPS position with a street name to a nominated other's mobile device, or call a nominated helper to help them conversationally to navigate to safety. Parents and caregivers of young people with intellectual disabilities, conscious of the widening gap between their child's capabilities and those of their non-disabled peers, feel they need to protect their child for longer and do not feel able to allow them the degree of independence allowed to their other children. For them, the possibility of receiving an alarm allows them the option of taking remedial action perhaps by giving advice over the phone to navigate to safety. Users with disabilities often stress the importance of having some way to locate themselves when they can no longer orientate themselves during a journey (Lindström 2007). It was hoped that this facility might lead parents and carers to feel that they could allow the person in their care a greater degree of independence.

An evaluation of RouteMate was reported by Brown et al. (2013). Eight young people with intellectual disabilities preparing to leave school first used RouteMate in a heavily scaffolded mode (with additional prompts of where to go next and what to do next) and subsequently with these prompts removed. There were significantly less navigational errors made with the more independent usage of the device, and less help required than in the earlier training stages indicating that with practice participants can use RouteMate to develop increasingly more effective navigational skills and do so more independently. In a qualitative study 43 case studies were carried out in 4 partner countries in 5 testing centres. All sites reported increases in measures such as confidence, engagement, self-esteem using the STAR Outcomes Model over three repeated sessions of using the RouteMate app in an increasingly independent manner.

Another advantage of mobile devices is that they can support learning in any environment the learner chooses. While desktop computing limited the delivery of material to a particular indoor location, with a mobile device learning can be undertaken precisely in the context in which it is to be used with a close relationship between the learning experience and the situation in which the learning need arises (Naismith et al. 2004). Ensuring that learning takes place in a context similar to that in which it is required is particularly important for a target audience described as 'concrete thinkers' whose performance is characterised as rigid, context dependent or as blind rule following and for whom generalisation of learnt skills from one setting to another is unreliable (Gow et al. 1990). Moving the environment of learning to a real world and real time context might also help to compensate for the poor memory skills often associated with this target audience (Burack and Zigler 1990). Recognising the social dimension of learning, students may perform the exercises cooperatively with peers who may be in diverse physical locations and classroom teaching can be complemented through facilitating the participation of families.

A straightforward version of mobile learning is to produce learning materials for a mobile device and allow the learner to access the materials wherever is best for them. This was the approach taken by Nordness et al. (2011) who report some preliminary results from a maths application for a hand-held computing device. They report an improvement in the subtraction skills of three individual second grade students described as having learning and behavioral disabilities.

Two further examples demonstrate how the wider attributes of mobile technology can be exploited to support learning. Schelhowe and Zare (2009) created a mobile application for people with mild to severe intellectual disabilities which could be personalised to an individual's profile by downloading learning materials from a server to a mobile device. It permitted a flexible learning speed but the user profile could not be reconfigured once it had been set. The second example was described by Fernández-López et al. (2013) and consisted of a platform for learning materials for display on the iPod touch, iPhone and iPad for users with special needs. They describe four learning activities, Association, Puzzle, Sorting and Exploration which could be personalised and played individually or cooperatively but learners would only interact with those activities that the teachers decided should be presented to them. They carried out a single group pre and post test evaluation with 39 students with special education needs and found an improvement in basic skills in language, mathematics, environmental awareness, autonomy and social skills.

Rehabilitation and Therapy

The use of the term rehabilitation is sometimes unexpected in the context of a life-long condition such as having developmental disabilities as it seems to imply that the aim of therapy is to reattain a state that the individual previously occupied for example before having a stroke or a traumatic brain injury. However, it is used here in a way that is becoming more commonly accepted and that is to lessen the impact of disease and disability on everyday life and to assist people in reaching their fullest potential. Unsurprisingly, most of the studies reviewed focus on cognitive skills although there is a growing body of work on physical activity and motor rehabilitation.

Recent commercial software developments claim to improve cognitive abilities and are especially targeted at alleviating the fears of those in middle age about impending senility. There is some evidence to suggest this approach is worth investigating. There have certainly been some positive effects observed in college aged students. Green and Bavelier (2003) found that after playing action video games, college students had an increased ability to monitor more objects in their visual field and do so faster than a person who does not play such games. A later study (Green and Bavelier 2007) demonstrated that the improvements observed could be explained not only by changes in strategy but also by changes in fundamental aspects of visual processing. According to Mahncke et al. (2006a) the brain is adaptive at any age and has a lifelong capacity to refine spatial or temporal features of sensory inputs or of movements. This conclusion was based on work with rats but Mahncke and colleagues also reviewed several studies reporting improvements in language-related cognitive abilities, verbal memory, and processing efficiency in children and young adults who had undergone brain plasticity-based training. Their own randomised, controlled trial (Mahncke et al. 2006b) of 182 participants aged over 60 resulted in significant improvements in assessments directly related to the training tasks and memory enhancement was sustained after a 3 month no-contact follow-up period.

Using similar interventions, there have been several attempts to discover whether this approach might benefit people with intellectual disabilities. The specific consideration of games for people with intellectual disabilities is dealt with in another volume (ref to other chapter in Eva and David's book). However, there have been a handful of explorations of their effect on cognitive skills. Standen et al. (2009a) assessed the effect on choice reaction time of playing a switch-controlled computer game with a time limit for responses. They found a significant decrease in choice reaction time in the intervention group compared to the control group who, for the same amount of time, played a game with no time limit. In a different study, Standen et al. (2009b) investigated whether computer games may give people with intellectual disabilities the opportunity to practice the underlying components of decision-making, a skill in which they can experience difficulties. After repeated sessions playing a Tetris-like game, the intervention group showed a significant improvement in two paper-based tests of decision-making. The decrease observed in the control group failed to reach significance.

Memory is frequently cited by authors as an area with which people with developmental disabilities need help and it is one to which computer software readily lends itself as an intervention. Both Brown et al. (2008) and Van der Molen et al. (2010) report encouraging evidence that memory skills of young people with intellectual disabilities can be enhanced through playing computer games. The latter study was perhaps the most rigorous of all those reported in this area. A total of 95 adolescents aged between 13 and 16 with mild to borderline intellectual disabilities (IQs between 55 and 85) were randomly assigned to one of three groups. These were either training adaptive to each child's progress in working memory, non-adaptive working memory training, or to a control group who played a game similar in appearance to one of those played by the intervention group but in a version which did not require any practice of memory skills. Participants trained for 6 min three times a week for 5 weeks. Outcome measures were taken before and after the 5 week training period and again 10 weeks after. Verbal short-term memory improved significantly from pre- to post-testing in the group who received the adaptive training compared with the control group and this was maintained at follow-up. An intriguing additional finding was that both intervention groups had higher scores at the 10 week follow-up than at post-intervention on visual short term memory, arithmetic and story recall compared with the control condition. In addition, the non-adaptive training group showed a significant increase in visuo-spatial memory. By way of explanation, the authors cite Holmes et al. (2009) who found a similar effect in typically developing children 'as any improved cognitive support for learning caused by training would be expected to take some time to work its way through to significant advances in performance on standardised ability tests' (p F13). There was no speculation on what was the exact mechanism by which this happens but it would certainly be wise to carry out follow up assessments in any future evaluation on the effect of memory training interventions.

The intervention used by Harrell et al. (2013) consisted of a commercially produced computer programme with exercises designed to improve attention, working memory, and processing speed. Their participants were 23 adolescents with chromosome 22q11.2 deletion syndrome. These children show some level of cognitive impairment with IQs between 59 and 109. Children were non randomly assigned to either the intervention or control group. The intervention group played three games per session four times a week for 12 weeks in their own homes, totalling approximately 32 h of intervention. Control participants were not asked to complete computer activities. In spite of small sample sizes two significant results were found that favoured the intervention group. First, on an overall composite index of cognitive function and secondly in one of the outcome measures for the Stroop, reflecting an increase in simple processing speed. An interesting addition to the study was a further investigation of the reasons four children dropped out of the intervention group. In two cases inconsistent or unreliable internet access was cited and in two cases lack of motivation on the part of parents or children. According to the authors: "The specific barriers to computer access were that one child's family sold their laptop and the other child's custodial parent blocked internet access due to concerns about the child's online social networking." (p2609). These drop outs highlight the importance of access to IT facilities which can be a challenge for those disadvantaged individuals on the wrong side of the digital divide.

People with Down Syndrome (DS) are commonly reported to have verbal short term memory (STM) deficits but also impairments in the visuo-spatial domain relative to healthy age-matched controls. Bennett et al. (2013) used a commercially available package designed to help improve concentration and working memory to see whether this would reduce these cognitive deficits in children with DS. Their participants were aged between seven and 12 years with mental ages ranging from 4 to 7 years. Ten children were randomised to a group using the preschooler version of Cogmed JM, which requires the completion of 3 visuo-spatial working memory tasks per day, 5 days per week for 5 weeks. Children were tested on the Automated Working Memory Assessment and parents rated behavior using the Brief Rating of Executive Function- Preschool Version (BRIEF-P) at baseline, post training (after 5 weeks) and after 4 months. Those in the intervention group improved significantly on trained and non-trained visuo-spatial STM tasks compared to a group that was exposed to no training and these gains were maintained at 4 month follow up. There was some improvement in the intervention group on parent ratings of behaviour as measured by the BRIEF-P with gains maintained at 4 month follow up but this was not the case for the control group. The authors are cautious in reading too much into this result as they acknowledge that the BRIEF-P is a subjective measure completed by the parents and group allocation was not blinded.

Taken together, these studies are encouraging as some of the studies are well designed (eg Van der Molen et al. 2010) and involve good sample sizes (eg Harrell et al. 2013). While Mahncke et al. (2006a) justified this sort of intervention on the grounds of neuroplasticity, not all the studies are driven by this claim. For a group who may have a limited range of experiences and methods of supporting their learning it is possible that these interventions might just provide the exposure to learning situations they have never had.

Physical Activity

Young adults with intellectual disabilities living in community settings have been found to have cardiovascular fitness levels indicative of a sedentary Iifestyle. A UK study (Messent 1997) found that adults with mild and moderate intellectual disabilities have disproportionately low levels of cardio-respiratory fitness compared with the general population. The study also revealed that 93% of the participants were performing significantly below the recognised daily minimum levels of physical activity (30 min of moderate intensity activity on at Ieast 5 days of the week). This level of physical inactivity is comparable to that found in the general population in the 75 plus age group. Increasing their levels of physical activity would have wide ranging advantages not only in terms of cardiovascular health but in weight control and enhanced mobility. Additionally, Vogt et al. (2013) found that moderate cycling exercise temporarily enhanced neuronal activity in relation to cognitive performance for adolescents with intellectual and developmental disabilities. Can information and computing technology help here?

A study carried out in South Africa (Ferguson et al. 2013) attempted to answer this question. Their participants came from three mainstream primary schools from a low-income community in Cape Town and were described as having the diagnosis of Developmental Co-ordination Disorder. Children were excluded if they had repeated any grade level more than once so it is likely that they were quite cognitively able, nevertheless the study has implications for a group with lower levels of cognitive functioning. Interestingly, the rationale for the study was to counter the limited access these children in this community had to physiotherapy services. There is widespread evidence of an association between disadvantage and disability and although there is no room to discuss this here, it must be borne in mind especially when recommending interventions that can end up being costly. The team compared two methods of improving functional motor and fitness outcomes: Neuromotor task training (NTT) and Nintendo Wii Fit Training. NTT involves therapists addressing motor problems using cognitive strategies such as reducing fear, increasing motivation, and improving motor control processes such as parameter setting and motor planning. This study compared the efficacy of NTT and Wii Training in improving motor activity and impairment parameters in children with DCD. Both interventions showed some improvement in motor and anaerobic performance from baseline to post measurement. However, the change in total motor scores over time was greater for the NTT group and children in the NTT group also improved in functional strength and aerobic performance scores. The authors thought it premature to conclude in favour of NTT as they thought that perhaps more learning of new skills was involved in use of the Wii Fit Programme and there is obviously more work to be done to ascertain whether this sort of technology can help improve physical fitness especially in people with lower levels of cognitive functioning. They did add that the decision to use either approach may be influenced by resources and time constraints.

Even those with profound disabilities can be helped by technology to exercise more. Lancioni et al. (2013) assessed the use of microswitch-aided programs to help three non-ambulatory adults with multiple disabilities to exercise their lower limb. This was an important activity for the participants as making the targeted response activated a largely neglected part of their bodies. Activity of their lower limbs might help alleviate or even avoid physical implications such as low blood circulation, swelling, and poor muscle strength. The intervention focused on movement of first one lower limb and then the other. Responses were monitored via microswitches and followed by an automatically delivered burst of preferred stimulation for example music or vibrotactile stimulation. The results showed that all three participants had high levels of lower limb responses during the intervention phases and a 3 week post-intervention check. The researchers also reported expressions of positive involvement from the participants for example they made music-related head movements, smiled or touched the vibratory devices.

Future Directions

Advancements in technology are constantly emerging and although some exciting directions are being followed as indicated above, there are some crucial areas in which surprisingly little work has been carried out. Three areas are described where future focus could produce significant benefits to people with developmental disabilities.

Making more use of technology for assessment As far back as 2001, Schultheis and Rizzo designed a virtual classroom for the assessment of young people with ADHD. Using computer technology for assessment has been developed for memory function (Parsons and Rizzo 2008) and utilised for children with specific learning difficulties (eg QbTest for children with ADHD) but there is potential for its use among those with more widespread developmental disabilities.

Improving access to IT for the most disabled Many people with intellectual disabilities have fine motor difficulties, as they suffer from conditions where damage has been caused to the central nervous system, such as cerebral palsy. This causes them to experience difficulties controlling the input devices needed to communicate with both desktop computers and smaller portable devices. These problems certainly put desktop virtual environments out of their reach as conventional devices for navigating in and interacting with virtual environments were difficult conceptually and physically (Standen et al. 2006).

Much of the work already described is designed to be used with individuals who could actually be described as being the more able with developmental disabilities. A recent systematic review by Kagohara et al. (2013) found 15 studies using iPods, iPod Touch and iPads in teaching programs for people with developmental disabilities with the first identified study appearing in 2009. What they noted was missing from the literature were studies on individuals with profound and multiple disabilities. They concluded that this group presents unique challenges with respect to the design of technology-based interventions but, as they had reported in an earlier paper (Kagohara et al. (2010), some individuals showed difficulty in learning to operate such devices with sufficient motor control so as to activate the device and software. This makes such devices for persons with significant motor impairments impractical unless effective access solutions can be employed such as adaptive microswitches or Bluetooth scanning switches.

Probably as a result of an increase in the survival of premature babies due to medical advances made in recent years (Moore et al. 2012), there are increasing numbers of people described as having Profound and Multiple Intellectual Disabilities (PMID). These people often have the most complex needs, due to a combination of extremely delayed intellectual and social functioning, no verbal communication and the presence of associated medical conditions usually neurological, sensory or physical impairments (Bellamy et al. 2010). It is the increase in this group that is responsible for the overall increase in numbers of people with developmental disabilities and future provision needs to take account of this. While most interventions described are designed for the more able, catering for the most disabled is where recent developments in computing technology can make a real impact. This group, particularly if nonambulatory, are at high risk of remaining marginalised and technological support could reduce their isolation and help them acquire some level of independence in interacting with the surrounding environment.

In the early 1990s Brooks (Brooks 2011) developed his own infrared sensor-based system to enable those with multiple disabilities to control multimedia through gesture or body movement. A massive body of work by Lancioni (see for example Lancioni et al. 2008) has demonstrated there is a way for almost anyone to activate a microswitch. Microswitches can be activated in a variety of ways, with the most common being a push switch, which is activated by applying pressure to a large button. However they can also be triggered by pressure sensors on the armrest of a wheelchair, by chin or eyelid movement (Lancioni et al. 2005) or by vocalisation (Lancioni et al. 2001). This then allows the user to exert environmental control, activate a piece of equipment which may produce speech on their behalf, or begin a pleasurable stimulus for the user.

A more recent development that can allow a profoundly disabled person to interact with their environment has been enabled by the appearance of low cost headsets that enable gamers to interact with games using their own brain activity. Welton et al. (2014) carried out pilot work using the Emotive Epoch with a group of young people with intellectual disabilities to effect simple commands.

Work with typically developing children has shown that robots can help attainment in a wide range of areas, particularly by motivating children (Barker and Ansorge 2007; Johnson 2003). A wide range of robots have already been used with children with disabilities (Salter et al. 2008), although the majority of these have focussed on children with autism or mild disabilities. For example, Robins et al. (2005) carried out an in-depth evaluation of segments of trials where three children with autism interacted with a robot as well as an adult. They were interested to see whether this scenario could assist joint attention which plays a fundamental role in human development and social understanding and which is underdeveloped in children with autism. Robots have enormous potential with children with ID, particularly those with severe and profound disabilities for whom less is available (Alper and Raharinirina 2006). Whilst studies involving children with profound disabilities are rare, some work has been done, often focussing on robots as motivational tools. Learning through play is one such strategy, which represents a "'natural' way in which children learn in an enjoyable manner" (Kronreif et al. 2005, p. 193). Klein et al. (2011) found that working with a robot increased playfulness in young children with developmental disabilities, which engaged children and encouraged the development of functional skills. Ibrani et al. 2011 used a mobile robotic platform with children with a range of disabilities. All the children showed high levels of motivation and engagement, which are crucial to learning in children with disabilities. As a preliminary step in the use of robots for profoundly disabled school aged children, Hedgecock et al. (2014) interviewed teachers of children with intellectual disabilities to discover their opinions of using a robot as an educational tool, which children they believed would benefit, what learning aims they would target, and what methods they would suggest to achieve them. Information derived from the interviews was then used to design a series of five case studies to evaluate potential teaching methods and outcome measures. For example, in one case study a 9 year old boy with severe intellectual disabilities and reduced vision learnt that by clapping his hands he could get the robot to perform a dance. However, he had problems with perseveration so the aim of the sessions was to help him learn to perform the action only once and to stop when the robot did what he wanted. The case studies were video recorded and recordings analysed to measure engagement, teacher assistance and goal achievement. A questionnaire completed by the pupils' teachers was also used to compare engagement in class to engagement within the final session. Analysis of the interviews highlighted the importance of having an appropriate input device to make the robot accessible, for example by making it sensitive to vocalisations, gestures or switch operations: whatever was favoured by the child. Teachers also emphasised the importance of "productive learning" rather than being seen as just play and of designing sessions tailored to individuals' needs and interests. In the case studies, pupils showed a significant increase in engagement when working with a robot when compared to not working with a robot, which was sustained throughout the 5 sessions.

These results are promising and further work is already underway to evaluate the impact of new ways of controlling the robot that will make it accessible to a wider range of profoundly disabled children.

Recognising the potential of technology for entertainment It is not an exaggeration to say that much of the use of information and computing technology in the mainstream is for entertainment whether this is through the use of dedicated devices such as Playstation or Wii or on mobile phones or tablets. Focussing on the acquisition of occupational skills and cognitive rehabilitation has overlooked the fact that technology can be fun. There is almost no research that recognises the need for entertainment or amusement apart from a pilot study by Weiss et al. (2003). They note that due to limitations in their physical abilities, people with cerebral palsy (CP) have relatively few opportunities to engage in independent leisure activities. A lack of opportunity can exacerbate their dependency on others and lead to the development of dependent behavioural patterns and learned helplessness. Their pilot study looked at ways in which virtual reality could provide positive and enjoyable leisure experiences during physical interactions with different game-like virtual environments and potentially lead to increased self-esteem and a sense of self-empowerment. Five young male adults with CP and severe intellectual disabilities who were non-speaking and wheelchair users experienced three game-like virtual scenarios that reacted in real time in response to their movements. Participants were extremely enthusiastic about the experience and the authors urge the consideration of how such experiences may improve self-esteem and a sense of empowerment in disabled groups.

Conclusion

In recent years there has been an increase in the number of studies that are endeavouring to use information and computing technology for people with developmental disabilities. From the earlier work on desktop virtual environments it is encouraging to see the range of applications using mobile and games technology. As most applications are designed for the more able members of this population there is a need for a focus on developing systems that meet the needs of those with profound and multiple disabilities and given the way technology is developing, there are an increasing number of ways these challenges can be met. It is still true that most of the publications reviewed describe either unevaluated developments or developments with minimal or pilot evaluations. There are a handful of well designed, well executed studies so it is possible to run evaluations that provide the evidence we need to be able to judge the value of interventions. However, the most likely reason for the lack of systematic, rigorous evaluations is lack of funding, something researchers, therapists and policy makers in this area should be lobbying to remedy.

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Chapter 13
Virtual Reality and Psychotic Disorders

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Introduction

In the early years of virtual reality in mental healthcare several reviews were published (Gregg and Tarrier 2007; G. Riva 2002; 2003; 2005). None of them mentions work done on virtual reality with psychotic disorders yet, though some early work was starting to get published around the same time. There are different psychotic disorders with each their own specified combination of symptom domains, symptom intensity and duration. Wood et al. (2011) suggest a dimensional staging of psychosis, ranging from psychotic-like experiences to severe persistent psychotic episodes. A large body of research is accumulating showing psychotic symptoms can be seen as a transdiagnostic and extended phenotype found in the general population (J. van Os and Reininghaus 2016). When psychotic experiences persist, transition to a psychotic disorder becomes a possibility. The main recognizable symptom domains of psychotic disorders are hallucinations and delusions. Hallucinations are perceptions a person experiences without a corresponding external stimulus. Hallucinations can occur for all five senses. Patients with a psychotic disorder for example often experience auditory hallucinations such as hearing voices. These voices can be

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commentary, give orders to the patient or call them names. Delusions are beliefs people have about the external reality which are strongly maintained despite strong evidence to the contrary or despite what almost everybody else (of a person's culture or subculture) believes. The most common delusion found in psychotic disorders is the persecutory delusion (paranoia). People with a persecutory delusion feel others (known or unknown) spy on them, pursue them and threaten their safety (van der Gaag, 2012) Hallucinations and delusions often cause anxiety and make the patient avoid (social) situations, which can be treated with exposure therapy. Other symptom domains of psychotic disorders are negative symptoms and impaired cognition. Patients with negative symptoms experience an diminished emotional expression and avolition. Impaired cognition is about learning deficiencies, whether insufficiently thought or thwarted by deficits. For both negative symptoms and impaired cognition training can help patients learn to master new skills. There are some additional symptom domains in psychotic disorders, but these don't play a part in virtual reality (yet). See Box 13.1 for an overview.

Box 13.1 Symptom Domains of Psychotic Disorders

1. **Delusion**: fixed beliefs despite evidence to the contrary.
2. **Hallucination:** perceptions without a corresponding external stimulus
3. **Disorganized Speech:** examples are neologisms, loose associations and perseveration.
4. **Abnormal Psychomotor Behaviour**: unusual movement or gestures
5. **Negative Symptoms**: diminished emotional expression and avolition.
6. **Impaired cognition**: deficienties can be found particularly in memory, attention and executive functioning.
7. **Depression:** a state of low mood and activity
8. **Mania**: a state of elevated mood and activity

(Heckers et al. 2013)

Even though more effective treatment options in medicine and psychotherapy have become available for psychotic disorders over the last decades, they do not work (well) for every patient. They can suffer from persistent symptoms and a substantial group of patients experiences functional limitations (Galderisi et al. 2013; Üçok and Ergül 2014; Zimmermann et al. 2005). Virtual reality could help us improve our understanding of psychotic disorders and improve treatment by providing an accessible and realistic environment for both practice and exposure exercises. Two studies published from the same group showed that (brief) virtual experiences were safe and acceptable for patients with psychosis (Fornells-Ambrojo et al. 2008) and for patients assessed with an at risk mental state for psychosis (Valmaggia et al. 2007), opening up possibilities for further research. A more recent review confirms safety and acceptability of using virtual reality with people experiencing psychotic symptoms (Rus-Calafell et al. 2017). An interesting publication on virtual reality for psychotic disorders was the 2008 article by Daniel Freeman 'Studying and

Treating Schizophrenia using Virtual Reality: a new paradigm'. In this article Freeman outlines seven possible uses of virtual reality for psychosis, as can be seen in Box 13.2. In two of the categories Freeman mentions, assessment and treatment, scientific research has made a decent start. A review by Veling et al. (2014) gives an update on virtual reality assessment and treatment in psychosis. Virtual reality applications for assessment and treatment seem to have great potential for enhancing our understanding of psychotic disorders and expanding the therapeutic toolbox with virtual training environments and exposure in virtual environments. Systematic review shows that, while promising, applications for assessment and treatment are in their infancy, and for most other categories of use work is just starting (Valmaggia et al. 2016). New treatments are being researched even if we don't fully understand the underlying effective mechanisms yet. This is common in psychology, and the interaction between treatment and exploring effective components gives opportunities direction to future research.

Box 13.2 Seven Possible Uses of Virtual Reality for Psychotic Disorders According to Freeman (2008)

1. Symptom assessment
2. Establishing symptom correlates
3. Identification of predictive variables
4. Identification of differential predictors
5. Identifying environmental predictors
6. Establishing causal factors
7. Developing treatment

When new technologies become available the first logical step is to translate and enhance existing research methods and treatments using the new medium. Virtual reality has been following a similar path. Social skills training is done with virtual people instead of real people, a 3D-virtual maze is used instead of a 2D-maze on the computer and paranoia is researched with virtual social situations instead of real (staged) ones. Virtual reality technology offers new possibilities for such core research and should continue. But a parallel path to follow would be to think outside of the box and use virtual reality to re-innovate healthcare for psychotic disorders. This chapter aims to give a general overview of the scientific work done on virtual reality in the assessment and treatment of psychotic disorders and addresses future challenges and possibilities.

Assessment

One of the possible uses of virtual reality for psychotic disorders is assessment. A review on using virtual reality in objectifying the process of diagnosing psychiatric disorders (van Bennekom et al. 2017) shows a variety of behavior and symptoms could potentially be assessed. A review on using virtual reality in assessment of psychosis suggests it to be a promising method for establishing cognitive deficits and relevant clinical symptoms (M. Rus-Calafell et al. 2017). On the assessment of two symptom domains of psychotic disorders some first research has been done; the assessment of (persecutory) delusions and the assessment of impaired cognition. Also, studies on the assessment of hallucinations and negative symptoms are starting to emerge.

Assessment of Delusions and Hallucinations

A common symptom of psychosis is paranoia. Paranoia in particular is a symptom that is inextricably connected to the social environment. Environmental factors have been associated with the development of psychotic symptoms such as paranoia (van Os et al. 2010; Wim Veling et al. 2006). In the Camberwell walk study (Ellett et al. 2008) the effects of exposure to one specific deprived urban environment on thirty individuals with persecutory delusions were studied. The individuals showed increased levels of anxiety, negative beliefs about others and jumping to conclusions. Their paranoia also increased. Freeman (2008) describes that studying paranoia using virtual reality applications has several advantages. In some cases suspiciousness about other people in real life may indeed be valid concerns. Because virtual reality gives the researcher complete control over the social environment, any paranoid thoughts that are grounded in reality can be ruled out. Also, strange behavior of other people in the social environment in real life may be an interaction effect with the behavior presented by the paranoid patient. If a paranoid person behaves divergent or awkward, other people in the environment are bound to take notice and react to this. Another advantage of virtual reality is the level of control about the social environment that is possible. While real-life social situations are variable, virtual reality can be used to create consistent social environments each time. A study (Fornells-Ambrojo et al. 2008) on the safety and feasibility of the use of virtual reality on people with persecutory delusions compared twenty paranoid patients with twenty non-clinical individuals. Each participant spent 4 min in an underground train with neutral virtual humans using a head-mounted display. A high percentage (65%) of the participants with persecutory delusions experienced paranoid thoughts about the neutral virtual humans in the virtual train. Interestingly, this percentage did not differ significantly from the non-clinical group. Other findings showed that the virtual reality experience did not raise symptoms of anxiety or simulator sickness. During the follow-up no side effects were reported by the participants. A study (Veling et al. 2016) linking virtual social environments and paranoia compared Fifty-five patients with recent onset psychotic disorder, 20 patients at ultra high risk for psychosis, 42 siblings of patients with psychosis, and 53 controls.. Subjects participated in five experiments with different levels of social stress during which they walked in a virtual café (see Fig. 13.1) for about 4 min. The effect of three suspect environmental factors for paranoia was tested: density of virtual

Fig. 13.1 Virtual café

visitors (being in a crowded or less crowded environment) and ethnicity of the virtual humans (café visitors with a person's own or from another ethnicity group) and hostility (avatars looked in an angry, hostile fashion at participants). Most participants showed some degree of paranoid thoughts about the virtual humans. Paranoia and subjective distress increased with degree of social stress in the virtual environment. Psychosis liability and pre-existing symptoms positively impacted the level of paranoia and distress in response to social stress.

Another study (Fornells-Ambrojo et al. 2013) looking into threat evaluation in a controlled virtual social environment again found people with persecutory delusions to report the same levels of paranoia as non-clinical participants. Thematic analysis of interviews from participants about the decision making process involved, showed that people with persecutory delusions are able to use a similar range of strategies when judging potential threat in a non-anxious making neutral environment. However, they were found less likely than controls to engage in active hypothesis-testing. They were found to favor their experienced affect in the environment as evidence of persecutory intention. More extensive research with a non-clinical population has been done by (Freeman et al. 2008a, b). They performed a large study (N = 200) with members of the general public, in which a substantial minority reported paranoia about virtual humans when exposed to a neutral social situation (train). This paranoia was predicted by anxiety, worry, perceptual anomalies and cognitive inflexibilities, similar factors as are found to predict paranoia in patients with persecutory delusions. (Freeman et al. 2010a, b) continued using virtual reality to investigate a possible continuum of delusional beliefs by researching three groups with different levels of paranoia, namely a nonclinical group with low paranoia (N = 30), a nonclinical group with high paranoia (N = 30) and a group with persecutory delusions (N = 30). The experienced levels of paranoia in the virtual environment differed significantly for each of the groups. Overall, the results of the study were consistent with the notion that there is a spectrum of paranoia in the general population. Together these studies show the research benefit virtual reality brings as the accumulated virtual reality research provides growing evidence for the notion that paranoia is a common trait that can be found in the general population, but in severe forms is a symptom of psychotic disorders. This also means that in an early development state of a virtual environment, its ability to evoke paranoid thought could initially be evaluated with a non-clinical sample and only involving a clinical sample at a later stage. This ability could even be further enhance by priming individuals by showing video and let them read text about aggression prior to exposure in the virtual environment (Isnanda et al. 2013).

But why do some people get paranoid in a social environment, while other people get socially anxious? Virtual reality can help differentiate not only between patients and healthy controls, but also between overlapping symptoms. A large study (Freeman et al. 2008a, b) on differential prediction between paranoia and social anxiety assessed two hundred non-clinical individuals. All participants were exposed to a neutral virtual environment for 5 min, representing a train ride between two stops. The study showed that paranoia and social anxiety share many predictive factors such as anxiety, depression, worry and interpersonal sensitivity. However, experienced perceptual anomalies were a distinct predictor only for paranoia. The presence of these perceptual anomalies increased the risk for paranoia, yet decreased the risk of social anxiety. Research shows the level of self-confidence also affects the occurrence of paranoia (Atherton et al. 2016). Patients do not only have difficulties with interpreting social situations, but distortions in reality perception, self-image and dysfunction in emotional processing seem to complicate their interaction with the environment even more. Perceptual anomalies or distortion in reality perception is a common manifestation in schizophrenia. Sorkin et al. (2008) created a virtual environment in which incoherencies could be found. Examples of these incoherencies are a red cloud, a guitar producing trumpet sounds and a giraffe grazing in a local store. Patients with schizophrenia (N = 43) and healthy controls (N = 29) were asked to detect the incoherencies. The healthy controls were reliably able to do so. Of the patients group, 88% failed in the task. They had specific difficulties when de incoherency was audio-visual, and this was significantly correlated with the PANSS hallucinations scale.

Assessment of Negative Symptoms and Impaired Cognition

Dysfunction in emotional processing is found in many patients with psychotic disorders. Park et al. (2009a) used virtual reality to simulate social encounters with virtual humans expressing happy, neutral or angry emotions. Twenty-seven patients with schizophrenia and twenty-seven healthy controls participated in the study. The patient group reported experiencing a significantly higher level of state anxiety in response to the interactions with happy virtual humans than the control group. This state anxiety with happy virtual humans correlated significantly with measures of negative symptoms such as social anhedonia, blunted affect and emotional withdrawal. The findings suggested interference in the experience of pleasure in social interactions in patients with schizophrenia. In a study with twenty schizophrenia patients and twenty control subjects, Dyck et al. (2010) found that emotion recognition impairments not only emerged when emotions were expressed by natural faces but also when the emotion was expressed by a virtual face. Confirming the usability of virtual faces to explore mechanisms of emotion recognition. Souto et al. (2013)

experimented with emotional recognition in a small trial with twelve patients with schizophrenia and twelve controls. Their results showed the emotions of happiness and anger to be better recognized by both groups compared to other emotions. Difficulties arose in the recognition of both fear and disgust. Bekele et al. (Bekele et al. 2017) show virtual reality can be used to research differences in the way individuals with schizophrenia process and respond to emotional faces compared with healthy control participants. Again, the benefit of all these virtual reality studies is to establish new insights.

Virtual environments can be used as a measure of cognitive functioning (Zawadzki et al. 2013). Such studies on memory (García-Montes et al. 2014; Spieker et al. 2012; Weniger and Irle 2008; Wilkins et al. 2013a; b) and visuo-spatial mechanisms (Thirioux et al. 2014) give us a better understanding of the processes in the brain that play a role in psychotic disorders. (Sorkin et al. 2005, 2006) attempted to develop an automatic tool for the diagnosis of schizophrenia. They studied sensory integration within working memory using a navigation task through a virtual reality maze. Thirty-nine patients with schizophrenia and twenty-one healthy controls participated in the study. They developed a procedure for classification based on the cognitive performance profile of the participants in the virtual maze. The classification system correctly predicted 85% of the patients with schizophrenia and all of the controls. Using virtual reality for the assessment of prospective memory has shown good construct validity, test–retest reliability, sensitivity and specificity in the context of first-episode schizophrenia (Man et al. 2016). However, because people suffering from mental disorders other than schizophrenia also regularly experience similar cognitive problems the question rises whether the current tools could be used to diagnose schizophrenia or rather assess more general problems with cognitive performance. A lack of cognitive flexibility has previously been linked with schizophrenia. Mental rigidity seems to hinder individuals in being able to discover or employ alternative solutions. A study on the assessment of cognitive flexibility (Han et al. 2012) found virtual reality to be an ecological valid measure for cognitive flexibility in patients with schizophrenia.

Real-life functioning is impaired for many individuals with a psychotic disorder, so Greenwood et al. (Greenwood et al. 2016) created a virtual shopping environment for assessment. They found the virtual functional shopping measures to enhance the predictions of real life performance, over and above existing cognitive testing. Another real-life behavior that can be assessed by using virtual reality is medication adherence. Medication is often used in the treatment of psychotic disorders, but medication compliance is a problem. One of the reasons for poor compliance is impaired cognition. A virtual reality study (Baker et al. 2006) using a virtual apartment, including helpful tools such as a clock and a reminder note on the refrigerator, studied medication compliance behavior in patients (N = 25) and controls (N = 18). The results demonstrated that the participating patients showed more difficulty in being able to comply with the medication regime than controls. The results suggest possible future use of such a virtual task as a measure of medication compliance. Virtual social environments were also used in a study to assess social behavior in patients with schizophrenia (K.-M. Park et al. 2009b). A head-mounted display was used to present a 3D-virtual environment in which the subjects socially interacted with an virtual human. Social performance was measured. A significant difference was found in functional skills between the twenty-four female patients and fifteen healthy females. The research also showed the virtual assessment technique to be sensitive to change in social competence, making it possible to use it for short-term clinical trials. In real life social situations are often complex, and Han et al. (2014) took a step in creating a more complex virtual social environment to assess abnormal social characteristics in patients with schizophrenia (N = 23) compared with healthy controls (N = 22). They created a virtual three-party conversation task which included emotion-laden situations and both speaking and listening phases in the conversation. Patients with schizophrenia were found to have an active avoidance of eye-contact during the three-party conversation. Though overall research is limited yet and more development is needed, virtual environments do seem to be able to complement the existing methods for assessment of symptoms and behaviors in patients with a psychotic disorder.

Virtual reality also offers new creative options to explore mechanisms. Using a person's height as a marker for social status and authority, Freeman et al. (2014) manipulated the height of participants in the virtual social environment. They experienced, in randomized order, a train ride between stations while attributing either their normal height or a reduced height. Interestingly, reducing a person's height in the virtual social environment did indeed result in more negative views about the self in relation to other people. People also experienced increased levels of paranoia when their height was reduced, but this was fully mediated by the changes in social comparison.

Treatment

The second category in which virtual reality is explored for psychotic disorders is treatment. Virtual reality techniques are used for enhancing established therapies such as skills training and virtual reality assisted therapies (M. Rus-Calafell et al. 2017). Cognitive behavioral therapy is often used in treating avoidance behavior when people experience delusions or hallucinations. Skills training can be used when treating the symptom domains negative symptoms, social skills and impaired cognition.

Treatment in Delusions and Hallucinations

Can virtual environments also be used for the treatment of social anxiety in people with psychosis? Symptoms of social anxiety in people with a psychotic disorder are common, even after their psychotic symptoms are in remission (Achim et al. 2011). Virtual environments using video capture were developed (Gega et al. 2013) in a pilot study to answer this question. The environments were used as a complement to cognitive behavior therapy. Six patients recovering from psychosis and suffering from social anxiety used interaction exposure in a virtual environment in their treatment program. Interesting about the video capture system was that participants were able to actually see a life-sized projection of themselves interact in the social environment. Results suggest the use of virtual reality could help patients understand the role of avoidance and the use of safety behaviors in the development and maintenance of symptoms. The next step would be to see if practicing cognitive and behavioral techniques such as exposure in virtual social environments enables patients to change their behavior in real life.

There is ample evidence that CBT with in virtuo exposure can be used to treat anxiety disorders (Meyerbröker and Emmelkamp 2010; Opriş et al. 2012), and now evidence is emerging that it can also be used in treating anxiety disorders in patients with a psychotic disorder. But could CBT with exposure in virtuo also be used to treat the avoidance seen in reaction to delusions and hallucinations in psychotic disorders? Treating paranoia seems a likely first candidate, due to the role of anxiety and avoidance in the development and persistence of paranoid delusions. The earlier mentioned study by Veling et al. (2014) found patients experiences of paranoia in everyday life to correlate with the experience paranoia of in virtual social environments. Broome et al. (2013) showed healthy participants (N = 32) an urban street scene in virtual reality using a head mounted display. The virtual scene was based on an actual street in a local deprived area. They demonstrated that the virtual street scene was able to elicit more paranoia in the participants than a virtual indoor environment. These results support the notion that factors in the urban environment play a role in experiencing paranoid thoughts, and virtual social environments could be used as an exposure tool for therapists. An experimental study by Freeman (Freeman et al. 2016) showed even a brief virtual reality intervention on testing treat belief and dropping safety behavior can lead to impressive reductions in delusional conviction and real-world distress. An obvious next step in research would be to study CBT with in virtuo exposure for treating patients with a psychotic disorder. Currently a study (www.controlled-trials.com/ISRCTN12929657/) is being conducted in The Netherlands attempting just that. From technological perspective, a next step would be to enhance the therapist control over the stimuli in the virtual environment, giving them the ability to personalize it and to gradually increase the level of stimulating material during a session in virtual reality. Instead of focusing a single paranoia-evoking element in the virtual environment, Isnanda et al. (2014) developed a virtual restaurant environment (see Fig. 13.2) that included a large set of these elements such as facial expression of virtual restaurant visitors, their eye gaze directed towards the individual being exposed, snatches visitors' conversation or laughter, flash news messages on TV screens, people passing by who could also stop and look around. Using a non-clinical sample (N = 24), Isnanda et al. found that controlling the stream by which these events occur in the virtual environment could affect the number of paranoid comments made when people described their experience in the virtual restaurant environment.

Fig. 13.2 Virtual restaurant

Fig. 13.3 AVATAR Therapy

Virtual reality can also be used for developing novel therapeutic interventions. Leff et al. (2013) created a new approach to the treatment of auditory hallucinations, which they called 'AVATAR Therapy'. Patients suffering from auditory hallucinations often feel hallucinatory voices to be powerful and able punish the patient when ignoring its commands. With CBT patients learn to conduct behavioral experiments showing the voices to be uncomfortable but otherwise harmless. The AVATAR Therapy research group developed a computerized system that enables patients to create an avatar, as to give a face to go with their persecutory auditory hallucinations, and the therapist can modify his or her voice to talk with patients through the avatar. This enables a dialog between patient and this virtual persecutor. The therapist controls the attitude of the avatar towards the patient. Gradually the therapist changes the attitude of the avatar towards the patient from controlling to yielding, giving the patient more control in the dialogue. This proof of concept study and the recent pilot study (Craig et al. 2014) show promising results. The AVATAR therapy is currently being tested in a larger controlled study in the Institute of Psychiatry, Psychology and Neuroscience (King's College London) and the results are expected by 2017. Some replications of the AVATAR therapy study can be seen in Fig. 13.3.

Treatment of Negative Symptoms and Impaired Cognition

Next to anxiety being a disabling factor in social situations, some patients might also lack some of the basic social skills needed to interact with other people. Virtual reality offers the possibility of training skills in a (social) environment developed for just that purpose. One of the problems people with a psychotic disorder face is low employment rates. Because employment is such an important part of autonomy, and building a life for yourself, this is a major concern. Bell and Weinstein (2011) developed a job interview skills training for people with psychiatric disability, among whom were patients diagnosed with schizophrenia. The goal was to provide an experience where participants could improve their job interview skills, reduce fear and increase their confidence about doing job interviews. One of the special features was ongoing feedback by an on-screen coach. The feasibility trial showed that participants found the virtual environment easy to use and thought the experience realistic and helpful. Participants indicated their anxiety lessened as their skills improved. Additional research on virtual reality job interview training specifically with individuals diagnosed with schizophrenia, shows trainees have greater odds of receiving a job offer and had to wait fewer weeks before receiving a job offer (Smith et al. 2015). A virtual job interview training could provide great help in the first steps towards employment. But could virtual reality also help in job training, improving patients chances to keep a job? Tsang and Man (2013) created a virtual reality based vocational training which they researched in a single, blinded, randomized clinical trial (N = 95). They developed a virtual shop to create a working environment for the participants, including a store room, entrance and inner shop where the trainee could interact with virtual costumers and practice problem-solving skills. Patients in the virtual reality training group showed improvement in cognitive functioning. Results also suggested that using virtual reality training may offer a better generalization effect than that of patients receiving a therapist-administered training; with the same training duration the virtual reality group performed better in real-life environments than the therapist group. A virtual reality-based vocational rehabilitation training program (Sohn et al. 2016) for people with schizophrenia found an improvement on general psychosocial function and on memory. Other researchers (Rus-Calafell et al. 2014) created a virtual reality program to be used in a social skills training intervention. The virtual reality program enabled patients meeting schizophrenia or schizoaffective criteria (N = 12) to practice social interventions with virtual humans. The program focused on the learning of social skills and provided positive or negative reinforcement. The virtual environments included conversational interaction with the virtual humans and special care was taken to include facial expressions. Results of the pilot study showed improvements in social anxiety and discomfort and social functioning. An important conclusion was that the use of the virtual reality program contributed to the generalization of the acquired skills of the patients to their everyday lives. Park et al. (2011) found that using virtual reality in role-playing for patients with schizophrenia may be particularly helpful for improving conversational skills and assertiveness. They also found that motivation for the training and generalization of skills were greater for patients in the virtual reality role-playing group than for patients in a traditional role-playing group.

As mentioned under assessment, reality distortion is common in schizophrenia and interferes with one's ability to function. Could virtual reality be used to reduce reality distortion? Moritz et al. (2014) explored this concept in a trial with thirty-three patients diagnosed with schizophrenia. Patients were instructed to navigate through a virtual street on two occasions (noise vs no noise), meeting six different pedestrians. Patients were then asked to recall information about the facial affect of the pedestrians. Afterwards, error feedback was given by both a computer display and the experimenter. The paranoia score declined significantly at a medium effect size. Further research is needed to explore what happens in the learning process. Chan et al. (2010) explored the possibility to use virtual reality in a cognitive training program among older adults with schizophrenia. Participants were randomized in an intervention group (N = 12) or a control group (N = 15). After the 10-session program the intervention group performed significantly better in overall cognitive functioning than the control group. Overall, using virtual reality to learn new skills is a promising research area. Especially interesting is the trend that training skills in a virtual reality environment tend to generalize into real-life, because this is a common problem with traditional skill-training in a therapeutic setting.

Conclusion and Future Developments of Virtual Reality and Psychosis

A systematic review (Alvarez-Jimenez et al. 2014) on internet- and mobile based intervention for the treatment of psychosis showed that 74–86% of the participating patients were able to use the web-based interventions effectively. Of the patients 75–92% perceived the interventions as positive and useful. A number of 70–86% completed the intervention or were engaged in it over the follow-up. Internet- and mobile interventions for psychosis are acceptable, feasible, and have potential to improve our mental healthcare. Ben-Zeev (2014) outlines some important advantages of new technologies such as increasing patients access to evidence based care. He also proposes that technology could facilitate new paradigms in treatment using things like wireless connections, sensors on telephones and tablets and the internet blended together, to help enhance the individual effectiveness of our treatments. Virtual Reality is part of this larger technological emergence we see in every-day life offering a range of tools, among which augmented reality and real-time applications such as Apps, to develop new evidence-based treatments and improve the understanding of psychotic disorders. Assessment and treatment are the two areas where most research on virtual reality and psychotic disorders has been done. Still, this research consists largely of proof-of-concept studies and small trials. Other possible uses for virtual reality are largely left unexplored yet. Most studies being conducted explore the use of virtual reality for enhancing existing methods of assessment and therapy. A few studies are emerging that explore novel approaches in how virtual reality can be used in research on psychotic disorders. Not only is additional research necessary to add to the small body of existing science on the subject of virtual reality and psychotic disorders, it also challenges researchers to utilize the full range of potential of this new technology. Virtual Reality is part of a larger process in the research and treatment of psychotic disorders were we move away from the unreality of the therapist office towards the real-time reality of everyday life. Virtual reality brings the real world into the therapist office, while augmented reality and Apps will bring therapy into the real world. Ideally, in the future, we can offer patients interventions directly when the distress in real life occurs because smartphones and watches, augmented reality glasses and Apps help monitor and signal when problems occur. They could also instantly offer personalized interventions. Until eventually research and therapy fully merge with everyday life, leaving behind us the days where we can only try to approach it.

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Chapter 14
Assessment and Rehabilitation Using Virtual Reality after Stroke: A Literature Review

Check for updates

Pierre Nolin, Jérémy Besnard, Philippe Allain, and Frédéric Banville

Introduction

This chapter focuses on assessment and rehabilitation publications using virtual reality after a stroke. A stroke is characterized by a sudden loss of brain function due to an interruption of blood flow to the brain after an ischemic stroke (caused by the formation of a blood clot) or bleeding (caused by the rupture of a vessel and subsequent bleeding into or around the brain). The interruption of blood flow to the brain causes the destruction of neurons. The effects of a stroke vary, depending on the part of the brain that is injured. One of the leading causes of disability, stroke affects 750,000 people in the United States alone. More than half of stroke survivors experience significant physical, cognitive, and functional aftereffects (Williams et al. 1999), and many require rehabilitation. Those people are dealing with a form of impairment such as paralysis or hemiplegia, sensory loss, impaired speech, vision problems, and other cognitive deficits like spatial disorientation, memory lapses, and dysexecutive syndrome.

We conducted a literature review of publications from 1980 to 2017 by searching Academic Search complete, CINAHL, MEDLINE, PsychINFO, Psychological and Behavioural Sciences collection databases. We used the following key words:

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stroke, vascular brain injury, cognitive functions, cognition, attention, memory, perceptual, executive functions, and virtual reality. We have excluded the publications based on the following criteria: they were duplicated across databases; they did not deal with cognitive functions; they were generally descriptive; they contained only general comments, or they had no results; the samples consisted of participants with different diagnoses or mixed diagnoses. For stroke, 143 articles were obtained in the first stage, and 50 were analyzed in the final stage.

This chapter consists of 3 sections. The first section describes the knowledge from previous literature reviews. The second section presents studies dealing with virtual reality with stroke patients according to the different cognitive functions that have been covered in previous publications: attention and spatial neglect, route representation, episodic memory, prospective memory, executive functions / multitasking. The third section summarizes the information in the form of discussion.

Synthesis of Literature Reviews

Some of the publications targeted were themselves literature reviews, the conclusions of which will be presented in this section. One of the first reviews of VR as an assessment and rehabilitation tool for specific disabilities resulting from brain injury (including strokes and TBI) was done by Rose et al. (2005). The authors looked at studies on executive dysfunction, memory impairment, spatial ability impairment, attention deficit, unilateral visual neglect, and some activities of daily living (driving, street crossing, travelling, food preparation, etc.). They noted that while VR was still under-exploited as a tool for brain injury rehabilitation, it was becoming notably more popular and might come to form an integral part of assessment and rehabilitation protocols within the next few years.

A review by Morganti (2004) also dealt with the use of VR in the assessment and rehabilitation of neuropsychological diseases (including strokes). The author discussed the benefits of the VR approach in the field of neuropsychology, especially in regard to the following cognitive functions: memory, plan and motor abilities, executive functions, and spatial knowledge representation. Cherniack (2011) reviewed studies on the use of VR in the identification and rehabilitation of cognitive disorders of the elderly (mainly Alzheimer's disease, Parkinson's disease, and stroke). This review differed from the previous two in that the information was organized according to the type of apparatus used (desktop visual display systems, head-mounted display systems, and additional devices). The authors noted the potential of VR in addressing the specific health needs of elderly patients, but also listed many methodological problems with previous studies including insufficient participants, weak study designs, costly systems, and failure to account for differences in how young and old participants use VR technology. These methodological problems suggest that applications of VR in diagnosis and treatment of diseases in the elderly are just in their nascent stages. Note that the studies targeted, in these 3 reviews, cover a wide variety of neurological pathologies, and therefore do not form a basis for statements about the use of VR among stroke patients specifically.

A review by Crosbie et al. (2007), which looked at studies on virtual reality in stroke rehabilitation published from 1980 to September 2004, listed only 2 articles out of a total of 11 selected. These articles had to meet the criteria of the American Academy of Cerebral Palsy and Developmental Medicine (AACPDM) adaptation of Sackett's work. The articles were classified according to a system with 5 levels of quality based on study design (Level I = randomized controlled trial to Level V = descriptive case series). The first study (Rose et al. 1999) dealt with using VR to explore a virtual bungalow for memory and layout training purposes after vascular brain injury was classed as a Level I. The second study (Weiss et al. 2003) looked at training stroke patients with spatial neglect to cross a street safely; it was classified as a Level III (Case-control study. Cohort study with historical control group). These 2 studies will be discussed in greater detail later in this chapter. The authors of the review concluded that their results were positive overall: both studies on cognitive functions reported statistically significant or positive results. However, there remains some work to be done to demonstrate the effectiveness of VR given that the studies examined were too different in terms of content (the cognitive functions under study), the apparatus used (patient-VR interface), and study design. The authors also note the importance of considering the adverse effects of VR (cybersickness, eye strain, vestibular system symptoms, etc.) and personal variables (age, ethnicity, physical fitness, etc.), which could influence participant performance. They also advise caution when using VR on patients with impaired hearing or psychiatric disease.

A review by Tsirlin et al. (2009) dealt exclusively with studies on the use of VR to examine unilateral spatial neglect. The authors described 7 studies on potential uses of VR in assessing patients with unilateral spatial neglect (Gupta et al. 2000; Tanaka et al. 2005; Broeren et al. 2007; Kim et al. 2004; Myers and Bierig 2003; Baheux et al. 2004; Buxbaum et al. 2008) and 6 studies on the potential uses of VR in training such patients (Ansuini et al. 2006; Castiello et al. 2004; Glover and Castiello 2006; Katz et al. 2005; Smith et al. 2007; Rushton et al. 1996). The authors of the review concluded that VR represents a potential improvement upon the methods currently used to assess, treat, and study unilateral spatial neglect. For example, VR techniques make it possible to gather data on head and eye movements, postural deviation, and limb kinematics. VR techniques also make it possible to study the different sensorial modalities in a stimulating environment that is more representative of daily life than current procedures. The authors do caution, however, that certain weaknesses of VR must be addressed, such as the ergonomic aspects of VR apparatus with respect to the physical limitations faced by participants (reduced mobility, paralysis, use of a wheelchair, etc.). The authors also note the importance of developing intuitive and easy-to-use applications so that VR can be used without having to depend on help from professionals. They also discuss the importance of lowering the costs associated with VR (by developing environments that run on compatible platforms) as well as the importance of developing multimodal batteries that would serve in both diagnosis and rehabilitation. Finally, collaboration among professionals from numerous disciplines (neuropsychologists, researchers, computer scientists, etc.) should be encouraged to ensure the future success of VR techniques.

Recently, Lisa et al. (2013) did a systematic review of the effectiveness of different treatment modalities for the rehabilitation of unilateral neglect in stroke patients. Of the 15 RCT's that have been included in this study, two were conducted with VR. These are publications made by Katz et al. (2005), and Kim et al. (2011a), the results of which will be detailed later in this chapter. The authors of this systematic review concluded that virtual reality was one of the most effective treatment methods of unilateral neglect after a stroke.

Cognitive Functions

The following section presents different studies that have been conducted using virtual reality for evaluation or rehabilitation of various cognitive functions among stroke patients.

Spatial Attention and Neglect

Baheux et al. (2004) and (2006) developed a 3D-haptic virtual reality (VR) system coupled with an eye-tracking device designed to improve assessment and rehabilitation of hemispatial neglect in affected individuals. The tasks used in this system include target cancellation, line bisection, drawing copies, and a virtual reality task consisting of grabbing an object (picking up sushi from a plate). The same team published a study conducted on 6 healthy participants and 5 hemiplegic participants (Baheux et al. 2005) and found that the hemiplegic patients proceeded by trial and error, unlike the healthy participants, who positioned themselves closer to the objects and slowed down to pick them up. While the authors did not report any data on the use of their VR system for rehabilitation, they are pursuing further research in this area. Tanaka et al. (2010) also showed that their head-mounted display (HMD) system, based on line cancellation tasks, could be used to evaluate unilateral spatial neglect in stroke patients (case study).

Using a virtual cancellation task as well as traditional neglect tests, Broeren et al. (2007) assessed hemispatial neglect in 8 patients with right hemisphere stroke and 8 control subjects. The patients were tested 5–39 weeks post-stroke. The virtual cancellation task involved a 3D image displayed on a tabletop (which the user was able to view using stereoscopic shuttered glasses). The participant used a handheld stylus (haptic device) positioned in the line of sight to interact with the virtual objects. The results from this study showed that the VR procedure was able to detect small variations in performance that were not detected by traditional pencil-and-paper tests.

Kim et al. (2004) developed a VR system involving a head-mounted display (HMD) and a 3 degrees of freedom position sensors, which "could be used as a patient's head motion to measure the subjective visual middle line." The VR system developed by this team makes it possible to assess and train patients with unilateral neglect. A calibration task is used to measure each participant's subjective visual middle line before the test begins. The virtual environment displays a landscape with a ball in the centre. The subject's task is to keep their gaze on the ball as it moves around the display; the gaze is represented by a small cross, which the subject can control. The task can be set to different levels of difficulty. The experimenter can help the subject by giving them auditory or visual cues. The study was conducted on 12 patients with unilateral neglect, 20 controls (group I) with high computer experience, and 20 controls (group II) with low computer experience. The results obtained for the 6 parameters in this VR assessment system (deviation angles, no-attention time, scanning time, number of cues, failure rate of omissions, and ratio of right/left scan) showed that the patients with unilateral neglect had much more difficulty with the task, while no such difference was observed between the control groups. Also, the experience of 3 study participants supports the potential of this system as a training tool for people with unilateral neglect.

A few years later, building on the foundation of the above-mentioned technology, the team of Kim et al. (2007) developed a 3-dimensional immersive virtual street crossing program for rehabilitation of stroke patients with unilateral neglect. In this program, participants are immersed in a virtual environment using an HMD capable of measuring head movements. The virtual environment consists of a 3D street with a virtual avatar positioned in the middle of a crossing. The participant must keep the avatar safe from traffic by watching out for vehicles in both directions. Vehicles arrive randomly from the left or right at different speeds; the participant can stop them by pressing a button on the mouse. In this study, the authors divided the participants into 3 groups. The first group was made up of 10 patients with right hemispheric stroke and left visual neglect. The second group was made up of 20 healthy subjects with high computer experience and served as a control group for the first group. The third group was made up of 20 subjects with low computer experience and served as a control group to study the effects of computer ability. The results of this study showed that this program could be used to train patients with unilateral neglect effectively: the ratio of right/left scan fell gradually over repeated rounds of training sessions using this system.

More recently, the same team (Kim et al. 2010) studied 32 inpatients who had suffered right-hemisphere stroke. Participants in the study were divided into 2 groups of 16 depending on whether or not they had unilateral neglect. The groups were comparable with respect to age, sex, modified Barthel Index score, Functional Ambulatory Category and computer experience scale. According to the results of this study, the group with neglect had more difficulty; their scores were significantly worse for the following variables as detected by the authors' VR system: deviation angle, left visual and auditory cue rates, failure rate on the left side, and left-to-right reaction time ratio. The authors also noted that their system was easily able to detect post-stroke neglect in extra-personal space.

The use of virtual environments to train right-hemisphere stroke patients with unilateral spatial neglect to cross the street safely was also the subject of a study by Katz et al. (2005). The study was conducted on 19 patients with right hemisphere stroke. Of these patients, 11 were given computer desktop-based VR street-crossing training while the other 8 patients were given computer-based visual scanning tasks. Both groups were studied in 12 sessions spread out over a period of 4 weeks, lasting 9 h in total. The virtual environment (non-immersive type) consisted of a street-crossing task presented on a desktop computer. There were various levels of difficulty, each graded by the number and velocity of the cars approaching the pedestrian crosswalk as well as the side (right or left) from which they approached. It was possible to measure 3 scores using this environment: the number of times the participant looked left and right, the total time to complete each level, and the number of accidents. Participants also completed conventional measures of unilateral spatial neglect on pencil and paper as well as a real street-crossing task from video footage. The results of this study showed that both groups performed equally well in classical conventional tests of unilateral neglect. However, the patients who were given VR training performed better in VR and real street-crossing tasks. Similar results, which support the relevance of this virtual environment in training stroke patients who experience difficulty crossing the street as a result of unilateral spatial neglect, were obtained in a preliminary study conducted by Weiss et al. (2003).

Buxbaum et al. (2008) looked at the potential of VR as an assessment method for spatial attention and neglect. Their study was conducted on 9 participants with right hemisphere stroke and 4 healthy control participants. The participants were seated in a motorized wheelchair operated by a joystick mounted on the wheelchair's right arm and moved around a virtual environment projected on a 42 by 31-inch flat-screen display. The participants' task was to travel along a virtual nonbranching path as virtual outdoor objects appeared to the right or left of it. They had to name the objects as precisely as possible. The task was varied in several ways: there were different levels of complexity (including the number of objects to be named), the wheelchair could be controlled by either the participant or the examiner, and the path was navigated in both the "coming" and "going" directions. The authors concluded that this VR task was a sensitive and efficient measure of real-life navigation.

In line with previous work, Dawson et al. (2008), and Buxbaum et al. (2012) developed the Virtual Reality Lateralized Attention Test (VRLAT) and presented its psychometric properties. The authors administered this new test, and other neuropsychological tests, to stroke patients (18 participants in the first study and 70 participants in the second study). The VRLAT requires participants to travel along a nonbranching path at a constant rate. Participants must identify virtual objects that are presented to the right or left of the path. They also need to avoid colliding with the objects. The authors demonstrated that this test is a sensitive and valid measure for assessing lateralized attention and navigation ability. The VRLAT also showed a better prediction of real-world collisions compared to traditional paper-and-pencil tests. A short version of 5 min is also available.

Fordell et al. (2011) used VR to develop a more sensitive assessment battery for spatial neglect in a study on 31 elderly patients who had either a left-sided lesion (N = 12) or a right-sided lesion (N = 19). The subjects were divided into 2 groups depending on whether they had (N = 9) or did not have (N = 22) spatial neglect. The authors used the VR-DiSTRO system developed at the VRlab at Umea University in Sweden. The apparatus consisted of a desktop computer with stereo headphones, a robotic pen, a separate numeric keyboard, a 19-inch CRT monitor, and shutter glasses for stereoscopic vision. The VR-DiSTRO included four subtests: VR-Star Cancellation Test, for visual scanning; VR-Line Bisection, for spatial judgment; VR-Visual Extinction, to distinguish between attention and sensory factors; and VR-Baking Tray Task, as a functional measure of spatial judgment. This study demonstrated that the VR-DiSTRO is a very sensitive battery for spatial neglect. It also showed that VR is an assessment method with high usability among elderly patients with a stroke and that this battery shows potential as a screening instrument for this population.

Kim et al. (2011a) used VR to rehabilitate unilateral spatial neglect among 24 stroke patients who were randomly assigned either to a conventional treatment group (visual tracking, reading and writing, etc.) or to a VR treatment group. The VR treatment was given using the IREX system, which consists of a monitor, a video camera, and computer-recognizing gloves. The video camera recognizes the patient's movements or position and transfers him or her to the virtual space. The authors used the "Bird and Ball," "Coconut," and "Container" environments, all of which require users to move around the virtual environment and stimulate the left side of their bodies. For example, in the "Bird and Ball" environment, the user must touch flying balls, which turn into birds when touched. Both groups received treatment for 30 min a day, 5 days a week, for 3 weeks. Significant differences were observed in post-training results for 2 of the 4 tests: the star cancellation task and the Catherine Bergego scale. The authors concluded that VR could be a beneficial therapeutic technique for stroke patients with unilateral neglect. Kim et al. (2011a, b) used the same system (IREX) with 28 stroke patients and concluded that virtual reality training, combined with computer-based cognitive rehabilitation, maybe of additional benefit for training cognitive impairment in this population.

Glover and Castiello (2006) and Ansuini et al. (2006) used VR to apply left visual neglect program to study 6 patients with right hemisphere stroke. The patients were divided into 2 subgroups according to the location of their cerebral lesions (one dorsal frontoparietal group and one ventral temporoparietal group) and compared to a group of healthy participants. The apparatus used in this research consisted of a monitor "on top of a hollow box into which the subjects could reach". Vision of reaching limbs within the box was occluded by a black partition between reaching limbs and the eyes. The targets for grasping consisted of either a) a real object resting on the table (white polystyrene sphere, 8 cm in diameter) or b) a virtual object presented on the computer screen" (a circle). The subject controlled the virtual hand movements in real time by means of a data glove. The task included a "motor" component, in which the subject had to pick up the object, and a "sensory component," in which the subject had to say where the object appeared. The objects could be located either in the centre or about 30° to the left or right of the midline. The experiment as a whole was comprised of a baseline task session, training tasks session, and a post-training sensory task session, all carried out on the same day. The results demonstrated that the virtual training was effective, but only for patients whose lesions did not affect the inferior parietal/superior temporal regions, which points to the crucial role these regions play in the recovery of space.

Navarro et al. (2013) demonstrated the relevance of their virtual reality training system for street-crossing. This study was conducted with 32 stroke patients with (n = 17) or without (n = 15) unilateral spatial neglect. The virtual system recreates a city with a real street intersection and the participant must move in the environment using a joystick. The participant is seated in front of a screen on which the virtual environment is projected. In this study, the performance of the neglect patients was significantly worse than the performance of non-neglect participants. The authors also noted that the scores with their virtual system had correlations with more traditional tests that measure different components of attention and executive functions.

Since unilateral spatial neglect is mostly studied in the visual domain, Guilbert et al. (2016) proposed a methodology to assess patients in the auditory domain. Fourteen right-stroke patients, including 10 with unilateral spatial neglect, performed 2 computerized auditory cueing tasks in a virtual environment in which the participant's head was located in the centre of a square room: a target-detection and a target-lateralization task. The detection task consisted in pressing a mouse button with the right index finger as soon as the signal is perceived, while the lateralization task consisted in pressing the left or right button of a mouse according to the spatial position of the target. Patients with unilateral spatial neglect shown difficulties only in the lateralization task. While the authors did not compare performances from vision and hearing, these results demonstrate auditory orienting deficits in unilateral spatial neglect, arguing for the development of assessment tools of auditory spatial attention using virtual reality.

Unilateral spatial neglect can affect near and far space differentially. Thus, Yasuda et al. (2017) proposed an immersive virtual reality rehabilitation program using a head-mounted display to train both near and far space neglect. Ten stroke patients with unilateral spatial neglect were evaluated with 2 environments. The first (far space) consisted in a virtual screen located at 15 m distance. Different stimuli flashed from the left to the right of the screen, so the tasks required patients to identify the flashing objects. The second environment (near space) consisted of a reaching task of 3 objects placed on the table in the virtual reality space. Given that unilateral spatial neglect is influenced by the presence of stimuli in the non-neglected hemispace, the authors included a moving slit in the virtual environment to draw attention to the left side and promote attention disengagement, via shutting down the stimulus on the right-side space. The potential benefits of this methodology were measured by evaluating near and far space neglect before and just after the virtual training with stimuli presented (1) in front of the patients on an A4 sheet placed horizontally at 40 cm and (2) by projecting the stimuli on the wall with an overhead projector at 240 cm distance between the midline of the subject's body and the display. Only far space neglect was improved after the rehabilitation program, but this result demonstrates the interest of virtual environments to reduce visual unilateral spatial neglect.

Route Representation

Carelli et al. (2011) studied route representation ability to use virtual mazes in a study conducted on 40 healthy participants and 8 patients with stroke-related focal brain lesions. These authors developed 8 different mazes in 3D, which were computerized versions of the paper-and-pencil mazes in the Wechsler Intelligence Scale for Children-Revised (WISC-R). After first completing the WISC-R mazes on paper, the participants entered the virtual environment and had to find their way through the corresponding egocentric mazes in VR. Positioned in front of the computer screen, the participants navigated through the virtual environment using the keyboard; they moved at a standard walking pace that was kept constant throughout the test. For statistical purposes, the authors organized the participants into one group of patients aged 50–59 years and another group aged 60–71. These groups were compared to healthy participants based on the variables measured in the virtual test, i.e. total number of VR mazes completed and total VR execution times. The results showed that the patients aged 50–59 had significantly poorer performance than healthy participants in terms of total number of VR mazes completed. No such difference in the virtual test was found for the participants aged 60–71. With respect to the paper-and-pencil mazes, there were significant differences between the stroke patients and the healthy participants.

Short-Term and Working Memory

Cameirão et al. (2016) were interested in training attentional and short-term memory deficits of stroke patients, arguing that these deficits impact severely daily life activities. The sample was composed of ten (7 female, 3 males) middle-aged (54.2 ± 9.2 years old) stroke survivors, and the experimental setup consisted of an eye-tracker, a hand tracker and a virtual environment displayed on a high-resolution monitor. Patients interact with the system through arm movements on a flat surface. The authors used emotional stimuli with different valence (positive, negative and neutral) to enhance attentional and short-term memory processes. They argued that the emotional salience may arise for positive and neutral, but not negative stimuli, according to the Socioemotional Selectivity Theory. The task consisted of finding a target image among 14 neutral distractors, and selecting it through arm movements. A recall task took place after performing this virtual task in which patients had to identify the target images among valence-matched number of distractors. The results confirmed the hypotheses: there were more false memories (more wrongly identified images) for negative stimuli. Overall, this study provides arguments for the relevance of the use of emotional content in virtual environments for short-term memory training.

Gamito et al. (2017) reported the results of a study designed to test the use of a virtual reality application in neuropsychological rehabilitation of stroke survivors. They developed a virtual reality-based serious game application with exercises designed specifically for the training of attention and memory processes. For example, the virtual scenario for the working memory task requires the patient to buy several items in a shop. Twenty stroke patients were randomly assigned to 2 conditions: waiting list control or exposure to the intervention of the virtual application. Participants in the control group were evaluated before and after a cognitive stimulation during their inpatient stay at the hospital, using subtests of the Wechsler Memory Scale (WMS-III). Participants in the intervention group were evaluated with these subtests before and after the virtual intervention program, which consisted of 60 min sessions of cognitive stimulation with serious games. The results showed significant improvements in memory functions (including working memory abilities) in the intervention but not in the control group, supporting the effectiveness of virtual environments for cognitive rehabilitation in stroke patients.

Maier et al. (2017) noticed that cognitive deficits associated with strokes rarely occur in isolation and they indicated that these impairments might share common neural substrates. Consequently, they proposed a virtual reality-based rehabilitation method which considers the various cognitive deficits of stroke patients, including short-term and working memory impairments. The rehabilitation system trains other cognitive domains (spatial attention, executive functions) in conjunction with memory abilities and adapts automatically to the impairment level of the patient in each domain. The sample consisted of 11 stroke patients randomly assigned to the experimental (n = 6) or control (n = 5) groups. All patients underwent a six-week long, daily training of 30 min (five times per week). The experimental training consisted of three cognitive training scenarios with a duration of 10 min, with two scenarios involving short-term and working memory. The patients of the control group received 30 individual cognitive tasks and were asked to spend every day 30 min with one task. Participants were assessed with a neuropsychological test battery before and after the treatment. Results showed that cognitive deficits in different domains are correlated, and that virtual training allows the improvement of cognitive performances (including short-term and working memory) over time. Overall, this study demonstrates that cognitive training may be more efficient when deficits are considered in conjunction rather than in isolation.

Episodic Memory

Rose et al. (1999) studied memory retraining after vascular brain injury in an experiment on 48 patients (24 with left hemisphere impairments and 24 with right hemisphere impairments) as well as 48 non-impaired controls. The participants were divided into 2 groups, which were respectively assigned active and passive virtual environment (VE) conditions. The environment consisted of a bungalow with 4 rooms (bedroom, music room, lounge, and kitchen), in which appeared 20 objects (e.g. a camera, a bottle of wine). The environment was presented on a desktop computer and explored using a joystick. In the active task, the participant had to find the correct route through the different rooms. The experimenter asked each participant to study the objects they saw and to find a toy car. The toy car was in the last room of the virtual environment (the kitchen). After each active participant had performed the task, their movements in the environment, which had been stored in the computer's memory, were replayed to the next passive participant. After these tasks were completed, participants completed spatial recognition and object recognition tests based on the virtual environment. This study demonstrated that vascular brain injury patients can perform virtual tasks, although their performance was impaired compared to control subjects. Also, the study showed that performance patterns differed by groups and by condition (active or passive), which involve different memory rehabilitation strategies.

Prospective Memory

Brooks et al. (2004) assessed prospective memory in 42 stroke patients (21 with right hemisphere impairment, 20 with left hemisphere impairment and 1 with bilateral impairment) 1 week to 2 months post-stroke. There was also a control group made up of 18 healthy participants. The environment, consisting of a 4-room bungalow, was presented on a desktop computer, explored using a joystick, and manipulated using a mouse. At the beginning of the assessment, the participant was told that the owner of the bungalow would be moving to a larger house and that they had to put "to go" labels on the furniture and objects to be moved. The participant had to complete 3 prospective memory tasks. Firstly, they had to ask the experimenter to label the items made of glass as "fragile" (event-based task). Secondly, they had to let the mover into the bungalow by asking the experimenter to click on the red button beside the clock in the hall at exactly five-minute intervals (time-based task). Lastly, they had to ask the experimenter to close the door every time they left the kitchen so that the cat would not get out (activity-based task). The results of this study showed that stroke patients were severely impaired at the event-based task and the activity-based task relative to control participants.

Executive Functions and Multitasking

Rand et al. (2005) developed the Virtual Mall (VMall) to train different functions (motor, cognitive, metacognitive) and to assess ability in shopping tasks. This virtual environment is a simulation of a large supermarket with several aisles. Each aisle has a maximum of 60 products, which are placed on the shelves according to different categories (e.g. baking goods, cleaning items), as well as a sign indicating product names with an image showing the type of products to be found there. The flexible environment allows users to select products of different types, numbers and locations. There are 4 items stocked for each different product, positioned on the shelf one in front of each other such that a few items remain if the participant takes one of them. Products are named and enlarged when selected by the participant. There are also auditory stimuli (e.g. background shopping mall-type music) whose purpose is to increase the feeling of really being in a supermarket. The VMall is presented on a video capture VR system (IREX). Once inside the VMall, the participant moves around by touching arrows, which scroll the screen left or right. Using a red glove worn on their hand, the participant can go down an aisle by touching its sign and select items by touching them. Selected items appear in a shopping cart. The participant may be required to perform different tasks, e.g. picking up ingredients for a recipe or buying items following a shopping list. The VMall is able to record a number of scores, such as the number of correctly chosen items, the time it took to perform the task, the order in which the items were chosen, etc. After some technical adjustments were made, the pilot study was carried out on 8 stroke patients (5 with right hemispheric stroke and 3 with left hemispheric stroke). This study confirmed the usability of the VMall by this population, as participants were able to perform the tasks and enjoyed doing so.

Rand et al. (2007) used VMall to compare the performance of 14 stroke patients, 11 of whom were at a subacute stage and 3 of whom were at a more chronic stage. Their performance was compared to that of healthy participants divided into 3 groups: children, young adults and older adults. The participants had to perform a 4-item shopping task in the VMall. The stroke participants scored significantly lower in mean total shopping time compared to the 3 healthy groups.

The Multiple Errands Test (MET), originally developed by Shallice and Burgess (1991) is a tool designed to aid in the assessment of executive functions in a real-life context. This test is composed of 3 tasks (purchase 6 items, find out 4 pieces of information, and meet the tester at a certain time at a preset location); these tasks are governed by certain rules and performed in a shopping centre. The Virtual Multiple Errands Test (VMET) was developed by Rand et al. (2009a). The VMET has the same number of tasks and some of the same instructions as the MET-HV (Knight et al. 2002) (i.e. purchase items and find out information). However, the items were changed to be more familiar in the VMall, while the third task (meeting the tester at a certain time) was replaced with checking the content of the shopping cart at a certain time. The participant was able to see a clock in the bottom left corner of the screen in order to perform this task. The experimenter observed participants as they performed the tasks and recorded a number of scores (non-efficiency, rule breaking, use of strategy mistakes, partial and complete mistakes of completing a task, and the total number of mistakes). In their study on the validation of the VMET, Rand et al. (2009a) showed that this new test was successful at differentiating statistically between 9 stroke patients (6 right hemispheric stroke and 3 left hemispheric strokes, 4 at a chronic stage and 5 at a post-acute stage) and healthy participants (younger and older).

Significant correlations were found between the MET and the VMET both for post-stoke participants and for older healthy participants.

In another study, Rand et al. (2009b) used the VMET to train multitasking ability in 4 stroke patients over 10 sessions, each 60 min in duration. Each session consisted primarily of shopping tasks in the virtual supermarket. Using a pre- and post-session assessment, the authors showed that this virtual environment substantially improved performance in executive functioning and multitasking.

The NeuroVR 1.5 system, developed by Riva et al. (2009), is a cost-free VR platform based on open-source software, available to clinicians and researchers in order to meet the assessment and rehabilitation needs of diverse populations (http://www.neurovr.org). In a study by Carelli et al. (2009), this virtual platform was used to present the virtual supermarket in order to rehabilitate shifting-of-attention and action-planning functions in 2 patients (aged 59 and 72 years) who had suffered an ischemic brain lesion. The virtual supermarket is presented on a desktop monitor. Participants can move through the different aisles of the supermarket using a gamepad. In this study, they were asked to pick various items from the products available on the shelves (in other words, to go shopping). The task can be set to different levels of difficulty depending on, for instance, the number of products the participant is required to buy or the order in which they must be collected. The environment allows for data on execution times and errors to be collected. The execution time scores suggest that the VR procedure was more sensitive than the traditional neuropsychological assessment, as only it was able to detect the patients' cognitive problems. As for error scores, both the VR tasks and the traditional tests were able to detect these difficulties. This study supports the idea that the behaviour of participants in VR environments is representative of their behaviour in complex, real-life situations.

The team of Raspelli et al. (2010) published a study comparing 6 stroke patients to 14 healthy participants. The results in this environment showed weaker performance in stroke participants as compared to control participants, especially in scores for "execution time" and "maintained task objective to completion." These studies support the idea that executive deficits can be detected in stroke patients when running Multiple Errands Test in the NeuroVR supermarket. Recently, a study by Raspelli et al. (2011) supported the validity of this virtual environment by showing that there were correlations between it and some tests of executive functions.

Lee et al. (2003) also developed a virtual supermarket made up of 4 displays stands, four refrigerators (each with a door), and 2 up-opened refrigerators. Participants used a joystick as a hand-held control to navigate through the environment, open the refrigerator doors, pick up goods, and put them in their cart. This virtual environment measured a number of parameters during the performance of the task (elapsed time, distance moved, number of collisions with walls, number of selected goods, number of refrigerator doors opened, number of joystick button presses, and error rate). This study was conducted on 5 participants with TBI or stroke. The participants performed the task 5 times over a period of 5 days. The authors did not go into statistical analyses in this study. However, the participants' performance results showed that elapsed time, distance, number of collisions, and error rate tended to decrease with time, while the number of selected goods and button pressing tended to increase with time. However, the participants' personal observations revealed major difficulties in using the interface, e.g. difficulty using the joystick. After improvements were made to the system, the team later published another study (Kang et al. 2008) conducted on 20 people diagnosed with a stroke due to unilateral brain lesions and 20 healthy controls. The results of this work are promising; they showed differences between the 2 groups in cognitive variables as measured in the virtual environment (performance error, delayed recognition memory score, attention, and executive index). Despite the improvements, a large proportion of the participants still reported experiencing difficulties using the interface, which must be addressed before this type of system can be used more widely as a training tool for this population.

Jovanovski et al. (2012) presented the psychometric properties of a new virtual environment: The Multitasking in the City Test (MCT). They administered this test and other neuropsychological tests to 13 participants, including 11 stroke patients and 2 TBI patients. The study also included 30 normal participants. The virtual environment of the MCT consists of a post office, drug store, stationery store, coffee shop, grocery store, optometrist's office, doctor's office, restaurant and pub, bank, dry cleaner, pet store, and the participants' home. Participants are required to purchase several items, obtain money from the bank, and attend a doctor's appointment within a period of 15 min. Participants can view information (i.e. list of errands, the amount of money in their wallet, etc.) at the bottom of the computer monitor. Results suggested that patients can be differentiated from normal individuals by quantitative (i.e., the number of errors) rather than qualitative (i.e., type o errors) aspects of performance. The authors demonstrated the ecological value of MCT based on significant correlations they obtained with the Frontal Systems Behaviour Scale (FrSBe). MCT is seen as a valuable tool to predict real-world functioning in patients with acquired brain injury.

Faria et al. (2016) developed a virtual reality-based intervention which involves a virtual simulation of a city (Reh@City) to assess several cognitive domains, including executive functions. They compared 2 groups of stroke patients from 2 rehabilitation units. Participants in the first group (n = 9) performed a virtual reality-based intervention, while the other (n = 9) performed a conventional cognitive rehabilitation. Both groups underwent a 12-session intervention (20 min each session) distributed from 4 to 6 weeks. In both groups, the efficiency of the treatment was measured by a pre- and post-intervention assessment with traditional neuropsychological tasks, including executive function tests (e.g., the Trail Making Test, the Picture Arrangement test from the Wechsler Adult Intelligence Scale III). According to the authors, the Reh@City assesses executive functions (problem resolution, planning and reasoning skills) by defining objectives that the participants need to accomplish. Within group analysis revealed that the control group improved only in social participation and self-reported memory, whereas cognitive deficits were improved in the experimental group. Moreover, between group analysis revealed significantly greater improvements in executive functions (among other cognitive improvements) when comparing performances of experimental and control groups.

Overall, these results suggest a better efficiency of virtual reality-based training than conventional therapy for the treatment of cognitive deficits, including executive impairments.

More recently, Nir-Hadad et al. (2017) pointed out that the assessment of executive functions must be done using ecologically valid assessments. In that perspective, they examined the ecological validity of the Adapted Four-Item Shopping Task, a task dedicated to the assessment of budget management, which can be considered as an instrumental activity of daily life. Participants performed this shopping task in both a virtual interactive shopping environment and a real shopping environment (the hospital cafeteria). The goals of the study were to examine construct-convergent validity of the shopping task by determining the relationships between this virtual task and clinical measures of executive functioning (e.g., subtests from the BADS), and to examine ecological validity by identifying the potential relationship between performance in the virtual shopping environment and in the real-world cafeteria. The sample consisted of 19 people with a stroke, aged 50–85 years, and 20 age- and gender-matched healthy participants. Several correlations were found in both groups between the performances on the virtual shopping task and clinical assessments of executive functions. In addition, there was a relationship between performances in the virtual shopping task and in the cafeteria, only in the stroke group. Ecological validity of the virtual environment is also highlighted by the fact that 70% of the participants indicated that they felt as if they were inside the environment. Overall, results provide good support for the validity of the virtual shopping task as an appropriate assessment of instrumental activity of daily living that requires the use of executive functions.

Augmented Reality

The Mixed Reality Rehabilitation System (MRRS) is a technique to aid in physical and cognitive rehabilitation of people with deficits resulting from brain pathology. Mixed reality can be thought of as being situated partway along a continuum between virtual reality and physical reality. The technique improves upon VR by combining real and virtual elements into a single seamless landscape. The technique consists of wearing a video see-through head-mounted display (VST-HMD). This creates an environment equipped with real physical components that is augmented by virtual elements. Salva et al. (2009) used this technique in a study conducted on 14 patients aged from 18 to 63 years who had suffered a cerebrovascular accident (CVA). The patients were immersed into environments and assigned entertaining and interactive tasks relevant to the virtual environment while still addressing their physical and cognitive therapeutic goals. The authors concluded that this interactive experience is very promising for rehabilitation but also point out certain areas in which the technique could be improved. Other authors note the potential of this approach to help stroke patients and other populations facing neurological problems apply rehabilitation activities in their everyday lives (Pridmore et al. 2007; Edmans et al. 2004).

Dvorkin et al. (2012) and (2008) developed the Virtual Reality and Robotics Optical Operations Machine (VRROOM) for mapping the neglected space. They studied samples of stroke patients, with and without neglect, and healthy participants. Their system included a Personal Augmented Reality Immersive System (PARIS) display for rendering the virtual environment; images are superimposed over a large workspace. The virtual environment consisted of a 3D room shape in which 3D virtual ball-shaped objects ("targets") appeared at different locations and heights in space. Each participant was seated in a dark room facing the VRROOM system holding a response button in their right hand with their head position kept constant on a chin rest. The participant had to push the response button as fast as possible whenever they detected a target. The results of these two studies showed that participants with neglect exhibited performance asymmetries characterized by a gradual reduction of attention across space, rather than a harsh transition. These studies also showed that the virtual task was able to provide assessment and monitoring of recovery neglect that was quantitative and more sensitive than traditional paper-and-pencil tests. Jannink et al. (2009) also showed that a virtual 3D test had the potential to detect and measure unilateral neglect in stroke patients in the subacute and chronic phases.

Discussion

Considering our synthesis, it appears that most of the work that has been conducted with adult stroke patients supports the fact that virtual reality is sensitive to cognitive deficits arising from this condition and that this technique is also promising to improve their cognitive functioning. The analysis of these publications also leads to stress that only a few cognitive functions were explored in virtual reality with this clientele. Those are mainly spatial attention and spatial neglect, and executive functions. Attention, short-term / working memory and episodic / prospective memory are also among the studied functions.

One of the qualities of virtual reality, emphasized in previous publications, is to be closer to real life than classical tests. Some studies (Jovanovski et al. 2012; Rand et al. 2009a) have pointed out interesting relationships between the virtual performance and functioning in daily life, supporting the ecological value of this approach. Moreover, some studies have shown that virtual reality was more sensitive than traditional "paper and pencil" tests in the assessment of deficits resulting from a stroke (Broeren et al. 2007; Buxbaum et al. 2012; Dvorkin et al. 2012; Katz et al. 2005, Rand et al. 2005). However, too few results are presently available to confirm with certainty the desired benefits of virtual reality. Several authors (Cherniack 2011; Crosbie et al. 2007; Morganti 2004; Rose et al. 2005; Tsirlin et al. 2009) have emphasized the potential of virtual reality compared to traditional assessments. It seems that virtual reality has added value in the assessment and rehabilitation of cognitive deficits compared to traditional setting, although this remains to be supported by further studies.

Other limits, already highlighted in previous publications, compromise the widespread use of data from studies done in virtual reality with stroke patients. The first limits of previous work are their methodological design. It should be emphasized often restricted the number of participants. It would be important to focus more on the participants' age and post-stroke phase (acute vs. chronic) to better differentiate the value of virtual reality. Other limitations concern technical and ergonomic aspects of virtual reality systems that were used. Great variability between devices and immersion techniques (joystick, mouse, HMD, 3D glasses, mixed reality, video-capture, flat screen, immersive or non-immersive techniques, etc.) limit the generalization of the studies because there are too few with the same conditions to reach valid conclusions. Thus, it appears necessary to: a) continue research on all kinds of cognitive functions; b) develop research designs that will validate the hypothesis that the virtual reality is an ecological approach; c) compare the virtual reality environments with classical and standardized tools to establish their validity and reliability. All this therefore highlights the importance of further work in this emerging field.

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Chapter 15
Assessment and Rehabilitation after Traumatic Brain Injury Using Virtual Reality: A Systematic Review and Discussion Concerning Human-Computer Interactions

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Introduction

Over the past several years, traumatic brain injury (TBI) has been labelled as a "silent epidemic" (Hoffman et al. 2010; Rose et al. 2005; Vaishnavi et al. 2009). TBI is an important and global public health issue in the United States and Canada (Cassidy et al. 2004; Langlois et al. 2006). In fact, this condition is quite widespread and leads to death and disability in millions of individuals around the world each year (Flanagan et al. 2008). More specifically, it is estimated that 5.3 million people are living with TBI-related disability in America. They also face numerous challenges in their efforts to return to a fulfilling and productive life (Langlois et al. 2006).

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While TBI can occur at all ages, it has been largely documented in adulthood and usually appears in young adults aged less than 45 years old. It is the most commonly reported neurological injury in children and people aged 65 years and over. Aging is known to influence rehabilitation outcome negatively, daily living, and overall autonomy (Thompson et al. 2006).

The spectrum of severity of TBI can be categorized into three main categories: severe, moderate and mild. This classification is based on several medical cues observed soon after trauma. These include the Coma Glasgow Scale (CGS) score, the duration of post-traumatic amnesia (PTA), the length of loss of consciousness and the presence or not of visible brain damage. Combined together, they can lead to a more precise diagnosis. In fact, Cassidy et al. (2004) stated: "*From a public health perspective, it is important to know the incidence of a condition in order appropriately to plan healthcare policy and provision*." Hoffman et al. (2010) have also reported that the costs of these injuries will be both extensive and enduring.

The Centers for Disease Control and Prevention define TBI as a "*craniocerebral trauma associated with neurological or neuropsychological abnormalities, skull fractures, intracranial lesions or death"*. As part of its work in helping survivors deal with the consequences of their injuries, the Congressional Brain Injury Task Force (2004) defined TBI as a "non-degenerate, non-congenital insult to the brain from an external mechanical force, possibly leading to permanent or temporary impairment of cognitive, physical, and psychosocial functions, with an associated diminished or altered state of consciousness".

Due to the high rate of post-injury neurological lesions, almost all individuals with moderate or severe TBI experience permanent cognitive effects (Fay et al. 2009; Pinkston et al. 2000).

It has been recognized for a long time that TBI greatly influences people's adaptive behaviours in daily life (Sosin et al. 1996). Moreover, these problems tend to persist for a long time after the individual has recovered from the acute effects of TBI (Anderson and Knight 2010). Specifically, TBI can result in a variety of cognitive impairments such as memory issues, dysexecutive impairments, learning or attention deficit, etc. From a neuropsychological standpoint, assessment followed by rehabilitation becomes the principal course of treatment. However, the main challenge here is to obtain a accurate idea of how exactly behaviours are directly affected by cognitive dysfunctions in daily living skills and activities. In this perspective, VR appears to be a promising tool owing to its capability to reproduce with reliability everyday life.

In this chapter, we will discuss the assessment and the rehabilitation of neuropsychological deficit after a TBI by using VR. The principal goal is to determine whether VR technologies can be helpful or more efficient than traditional methods to assess or treat neuropsychological post-traumatic problems. To achieve this goal, we have produced a systematic literature review on the use of VR after TBI at all ages. More specifically, our literature review has been conducted based on French or English publications from 1980 to 2017 found in the following databases: Academic Search Complete, CINAHL, Computer & Applied sciences, Eric, MEDLINE, PsychINFO, FRANCIS and Psychological and Behavioural Sciences collection. The following keywords were used to search papers: traumatic brain injury (including mild TBI), AND cognitive functions, cognition, attention, memory and learning, perceptual, executive functions, AND assessment, rehabilitation, remediation AND VR. All text duplications across databases were deleted. Furthermore, we have excluded publications based on the following criteria: texts with non-related subject matter (i.e. not dealing with cognitive functions such as social skills or disruptive behaviours, using VR to treat physical deficiencies); texts of a generally descriptive nature (description of a research program or a virtual environment designed for assessment, rehabilitation or a proof of concept); texts with general comments or no results; texts containing samples of participants with different or mixed diagnoses (e.g., acquiring traumatic injury, head trauma, post-traumatic disorder, stroke, tumours, etc.); texts where the virtual environment did not target a "pure" cognitive function (e.g., studies on activities of daily living such as cooking, driving, etc., were not considered). Even if meta-analyses or systematic reviews in the same subject have been rejected for this paper, the references were screened as well as the references listed in the selected articles synthesized in this chapter. Some authors have been contacted to obtain more details on the participants, methodology or results. Altogether, five authors have been contacted by email; unfortunately, we received no answer. At the end of this process, 254 articles were obtained in the first stage, and 32 were considered as relevant, and therefore were selected and analyzed in the final stage.

This chapter consists of three sections. The first section concerns neuropsychological assessment of children and adults and summarizes the literature for attention, memory and learning, spatial navigation and multitasking (including prospective memory and executive functions). The second section presents studies dealing with neuropsychological rehabilitation for some cognitive functions. The last section summarizes the information obtained via the systematic review and lead to a specific discussion regarding the effects or influences of human-computer interaction (HCI) that could also impact the quality and correctness of the measures obtained by the VR neuropsychological assessment.

Neuropsychological Assessment

Neuropsychological assessment following TBI is very important to detect subtle (and less subtle) cognitive deficits. At each stage of recovery, neuropsychologists have to describe deficits, progress, and at the end of the process, permanent deficits. Presently, there is a debate raging between two schools of thought: traditional (or classical) vs ecological assessment. On the one hand, traditional "paper & pencil" tests are specific enough and sensitive enough to detect fine cognitive deficits, and then allow the elaboration of rehabilitation plans. On the other hand, assessment of these traditional tasks are not accurate enough to measure how exactly each cognitive function works together in everyday life. Consequently, the generalization and the transfer of the experiments made in rehabilitation programs towards the everyday live should be limited. Most neuropsychological tools have been developed in the laboratory, a setting in which tasks can appear artificial compared to the challenges encountered in daily life. An ecological approach of cognitive assessment, by contrast, would include tasks that are more realistic (and similar) with respect to everyday life and consequently yield greater sensitivity in detecting post-traumatic cognitive impairment.

Some research on cognitive deficits after TBI has taken an ecological approach. Most of this research has demonstrated the relevance of using virtual environments in reliably assessing neurological deficits as they are encountered in daily life (Kinsella et al. 2009; Knight et al. 2006; Titov and Knight 2005). At the same time unfortunately, few studies have shown the contribution of 3D video games in neuropsychological assessment and rehabilitation after a TBI (Caglio et al. 2009).

The main advantage using immersive (or non-immersive) assessments is that the subject is exposed to realistic stimuli. In addition, measures are easily standardized. Virtual reality is at the confluence of ecological assessment (in which tasks are lifelike) and traditional assessment (in which reliability, standardization and normalization are crucial). Virtual reality has been described as a tool for systematic, rigorous and standardized assessment of cognitive functions (Schultheis and Rizzo 2001; Tarr and Warren 2002; Zhang et al. 2003). It also represents an ecological and a valid means to measure specific functions by allowing users to interact with computer-simulated objects and environments that are both in 3D and in real time, 'like in real life' (Pratt et al. 1995).

Assessment after TBI in Childhood and Adolescence

We have searched in the literature of assessment of cognitive deficits using VR after TBI in children and teenagers and have identified only five published papers:

- Erez et al. (2013) used the VMall (a virtual supermarket) to assess executive functions after pediatric TBI.
- Lee (2011) used the Virtual Classroom (a VR Continuous Performance Task) to assess attention after mild TBI (mTBI).
- Nolin (Martin and Nolin 2009; Nolin et al. 2009) used the same virtual environment (V-Classroom) to compare a traditional tool (the VIGIL for testing attention processes) with immersive assessment to detect attention deficits in children with TBI.
- Nolin et al. (2012) have used the experimental design mentioned above to explore if VR can highlight better cognitive deficits after mTBI following a sports injury (i.e. sports concussion) than traditional tests.

Executive Functions

Erez et al. (2013) elaborated a pilot study to estimate the feasibility of assessing executive functions in children and adolescents with severe TBI aged 8–16 years old. For this, they assessed the performance during Virtual Shopping Tasks (VST) in 20 children with TBI and 20 control children, age and gender matched. In these tasks, the subjects had to shop four items located in two different aisles of a virtual supermarket (VMall) using the non-immersive IREX system. The completion time, numbers of errors and sequence of products bought were collected. The authors found a significant difference in the four-item shopping performance between the groups regarding the following variables: shopping time (TBI subjects took longer than the control group), number of mistakes (TBI subjects committed more errors than the control group), and efficiency (the strategies used by TBI group were less effective when compared to the control group). A discriminant analysis has shown a classification rate of 75% of the participants into each group. Considering these results, it appears that the VMall is an interesting and promising tool to assess dysexecutive syndrome after pediatric TBI. However, further research is needed to enhance this tool mainly in terms of validity and reliability.

Attention Processes

Lee (2011) compared a group of eleven youths with mTBI (aged between 8 and 14 years) to a group of eight normally developed children (paired by age, gender and grade in school) in order to detect attention problems using a Virtual Continuous Performance Task: the V-Classroom (by Rizzo et al. 2000). In this immersive virtual environment, the children are sitting at a virtual desk and can look around to see other students and desks, a teacher's desk and a virtual teacher, a blackboard, a large window looking out (a playground with buildings, vehicles, and people), and a pair of doorways at each end of the wall opposite the window, through which activity occurs. To assess attention, the children are instructed to observe a set of letters presented, one after the other, on the blackboard in front of them. They must press the mouse button rapidly and precisely when the letter "X" appear immediately following the letter "A". The results have not shown any statistical difference between groups on the omission and commission of error indices. In this case, the results seem to indicate that the V-Classroom is not sensitive enough to detect attention deficit after mTBI. On the other hand, it seems to be important to question the number of subjects used for statistical analysis and the lapse of time between the assessment and the accident (6–12 months). The latter could explain the absence of any problems: after mTBI, it is known that the spontaneous recuperation bring the subject to meet is/her premorbid cognitive level of functioning that is often without attention deficit.

Nolin and his collaborators have conducted three studies. Firstly, in the Martin and Nolin (2009) study, the aim was to demonstrate the sensitivity of VR in the detection of attentional deficit after a moderate-severe TBI. For this, eight children with a TBI were compared to six children without a history of neurological impairment. The results obtained in the Virtual Classroom (V-Classroom) were compared to those obtained on the VIGIL Continuous Performance Test (CPT). Statistical analysis has demonstrated that, contrary to the V-Classroom, traditional CPT can't differentiate the two groups. When assessed with the V-Classroom, the TBI group had more errors of inhibition and moved more frequently their heads as detected by the head motion tracker.

Secondly, in the Nolin et al. (2009) study, a group of eight children aged between 8 and 12 and having sustained TBI were evaluated with the VIGIL CPT and the V-Classroom. Mean comparison tests with repeated measures were used by the authors to compare the output of children with a TBI concerning the number of omissions, commissions and the reaction time on the traditional VIGIL CPT and in the Virtual Classroom. Paired t-tests showed that children with TBI made significantly more commission errors. Furthermore, their reaction time was significantly longer in the V-Classroom but not in the traditional CPT. These studies indicated a good potential for V-Classrooms to detect attention deficit and other behavioural particularities (such as agitation or hyperactivity) on a sample of TBI children. On the other hand, it is important at this stage to question if the technology (namely head-mounted display, mouse and keyboard) has potential to overload the attentional network.

Lastly, Nolin et al. (2012) have recruited 25 adolescents who sustained a mTBI after a sport accident. The experimental group was paired with a group of 25 healthy controls with similar sociodemographic characteristics and without sport concussion. The experiment aimed to compare the performance of the two groups of V-Classroom and VIGIL-CPT. The preliminary results indicated that the experimental group experienced more cybersickness compared to the control group. This variable (i.e. cybersickness) was then included in covariance in further statistical analyses. The main results showed that VR was sensitive enough to detect inhibition deficit, as it was observed by the following indicators: number of commission errors and the number of left-right head movements. Hence, the authors concluded that VR is more sensitive and maybe more ecological than traditional tasks.

Overall, these studies have covered only two aspects of TBI deficits: attention/inhibition disorders and dysexecutive impairments. While V-Classroom is a good instrument to detect attention deficits after moderate and severe TBI, it may not entirely be applicable to the case of mTBI. In fact, two studies interested in post-traumatic deficits after mTBI have given different results. In the light of these studies, it is not clear if the V-Classroom appears to be less sensitive to light trauma as seen in Lee's study with a group of mTBI (Lee 2011). Indeed, these results were not supported by those obtained by Nolin et al. (2012), who propose the V-Classroom as a more sensitive tool to detect subtle change in cognition after brain concussion. These different results could certainly be re-analyzed by considering methodological issues.

On the other hand, the VMALL seems to be a promising tool to assess executive dysfunctions. The use of an enjoyable task could enhance the motivation and participation of children to perform daily life-like tasks to detect post-traumatic deficits. However, we can question whether the tasks performed in a supermarket are realistic, considering the participants' age and the reality of parental demands. Obviously, more studies are needed to have better proof concerning the utility of VR in detecting cognitive deficits after TBI in childhood. Specifically, we need to increase the amount of assessment protocols, which in turn will target a wider range of cognitive functions permitting a more precise and global view to help clinicians in their choice of assessment means. Finally, it is very important that researchers and 3D resources create assessment protocols that take into account the neurodevelopmental aspects of each age group.

Assessment after TBI in Adulthood

In our literature review, we found no research on the assessment of cognitive deficits after TBI in old patients. The researchers using VR with older adults were only interested in physical rehabilitation after a stroke. The only paper found using the terms "VR", "traumatic brain injury" and "aging" or "older" or "elderly" was written by Bisson et al. (2007) to determine the effect of VR and computer-based biofeedback training on balance and reaction time in older adults (without TBI). Concerning the assessment of cognitive deficits in adulthood after TBI, we have found 18 articles that cover memory and learning, spatial navigation, multitasking, prospective memory and executive functions:

- Arvind Pala et al. (2014) created the Virtual HOMES, a virtual apartment to assess learning capacities.
- Banville and Nolin (2012) and Banville et al. (2010) used the Modified Max Payne video game to assess prospective memory.
- Besnard et al. (2016) used the non-immersive coffee task (Allain et al. 2014) to assess executive function integrated into an activity of daily living in sTBI.
- Canty et al. (2014) used the VR Shopping Task (VRST) to assess prospective memory.
- Knight et al. (2006) were interested in understanding the effect of distraction in prospective memory within a Virtual Street environment.
- Lengenfelder et al. (2002) observed the potential of an attention task in order to assess attention disorders after TBI.
- Matheis (2004) and Matheis et al. (2007) used a VR Office to test visual-spatial memory.
- McGeorge et al. (2001) designed a virtual university (the Virtual Errand Test) to assess the multitasking abilities of a group of TBI survivors.
- Mioni et al. (2013) adapted and simplified the Italian version of the Virtual Week (Mioni et al. 2015), a board game evaluating prospective memory.
- Martínez-Pernía et al. (2017) used a serious game developed with the eAdventure platform to assess executive functions.
- Renison et al. (2012) constructed a Virtual Library Task analogous to the Real Library Task to assess executive functions after TBI.
- Skelton et al. (2000) and Livingstone and Skelton (2007) used a Virtual version of the Morris Water Maze to assess memory and orientation.
- Skelton et al. (2006) also used the Virtual Morris Water Maze to observe navigational capacities in a virtual environment after a TBI.
- Slobounov et al. (2010) studied if participants who sustained a mTBI after a sports concussion presented functional deficit on spatial memory.
- Sorita et al. (2013) used a virtual environment to evaluate if spatial representation and route learning is different in VR compared to a real environment.
- Zhang et al. (2001) used a Virtual Kitchen (previously developed by Christiansen et al. 1998) in order to assess a set of selected cognitive functions.

Attention

Lengenfelder et al. (2002) aimed at finding how VR could help to examine directly the impact of divided attention on driving performance after a TBI. In this pilot study, three subjects who had sustained a TBI were paired with three healthy subjects by age, gender and education. The research procedure involved a standard neuropsychological assessment by administrating Auditory Consonant Trigrams and the Paced Auditory Serial Addition Test (PASAT) to assess divided attention, working memory, and information processing. The virtual tasks consisted in driving on a VR route (primary task) and paying attention to numbers in the subject's visual field (secondary task). The virtual divided-attention task was broken down into following conditions: simple (the stimuli were presented in a fixed central location on the windshield of a virtual car at a pace of 2.4 or 0.6 s) and complex (the stimuli were presented in a random location at a pace of 2.4 or 0.6 s). The results did not indicate any differences in relative speed between TBI and healthy control subjects on any of the four divided attention conditions. In addition, TBI and healthy control subjects did not seem to differ when the secondary task was either simple or complex. No group differences in errors were observed. The same conclusion was made on the standard neuropsychological assessment. Errors on the virtual divided-attention task were correlated with the PASAT, thus indicating more errors on the divided attention task, and a lower total number of correct responses on the PASAT.

Memory, Learning and Wayfinding

Matheis (2004) wanted to observe if persons with TBI were able to acquire a predetermined learning criterion, and if a learning strategy could impact the remembering of target items in a more functionally valid testing paradigm. In addition, the author wanted to compare VR memory tasks with several neuropsychological measures in order to provide an initial measure of the concurrent construct validity of his VR memory task. For this, Matheis (2004) examined the memory performance of 20 individuals with TBI paired with 20 healthy controls. The VR memory testing consisted of a list-learning task implanted in a VR office environment. The task gave the opportunity to learn 16 targets, arranged throughout the office, with the person having a maximum of 12 learning trials. Results have shown that TBI and control subjects did not differ in the number of trials required to initially learn target items. Delay recall (30 min and 24 h) did not differ between groups. In a similar study, Matheis et al. (2007) aimed to investigate how memory performance in a virtual environment may differ from standard testing. Their second aim was to demonstrate that VR memory tasks could distinguish TBI from the control group. To do so, 20 individuals with moderate to severe TBI were paired with 20 healthy controls matched according to age, gender, and education. The memory tasks in the VR Office were a verbal list-learning paradigm, which required the participant to learn the 16 target items, depicted among numerous other office distracters (e.g., computers, file cabinets, etc.), during a set of sequential exposures to the VR Office environment. The results have not shown a difference in the number of trials needed to learn the target. A subgroup of TBI (TBI-NOT-MET the learning criterion) seemed to recall fewer items immediately and at a 30 min delay when compared to other TBI (TBI-MET the learning criterion) and control subjects. The difference between the groups disappeared apparently after the 24 h delay. The same pattern was repeated for the recognition task.

Arvind et al. (2014) have elaborated a non-immersive virtual apartment (Virtual HOMES) in order to assess memory and learning. Several scores were obtained after the exploration of the virtual apartment: learning, proactive interference, semantic clustering, retrieval strategies, and recognition. For their experimental design, the researchers have recruited one group including moderate-to-severe TBI patients (n = 15) and two groups of healthy adults (16 young and 15 elderly). They observed that older adults and TBI patients perform similarly for learning, proactive interferences, retrieval strategies and recognition score. However, cognitive mediators, that differentiates older adults and TBI patients (e.g., executive functioning (for the first group) and memory process (for TBI group) were found. These results suggest that the rehabilitation of TBI patients should take into account the complexity of cognitive interaction between several brain functions. However, there is some concern about how the HCI could influence the performance of both TBI and elderly group. Indeed, the cognitive health of the elderly group should also have been taken under consideration in this sample.

Slobounov et al. (2010) evaluated if a mTBI caused by a sports accident can provoke functional deficits on spatial memory and brain functioning in asymptomatic individuals. To do so, 15 mTBI participants and 15 athletic participants with no history of brain damage were recruited. Participants were asked to encode a navigation route after they walked in a Virtual Corridor. They were asked to navigate randomly or with a specific goal such as to find a specific room. When they experimented the task, a fMRI examination helped assess cerebral activation. No difference between the two groups was found based on the following indices: accuracy of task performance and completion time. Furthermore, the cerebral activation during encoding or retrieval was similar in both groups. However, compared to the control group, mTBI participants showed a particular pattern in the prefrontal and parietal cortex as they were encoding information.

Skelton et al. (2000) evaluated how people with TBI could solve a task similar to the Morris Water Maze simulation. In order to achieve this goal, 12 participants with TBI and 12 ages- and gender-matched comparison participants were exposed to a three-dimensional 'virtual arena maze', consisting of a large round arena within a very large square room. Participants were required to learn the place of an invisible target on the floor of the room based solely on distal cues on the walls of the room. The results of this study showed that subjects who had suffered a moderate to severe TBI were worse at learning the location of an invisible target in the computer-generated space than the control group. Individuals with TBI showed longer latencies and path lengths on invisible target trials and spent less time searching for the correct quadrant on probe trials than matched controls. Ultimately, it was found that most of the samples had significant deficits in place learning and that these deficits correlated with those found in the Rivermead Behavioural Memory Task, as well as with self-reports of difficulties in wayfinding and episodic memory. At the end of the study, the authors questioned whether the problems observed could be generalized in another sample and what role could be played by visual spatial deficits following TBI.

To answer these questions, Skelton et al. (2006) reproduced their own study (Skelton et al. 2000) with the goal of understanding better spatial cognition deficits after brain injury. Three sub-goals were reached in this study: (1) to validate a more realistic Virtual Morris Water Maze simulation, (2) to replicate their previous study with a new sample of TBI survivors and (3) to determine the best dependent variables to identify deficits in spatial navigation in this population. Seventeen subjects who had suffered a TBI and 16 healthy matched controls were recruited to conduct this research. Participants did tasks concerning spatial learning and memory in the Virtual Morris Water Maze using the Unreal Video Game Engine. The results showed several deficits compared to the control group: firstly, they took more time and longer more circuitous paths to find the platform when it was invisible. Secondly, the results showed significant learning over trials in terms of both distance and latency. Otherwise, those with brain injury did not show significant change over trials on either measure. More specifically, the authors stated that subjects without brain injuries appeared to learn the platform location on the first trial and were able to go to its location thereafter, whereas those with TBI learned slowly and never achieved the same level of performance. Skelton et al. (2006) had concluded that TBI subjects showed severe impairments in spatial navigation in a virtual version of the Morris Water Maze. Thus, they confirmed that people suffering from TBI tended not to have trouble with desktop virtual environments. They verified that the deficits observed in the previous study were not due to the primitive graphics available at the time, but persisted in a much more realistic environment. In the end, they successfully identified which of the many possible measures of behaviour in the maze were practical, sensitive and specific.

Livingstone and Skelton (2007) aimed to investigate the pattern of cognitive processes implied in wayfinding, namely the abilities to associate a landmark with a destination, to discriminate this landmark from other distracting stimuli and to navigate a path to a destination using the landmarks. Specifically, they assessed if individuals with TBI were able to find a target both with egocentric and allocentric spatial navigation using adequate (egocentric or allocentric) strategies. To conduct this research, the authors recruited 11 participants with TBI paired with 12 healthy control subjects. The virtual environment consisted of a large virtual arena (The Virtual Morris Maze) located within a very large room with walls, doors and windows that provided views of a naturalistic landscape. Two principal experimental tasks were designed in this environment: the Single Object Maze to test the ability to associate a target with a single landmark object, and the Ambigous Maze to test ultimately the learning of a target location allocentrically or egocentrically. The experiment ended with complementary measures about memory and visuoperceptual abilities. More specifically, the experimenters asked the participants to find proximal objects (which allowed participants to use egocentric navigation strategies) or distal objects that forced participants to rely on distal features of the environment (e.g. room walls, landscape elements, etc.). This permitted the authors to test the ability of the participants to use allocentric navigation strategies. Results showed impairments for TBI when they had to navigate without proximal landmarks or by using only distal landmarks. For the authors, these results indicate that it is difficult for TBI survivors to construct, remember or use cognitive maps of large-scale space during spatial navigation. In other words, TBI survivors have difficulties with their cognitive mapping abilities: difficulties associating a landmark with a destination, discriminating a landmark from other distractions and navigating a path to a destination using the landmark. These difficulties observed in the TBI participants were not due to trouble in the use of equipment or a failure of imagination (e.g., difficulties imagining themselves in the virtual environment).

In a more recent study, Sorita and his colleagues (2013) evaluated if survivors of TBI learn a route similarly in a virtual environment by comparison to a real environment. To do so, 27 participants with moderate or severe TBI were recruited and associated with an experimental group in a virtual environment (n = 13) or with a control group to realize the task in a real environment (n = 14). The subjects had to perform five different tasks: 2 in the virtual or real environment (immediate and delay route recall), and 3 during an assessment session (sketch map test, route-map test and scene arrangement test). A third delay recall was done 24–48 h later in order to assess delayed topographical memory. The experiment was inspired by the Route-Learning Task (Barrash et al. 1993), with the virtual environment reproducing the real environment closely. The results of this research have been analyzed in two different ways. They firstly established that the experiment couldn't differentiate groups on route learning and wayfinding because the performance was nearly the same. The authors stated that virtual environments could produce ecologically valid information on topographical or spatial learning. That being said, it would have been interesting to compare the performance of a control group to determine the potential of discrimination of the virtual environment. Specifically, it is fairly possible that the performance of TBI will be worse than the control group in all types of environment (real and virtual) and it would be clinically interesting to have more knowledge on this specific topic. Secondly, the statistical analysis showed a significant difference in the way to arrange the scenes in the scene arrangement task. For the authors, learning in a real environment could be favourable for facilitating the chronological arrangement of scenes. The latter argument implies that the cognitive functions could work differently in a virtual environment because of the influence of some technological aspects.

These researches demonstrated that the assessment of memory and learning is complex when using VR. In Matheis's works, TBI showed an apparent subtle deficit but the virtual environment seemed to need some other development in order to improve specificity and sensibility of the measure. Moreover, Arvind et al. (2014) showed that TBI participants were less effective on some memory processes and that their performance is almost similar to elderly adults. The research conducted by

Skelton et al. (2000, 2006) demonstrated that individuals with TBI are slower when compared to the control group and have difficulties with cognitive mapping abilities. This could have an impact on route learning in the virtual environment even if Sorita et al. (2013) showed that route learning capacities are similar, be they realized in a virtual or real environment. Most importantly, the results obtained lead us to think that memory and learning could be influenced by the navigational and orientation aspects of moving within a virtual environment. Finally, Slobounov et al. (2010) observed a different pattern of brain activation after mTBI caused by sports injuries mainly located on the frontal and parietal areas.

Prospective Memory, Multitasking and Executive Functions

Banville et al. (2010) have compared the performance of 31 TBI adults to a group of 31 control subjects paired by age, gender and education on a virtual prospective memory task. Subjects had to explore a city in a learning phase and then visit two apartments and realize some prospective memory tasks. When the two groups were compared, the TBI subjects were less successful in the virtual task in terms of time and precision in the realization of tasks. In another experiment, Banville and Nolin (2012) measured if VR could discriminate against the subjects about their group (TBI vs. control). The authors used Max Payne modified virtual environment and the Rivermead Behavioural Memory Test (only two prospective memory items have been used), an ecological and traditional tool to assess everyday memory disorders. The task was the same as the first paper (Banville et al. 2010): participants had to realize some prospective memory tasks during the visit of two apartments. Results illustrated that, when the assessment tools are combined (Virtual and Classical), the experimenters can identify in a proportion of 75% the subject to their group. At the end of this study, it was concluded that the task in the VR environment ought to be more complex and difficult to be more sensitive and discriminative.

Besnard et al. (2016) used the non-immersive coffee-task, first presentation by Allain et al. (2014), to assess a set of executive functions liked to the realization of instrumental activities of daily living. To do so, they compared, in a quasi-experimental research design, a group of 19 individuals who sustained a severe TBI and a group of 24 healthy volunteers without neurological or psychiatric antecedents. There was no difference between the two groups on the basis of age, gender and education. The non-immersive coffee task is a virtual kitchen where all virtual objects necessary for the task realization are directly on the cooking plan. Some other objects, called distractors, are also on the table and were used to deconcentrate participants. In this task, they must prepare a cup of coffee with milk and sugar both in real and virtual context. Several interesting observations were found: a) the TBI subjects performed worse than healthy control of all traditional executive function tests; b) experimental group took more time to complete the task. The TBI individuals were slowly in VR; c) the patients' group make more errors than the control group and they are worst in the VR condition. This study had also demonstrated the ecological validity of the non-immersive coffee task since all variables studied were correlated with the actions realized into the real context.

Canty et al. (2014) designed an evaluation procedure to assess prospective memory after severe TBI. The tool aimed to compensate for some limitations that actual measures show. In the psychometric validation procedure of this new tool (VR Shopping Task [VRST]), Canty and colleagues compared the performance of 30 subjects who had sustained a severe TBI to a group of 24 healthy participants with no neurological antecedents. In the VRST, participants had to purchase 12 items from a selection of 20 shops (ongoing task). Furthermore, each participant had to realize 3 time-based and 3 event-based prospective memory tasks. Results showed that the TBI group performed worse compared to the control group on the following variable within the VRST: ongoing task, time-based and event-based prospective memory. Interestingly, both control and TBI groups performed worse on the time-based prospective memory task than the event-based one. Indeed, Knight et al. (2006) have shown that time-based tasks were more demanding in terms of attention and time management. Finally, the authors observed a good discrimination rate from the total score of the VRST that was also moderately correlated to the independent living skills.

Knight et al. (2006) elaborated an experimental design to know if participants suffering from long-term TBI have persisting prospective memory disorders and to observe whether TBI participants are more sensitive to distraction in correlation with their prospective memory functioning. To achieve these goals, 20 individuals with a TBI living in the community were recruited. Because the study wanted to analyze the long-term effects of TBI, the participants had to have sustained their injury 4 years previously. Twenty other participants without neurological history were recruited and paired with participants in the experimental group. The task was done within the context of an unknown (by the subjects) virtual street including outside shops and businesses in a downtown shopping precinct. For this study, the street was divided into two different areas: one with high distraction and the other with low distraction. The entire procedure consisted of completing three different prospective memory tasks and an ongoing task, which involved running personal errands. Concerning the performance of the ongoing task, results showed that TBI participants, when compared to the control group, were able to achieve the shopping task at the same level only when the environment was without distraction. Concerning prospective memory performance, results indicated that the TBI group showed a poor performance independent of the condition (low or high distraction). To conclude their study, the authors stated that VRST was sensitive enough to detect the long-term deficit of prospective memory after TBI.

Mioni et al. (2013) compared the performance on prospective memory task of two groups of participants. The first one was composed of 18 TBI adults and the second included 18 healthy control participants. The Virtual Week, a board game evaluating prospective memory, was playing with a dice that let participant move on the board. The circuit was represented by a weekday. When participants were moving on the board, the interactive game became more challenging for remembering and achieving goals and intention in the future. Eight prospective memory tasks were elaborated (4 time-based and 4 event-based tasks) separated into two classes: regular (e.g., remembering to take medication) or irregular (non-recurrent) tasks. At the end of the experimentation, the results shown three main observations concerning TBI participants: (1) similarly to other studies, TBI participants performed worse at any prospective memory tasks compared to controls; (2) the TBI participants performed well at both regular and irregular tasks indicating that retrospective memory had a marginal contribution to the prospective memory action; (3) the pattern of errors is different between TBI and healthy participants. However, from a theoretical point of view, it is important to state that a regular task cannot be a prospective memory task. In that sense, to solicit the executive functions, remembering an intention in the future ought to be an irregular and a non-routine task.

The study realized by McGeorge et al. (2001) compared the performance on the Virtual Errands Test between two groups of participants: one comprised of TBI patients and the other a control group. The participants were matched for gender, age, years of education and handedness. The principal goal of the study was to compare the effectiveness of virtual environments and real-life settings in the assessment of planning and multitasking in patients with TBI. The Virtual Errands Test is analogous to Shallice and Burgess's (1991) Multiple Errands Test. In that study, participants with a neurological condition accomplished significantly fewer required tasks than the control group, in both virtual and real environments. Results indicated a major group difference for the number of completed errands. TBI participants realized fewer errands when contrasted with a normal score obtained in the Behavioural Assessment of Dysexecutive Syndrome, a standardized neuropsychological assessment of executive functions. Moreover, the authors found a significant correlation between the number of errands realized in the virtual environment and in the real environment. Thus, they had a good indication of the concurrent validity of the virtual environment.

Martínez-Pernía et al. (2017) wanted to develop a novel approach using a serious game authoring platform (eAdvendure) that is in fact a non-immersive assessment for executive dysfunctions after TBI: the SBS cup of tea (SBS-COT). The virtual environment is quite similar to those used by Besnard et al. (2016) and Allain et al. (2014) and the task consist to make a cup of tea. To see the relevance of the SBS-COT, seven pairs of therapist/patient were recruited. To be part of the study, TBI participants must have sustained the injury in the last 6 months and suffering to a mild dysexecutive disorder. The role of the therapist was to administer the assessment task to the patient. For this, they were formed to the task. Several results emerged to that research depending on the researcher's aims. For our purpose, the outcomes of interest are divided in two points: a) the assessment protocol is useful and can be integrated in assessment of patients with executive dysfunction and b) the task was too easy for the patients who did not have any difficulty to accomplish the task of making a cup of tea based on commission, omission or perseverative errors.

Renison et al. (2012) elaborated and evaluated the psychometric qualities of the Virtual Library Task (VLT). The VLT is a non-immersive environment that reproduces the dimension and content of the library at the Epworth Hospital. Six main goals were presented in the paper, the third being interesting for this review. Here, the authors wanted to see if the VLT could discriminate between TBI and healthy participants. To do so, 30 participants who had sustained a TBI were recruited and paired up with a group of 30 healthy adults with no history of neurological lesion. In this virtual task, the participants had to achieve several specific tasks associated with visiting a library while respecting certain rules. The VLT content tasks solicited seven components of executive functioning (task analysis, strategy generation and regulation, prospective working memory, interference and dual task management, response inhibition, time-based and event-based prospective memory). Results indicated that the TBI group, in comparison to the healthy group, performed worse on the following variables: total score, prospective working memory, interference and dual task management, time-based and event-based prospective memory. The authors therefore concluded that the VR task seemed to be more difficult than the real environment as the navigation within the environment could generate cognitive overload.

Zhang et al. (2001) used for this study a Virtual Kitchen, a task developed by Christiansen et al. (1998) and psychometrically validated later by Zhang et al. (2003). The principal goal of this study (Zhang et al. 2001) was to use a soup preparation task in order to see if VR could shed some light on some cognitive dysfunctions after TBI. To achieve this goal, 30 TBI patients were recruited from a rehabilitation center and paired with a group of 30 participants without TBI. The virtual task was an immersive one and simulated a standard kitchen with different objects and appliances. They found significant differences between the two groups in several steps where TBI patients performed worse than the control group. The following tasks were less successful for the TBI group: following directions, emptying the soup can, putting the can in the sink, opening the faucet to fill the can with water, turning off the faucet and selecting the right size spoon. After analyzing the data, the authors concluded that TBI patients had difficulties with logical sequencing, process information and speed of cognitive responding.

In light of these studies, the results have demonstrated the potential of VR to identify several cognitive dysfunctions after TBI. Indeed, multiple studies have given credence to the assertion that VR, with its potential to reproduce daily living, can be more sensitive (than traditional assessment) in detecting cognitive disorders. As demonstrated in the present review, TBI patients have shown difficulties in paying attention to multiple tasks, learning within a virtual environment, planning, sequencing actions, organizing tasks and remembering to carry out some actions or specific tasks in the future. Moreover, while the assessment protocol with its psychometric values offers numerous possibilities to clinicians, it still remains necessary to improve the clinical diagnosis procedure in neuropsychology in order to render it useful.

More specifically, in the section concerning the assessment of cognitive functions after TBI, we have found several interesting elements that can help to improve the development of virtual environments and tasks for clinical settings. Firstly, in the studies of Banville and Nolin (2012), Matheis et al. (2007) and Martínez-Pernía et al. (2017), we have noticed the importance of task complexity in detecting subtle impairments in an ecological-like environment. Secondly, regarding the results obtained in the studies led by Skelton et al. (2000, 2006) and by Livingstone and Skelton (2007), we can suppose that navigational difficulties may bring some orientation and spatial memory impairments. Finally, the study of McGeorge et al. (2001) and Besnard et al. (2016) confirmed the findings of Shallice and Burgess (1991) regarding the multitasking difficulties of a group of TBI survivors. Moreover, they have shown the ecological validity of a virtual environment in this assessment field.

Neuropsychological Rehabilitation

Rand et al. (2009) stated that virtual environments have been initially used to improve rehabilitation outcome. The initial goal of these new training procedures was to increase the cognitive capacities of individuals in their everyday life. The effectiveness of rehabilitation is crucial to a social and individual perspective. Firstly, a good outcome after treatment is associated with a reduction of financial and social burden. In fact, if the individuals can have an efficient and shorter rehabilitation process with a maximum of gain, they could be less dependent on the State. Secondly, from an individual perspective, the principal goal of rehabilitation is the development of autonomy, functional capacities and neurological recuperation of the client with a TBI. Specifically, the purpose of rehabilitation is to help people to return to work or to school; in other words, to a maximum of premorbid roles and activities (Larson et al. 2011). Concerning the benefit of using VR for training people with post-traumatic cognitive disorders, a total of 8 studies were found. The following paragraphs constitute a synthesis of this research.

- Caglio et al. 2009, 2012) and Gamito et al. (2010) realized three studies to demonstrate the potential of VR to improve memory with an exploration task in a complex city or with a realization of several everyday activities into an apartment.
- Dvorkin et al. (2013) designed a VR training program in order to improve sustained attention to severely brain injured patients. Grealy et al. (1999) were interested in knowing if a program of physical activity could improve a selected set of cognitive functions.
- Jacoby et al. (2013) wanted to teach executive functioning to a group of patients with TBI within a virtual environment, after which they would compare the results to conventional treatment administered by occupational therapists.
- Larson et al. (2011) created a Virtual Attention Process Training (VAPT) similar to the Attention Program Training (APT) elaborated by Sohlberg and Mateer (1987).
- Man et al. (2013) compared a VR-based vocational training system (AIVTS) to a conventional psycho-educational vocational training program (PEVTS) in order to see if cognitive functioning could be improved after a rehabilitation program.

Attention Training

Dvorkin et al. (2013) wanted to analyze how haptic cues could be useful in order to improve attentional capacities after severe acute TBI. To do so, 21 inpatients in acute phase were recruited from a rehabilitation center. It was required that participants without hemispatial neglect or visuoperceptive difficulties had attentional problems. The system used was the VRROOM (VR and robotics optical operation machine). The apparatus displayed targets, one at time, in various locations and could be seen by using a head-mounted display (to see the target) and haptic system (to measure force and arm movement). During training, participants held and moved a handle toward the targets that appeared randomly one at a time until the target was acquired or until 10 s had elapsed; then a new target would appear on the screen. The remediation procedure tested the patient on two consecutive days. During the program, participants achieved six trial blocks of 4 min long, each one with an unlimited number of trials. Three haptic conditions were designed by the authors: (1) no haptic feedback or no force condition, (2) a breakthrough condition, where the force applied was similar to a popping balloon, (3) a haptic nudge condition also named a gentle pulse of force. The function of the nudge was to capture the attention of the patients. At the end of the rehabilitation program, only 18 patients completed the treatment. The remaining 3 patients who didn't complete the 2 day sessions experienced fatigue or frustration. Results indicated that patients could improve their attention capacities after two training sessions. Analyses showed a clear improvement between the two training sessions. In fact, the authors observed a significant increase in the number of targets acquired, which means that the subjects benefited from practising across the block. More specifically, the authors demonstrated that these patients benefited from the haptic nudge before and during the movement. This can help patients to focus on the task.

Larson et al. (2011) evaluated the potential of VR in the rehabilitation of attention disorder after a TBI. To carry out the study, 18 individuals with severe TBI were recruited from a rehabilitation hospital. At the end of the experiment, 15 subjects terminated 12 intervention blocks. The VRROOM, a personal augmented reality immersive system, was used for the study in association with a haptic system. The virtual environment was minimalist with no textures. In their field of view, subjects could see the target and cursor. The virtual protocol was a three-dimensional cancellation task analogous to the Attention Program Training. The test included three different haptic conditions similar to those presented above in the Dvorkin's study (i.e. Nudge condition, Balloon condition and "No haptic feedback" condition). The first consisted of reminding the participant to pursue the cancellation task when he was inactive; the second reproduced the sensation of popping a balloon; and the third was characterized by no haptic force during the movement. The participants benefited from a two-day course for a total of 12 blocks with duration of 4 min by trial. Results showed that the Nudge condition helped with target acquisition. At the end of the intervention, participants showed an improvement in terms of speed. Finally, the authors explored how TBI subjects with a post-traumatic amnesia (PTA) worked. They found that PTA participants can improve their attention capacities with virtual training.

Memory

In a serial case studies, Caglio et al. (2009, 2012) explored whether video game training, in the context of post-traumatic rehabilitation, could improve spatial and verbal memory. They also wanted to know if the signal in hippocampal and extrahippocampal brain region increases after treatment. The participant in this case study was a young man of 24 years old with moderate TBI. The rehabilitation program consisted of a five-week training session, three times per week. The length of each session was 1.5 h for a total of 22.5 h of practice. During the training, the patient had to visit a complex town using a driving simulator. The experimental design was a pre- and post-test with a follow-up at 1 and 2 months post-training. During training, participants had to explore each street with minimal backtracking. At the end of the rehabilitation program, the subject showed improvement in several neuropsychological tests. In fact, the authors observed that visuospatial memory and learning were improved by the treatment plan. The same observations were made for verbal learning and phonemic fluency. Finally, the authors also confirmed their hypothesis concerning the potential of VR for training and increasing the activation of hippocampal and parahippocampal brain regions involved in memory processing.

Gamito et al. (2010) evaluated whether an immersive VR program could potentially improve memory deficits after TBI. In order to achieve this goal, researchers have recruited a 20 year-old man with attention and memory deficits consecutively to a severe TBI. The virtual environment was a town eight squared blocks that contained a two-room apartment and a small market. The participant was free to move into the town and pick up the object he wanted to use. The training consisted to a structured 9 sessions program. During the sessions, patient realized several tasks: daily life activities, working memory tasks, visuospatial orientation tasks, selective attention tasks, recognition memory tasks, and calculation and digit retention tasks. At the end of the experiment, the results indicated that these activities conducted on the virtual apartment led to an improvement of working memory (both verbal and spatial – stable at a follow-up) and attention. The authors concluded that their data "support the idea that the navigation of the large-scale environment may strengthen hippocampal activity (p. 197)"; which is similar to the results of Caglio et al. (2009, 2012).

Executive Functions

Man et al. (2013) hypothesized that TBI survivors, that had received VR vocational training, would significantly improve their problem-solving skills compared to a group of TBI patients trained by a conventional psycho-educational program. They also thought that the VR program would lead to better employment outcomes. To do so, 40 TBI survivors were recruited and randomly allocated to one of two groups: experimental or control group. They participated in a 12-session training program including several clerical tasks (e.g., identifying office items, handling correction fluid, filing, photocopying, printing, faxing, sending and receiving mail, learning about safety use and correct working posture, etc.). The virtual and real tasks were similar. Results based on the differences between the pretest and post-test, showed an improvement in selective cognitive functioning based on the Wisconsin Card Sorting Test (regarding the percentage of errors and conceptual responses) being that the performance was better for the experimental group in comparison to the control group. The authors explained that the VR training module included a strong component of executive function training such as concept formation, reasoning and planning. In contrast, the link between vocational outcome and VR training was not established because of the local job situation and the problem of low employability status in the city where the research was realized.

Jacoby et al. (2013) elaborated a research design in order to see if an executive function program could improve cognitive functioning after a TBI. The authors thought that while any training (virtual or conventional) could improve executive functions, they felt that virtual protocol would be better. In order to test this hypothesis, a total of 13 TBI survivors were assigned to an experimental group or a control group. At the end of the research, 12 participants finished their training. The Multiple Errand Test – Simplified Version (MET-SV) and the Executive Function Performance Test (EFPT) were used as tools to measure outcomes in this pre−/post-test experimental design. The intervention for the control group was given by an occupational therapist and based on a cognitive retraining model (Averbuch and Katz 2011). As for the training of executive functions (Sohlberg and Mateer 2001), this included components such as task planning, task performance, time management, monitoring performance, and metacognitive strategies. The VR group was trained by using the VMall. Also, the protocol respected the same principles for the control group training. The results were based on MET-SV and on EFPT pre- and post-tests and they didn't show any difference between the groups even if participants in the VR group improved their final score compared to their initial score on MET-SV and on EFPT. Obviously, the lack of participants in each group can play an important role in this absence of difference. It is also possible that both VR and Traditional training can improve in the same manner as executive functioning. Future researchers could take advantage of reproducing their studies with a larger sample.

Training a Set of Cognitive Functions

Grealy et al. (1999) wanted to know if a physical exercise program using non-immersive VRcould be effective after a TBI in order to improve cognitive functions (ex. attention, information processing, learning and memory). Thirteen TBI survivors were then recruited as participants in the rehabilitation program (experimental group). In order to create a control group (participants didn't help create the program), the authors consulted the database at the same hospital. The data of 25 TBI clients was taken and, based on this, 12 control participants were designated to undergo neuropsychological assessment. Each participant of the TBI comparison group was paired (age, severity, time post-injury) with a participant in the experimental group.

The experimental group was exposed to three virtual environments linked to a cycle ergometer. The patients had to make a virtual race around the world. After a 4 week intervention program, the difference between the pre- and post-tests showed a marked improvement with regard to several cognitive functions within the experimental group: learning (both auditory and visual), chunking or organizing material. There was no change in rehearsing or in the ability to switch between the tasks. Finally, when experimental and control groups were compared, it was possible to observe that physical activity in a virtual environment could improve the response and movement time for those participants in the rehabilitation program.

As for publications on rehabilitation after TBI, we must acknowledge the paucity of studies in this field. Furthermore, the training program using the VRROOM seems to be an interesting development for a clinical setting but it could benefit from a longer training session, or at least certainly more than only two sessions. Nevertheless, the use of specialized equipment (ex. Ascension's Flock of Bird, a Robotics sub-system) makes migration from a laboratory setting to a rehabilitation center uncertain, particularly with regards to the cost of the equipment. In Grealy et al. (1999)'s study, accepting that physical exercise can lead to a recuperation of the brain does not, in our opinion, explain change by spontaneous recuperation. For the studies presented by Jacoby et al. (2013) and Caglio et al. (2009, 2012), the principal limit is the weight of the sample. The experimental protocol appears interesting, but it is difficult to understand the real impact of the training session. Finally, the study of Man et al. (2013) seems intriguing and pursuing this work could demonstrate the psychometric validity and potential of the generalization of the training protocol. In conclusion, this reflection underlines the necessity to continue research in the development and validation of virtual environments with the goal of creating a better cognitive rehabilitation setting.

Discussion: Can Human Computer Interaction Influence the Cognitive Measures?

Compared to healthy controls, TBI patients demonstrated greater difficulty in tasks measuring attention, memory and executive functions (Fleming et al. 2008; Groot et al. 2002; Kinch and McDonald 2001; Kinsella et al. 1996; Kliegel et al. 2004; Knight et al. 2005; Mathias and Mansfield 2005; Shum et al. 2002, 1999). These impairments significantly affect the completion of a normal lifestyle, particularly, in the work or school domain. Disabilities related to TBI are not only secluded to those with brain damage, they also affect family caregivers (Verhaeghe et al. 2005). Hence, VR technologies could be used to better detect cognitive dysfunctions in everyday life than traditional tests and to offer the possibility to begin rehabilitation of the TBI survivors through several situations related to naturalistic tasks using virtual environment. The first objective of this chapter was to review the literature to clarify the relevance and effectiveness of the use of VR, in both children and adults, within the context of neuropsychological assessment and intervention. The second objective was to reconsider the ecological validity of virtual environments by analyzing the possible effect of human-computer interaction (HCI) on cognition during a neuropsychological assessment using VR.

The interaction with a virtual environment for children and teenagers could be closely related to playing a video game for young participants with TBI and so may lead to more motivation, at least when it's used for the first time. Even if the use of VR to assess cognitive functions during childhood and adolescents may better involve them during the task, it is not a trend. Indeed, only five studies have produced results based on an experimental design and results are disparate. Lee (2011) could not determine the superiority of VR in the assessment of attention disorders after an mTBI. For its part, the team of Nolin et al. (2009, 2012) have shown that the virtual classroom has an interesting advantage in terms of sensitivity in the detection of attention disorders in children with TBIand in adolescent with mTBI due to a sports accident. However, it is clear that further studies are needed with this clientele. Finally, Erez et al. (2013) found an interesting preliminary result, but the research ought to be continued in order to explore the ecological validity and generalization potential of the Virtual Shopping Task with children and adolescents. In summary, it appears that the first thing to do is to allow the development of assessment tools that are relevant for screening cognition during everyday life contexts, then to demonstrate the usefulness and sensitivity of VR with children and adolescents who have sustained a TBI. Furthermore, researchers and clinicians could develop VR rehabilitation programs for pediatric clients who have sustained a TBI. Virtual rehabilitation tools could become more used because the young TBI survivors could practice independently and may repeat the task as many times as necessary. What's more the links between VR rehabilitation tools and serious game should be more study. Indeed, serious games integrated in VE are more effective in terms of learning and retention (Wouters et al. 2013). If VR tools are closed to serious game and lead to a better information retention than traditional rehabilitation methods, we could suggest using them systematically.

Regarding adulthood, the clear majority of works conducted supports that VR is sensitive to detect cognitive deficits and to improve cognitive functioning. The analysis of these publications identified for this review also revealed that a few cognitive functions and a small number of studies were conducted with VR and traumatic brain injured people and few cognitive functions are studied: Attention (one study), memory, learning and wayfinding (8 studies) and executive functions (10 studies) are also among the specific studied functions.

The same conclusion could be applied to concerning the rehabilitation program: Attention (2 studies), memory, learning and wayfinding (3 studies) and executive functions (1 study) are also among the specific treated functions. One other study explored the potential of VR to treat a set of cognitive deficits after TBI. Indeed, few studies have demonstrated, with a large sample, the superiority of VR to contribute to cognitive improvement after TBI (by comparison to traditional rehabilitation). More studies are therefore needed. Our point of view here is similar to this written by Pietrzak et al. (2014) whom conducted a structured literature review about using VR for TBI rehabilitation. Even if the studies listed here can show some improvement in patients after treatment, the evidence that VR rehabilitation improve the cognitive functioning in daily living is far from being evident. The best protocol should be the one that compare a gold standard (ex.: traditional well-known rehabilitation program) with a new program based on ecological activities implemented into a virtual environment; the principal goal here could be an improvement of cognitive functioning and generalization of the learning in the everyday life of the patient.

One of the qualities of VR, as emphasized in previous publications, is to be closer to real life as opposed to classical tests. Some studies (Rand et al. 2009) have pointed out interesting relationships between virtual performance and functioning in daily life, supporting the ecological value of this approach. Moreover, some studies have shown that VR was more sensitive than traditional "paper and pencil" tests in the assessment of deficits resulting from a TBI. However, too few results are presently available to confirm with certainty the desired benefits of VR. Several authors have emphasized the potential of VR compared to conventional assessments (Crosbie et al. 2007; Morganti 2004; Rose et al. 2005; Tsirlin et al. 2009). It seems that VR has added value to the assessment and rehabilitation of cognitive deficits compared to traditional tests or conventional rehabilitation training, although this remains to be supported by further studies. The clinical challenge is therefore to fairly and accurately assess cognitive dysfunctions, as they arise in the daily life of TBI survivors. Thus, a "more" accurate evaluation would allow the development of a treatment plan better suiting of the needs of patients and their family for autonomy, security and emancipation.

However, even if almost all studies summed up here permit us to consider VR as a perfect tool to reproduce everyday life, some important considerations should be kept in mind when we construct a virtual environment for post-traumatic assessment or rehabilitation. The verisimilitude of the environment (i.e., its naturalistic handling and user's feedback), the nature of the tasks, and the HCI are among essential concepts to consider. More particularly, the HCI is rarely discussed in the literature as a potential limit to the validity or reliability of the measure. However, to be in interaction with the virtual environment, the individuals have to learn how to manipulate the device and they must understand the different rules in order to function correctly in the virtual environment. These processes require the participation of some cognitive functions (such as memory, attention, planning, etc.) and they could potentially create cognitive overload, which would interfere with a reliable or valid measure of the behaviour.

Consequently, if a dual task could deteriorate the performance, especially after a brain lesion (Kizony et al. 2010), similar reasoning could be formulated regarding the potential to create a cognitive overload via the use of VR technologies. Indeed, the latter could happen by the simple fact of having to navigate through a virtual environment. Hence, the cognitive (over)load generated by the need to handle devices (being in the virtual environment in which objects are manipulated to carry out tasks) could constitute a bias in the measurement if this phenomenon is not considered. This hypothesis, along the lines of Morris et al. (2002) which addressed the need to rethink the neuropsychological evaluation, invites us to reflect on the development of ecological tests that would change the structure and the assessment procedures by taking under consideration the impact of the technology and equipment on the cognitive efficiency.

Eysenck and Calvo (1992) proposed a theory of cognitive efficiency that discriminates between the efficiency of performance and the efficiency of cognitive processes. More specifically, the efficiency of performance represents the quality of the accomplishments of an individual, depending on whether they succeed or not the requested tasks. The cognitive efficiency, for its part, is based on the relationship existing between the efficiency of performance and the amount of effort or intellectual resources used by the person to achieve a given level of performance. Following this train of thought, it is possible to claim that the HCI may cause cognitive overload, or at least raise the cognitive load by increasing the amount of effort required to perform a cognitive task set in the virtual environment.

Cognitive overload, for its part, is defined as the difficulty to deploy a "sufficient amount of mental energy to manage a large amount of information" (Feinberg and Murphy 2000). Such an overload could potentially be created by the manipulation of the interfaces between the person and the virtual environment in which a certain level of performance is expected. Thus, the idea behind cognitive overload implies that data processing possesses channels that are limited (Doolittle 2002; Mayer 2001) in terms of resources. This is especially the case when attentional processes and working memory (integrated to the Supervisory Attentional System, Norman and Shallice (1986) are solicited in a new task involving problem solving. In the same vein, Smith (2003), in her demonstration of the theoretical model of prospective memory (Preparatory Attentional and Memory Processes theory), brought the idea that tasks carried out simultaneously make continual requests to attentional resources that are already limited. Thus, the Cognitive Load Theory (Cooper 1998) suggests that all mental activities require a certain amount of energy at a given time. The modulation of the latter depends on the individual's capacity to divide his attention and on the specific characteristics of the task (Paas et al. 2003) or environment, which by default should include the effects of handling equipment and stress caused by these interactions. Hence, multitasking activities conducted in VR could create a cognitive overload and reduce the cognitive efficiency of participants.

To sum up, cognitive load is linked to the task characteristics, to the environment and to the individual capacities (Chanquoy et al. 2007). The task characteristics represent the level of difficulty of the task whether it is demanding or not. The environment refers here to the distractors, not linked to the task, but susceptible to interfere with the subject's performance. Moreover, individual characteristics refer to the cognitive resources that support or help the subject into the task realization. The HCI could take action directly on each of these dimensions. In addition, Ang et al. (2007) illustrated that the virtual environment can alone generate cognitive overload, mainly for people who are not accustomed to video games, which is the case for most of clients who would be evaluated in neuropsychology with VR. Nelson and Erlandson (2008) found that students without brain damage who were performing tasks in a virtual environment experienced a cognitive overload effect. More specifically, they report having difficulty to direct their attention, to keep in mind several sources of information when exploring the virtual world. Therefore, there would be several active cognitive processes in the foreground and in the background when it comes to using a virtual environment to evaluate the cognitive skills of an individual (Cicourel 2004), particularly in the mobilization of cognitive resources by the devices used to interact with the virtual environment.

To verify the relevance of these ideas, we conducted three complementary pilot studies (Banville et al. 2017). All these studies contained participants without traumatic injury or psychiatric history and evaluated normal functioning of adults during tasks in a virtual environment: The Virtual Multitasking Test (VMT; Banville et al. 2007). Specifically, the theoretical framework of VMT is inspired by the work of multitasking initiated by Shallice and Burgess (1991). The VMT portrays several interrelated tasks that are performed one task at a time. There are also interruptions, unexpected results during the process, and delays in achieving certain intentions. Consequently, certain tasks are delayed and there is not always immediate feedback. The VMT wants to evaluate and possibly to readapt prospective memory and executive functions. The different scenarios of the tool are implanted into a virtual apartment with 6 ½ rooms, each room including at least one task. At the beginning of the VMT, participants are told that they are visiting their good friend. During the day, the friend is at work and they must live in his apartment as if it was home. In the evening, they will go to a show with their good friend. However, during the day, they must perform several tasks alone based on daily life. For instance, they must store the groceries on the counter as quickly as possible (even if they are told there is no time limit to complete the activities), answer the phone, and perform other tasks such as faxing a document, search for show tickets, dry a shirt, feed a fish. Prospective memory tasks require, among other things, to close a door just when exiting the master bedroom to prevent a dog from climbing on the bed. Unforeseen events occur during the execution of the task. For instance, the occurrence of a storm which overthrow objects in the guest room and let water seep into the dining room. For example, storms that reverse objects in the guest room and that let water seep into the dining room. VMT can be achieved in an immersive or non-immersive manner. Every time a person is exposed for the first time to the VMT, they start a training phase or familiarization of the environment. Afterwards, the experimental phase has begun and the person carry out tasks proposed by the scenarios planned by researchers. The latter remains in communication with the environment through an interface that allows modification of the task *in virtuo*, meaning during their realization. This interface is especially useful in cognitive rehabilitation in order to modulate the level of difficulty and complexity of the initial scenario.

These three studies, mentioned previously and using the VMT, showed that the use of the interaction technique, the nature of the task and the virtual environment itself and participant's characteristics can all lead to more cognitive load during the experience in VR (Banville et al. 2017). Specifically concerning HCI, the interaction technique used to navigate and select 3D objects virtual environment asks more effort and generate frustration for the user. Moreover, when the interaction technique is not intuitive (bringing a bias when compared to a naturalistic tasks), its utilization raises cognitive load, especially when the virtual environment is designed to navigate with three axes (i.e. X, Y and Z offering 6 degrees of freedom).

Indeed, navigation in VR involve that participant has to understand their relative position between them and the objects (i.e., proprioception) included in the task realization. For Chen and Or (2017) these participants are more likely to "*overestimate or underestimate the distances between themselves and the target objects, which [cause] more mistakes in pointing or dragging-and-dropping*". Navigation is also supported by the manipulation of specific devices such as mice and keyboards. VR supported by more or less complex HCI technology provides different kind of input interface that allows interaction with computer objects in the VE (Chen and Or 2017). Hence, the HCI fidelity in such virtual environments can be very different and depend of its handling complexity.

So far, selection which involves the specification of one or more objects by the user is a fundamental interaction task (Bowman et al. 2004). To select a target, the user must move the selection cursor on it and then select it (i.e., point and click). Another selection technique is known as drag and drop, where the user must move an item from its location to another by a constant activation of selection devices (e.g., pressing the mouse button). The selection time of a target can be predicted by Fitts' Law (Fitts 1954) which specified that the time selection needed depending on distance between targets and target size. A user will need more time to select a far and small target than a close and big one. In other words, when the objects in the virtual environment are small, due to object scale, occlusion, or distance from the participant, the selection of the item is more difficult and the participant is more susceptible to make mistakes (Steed and Parker 2005). Accurate selection in these situations could solicit several cognitive functions and demands some effort on the part of the individual. In addition, this must oblige the participant to move closer to the object to be able to select it. To make an intuitive selection for one particular task, that require the participant to remove occluding objects or travel closer to the targets, resulting in long selection times (Bacim et al. 2013) and adding some navigational process.

The selection technique (e.g., point and click) used to interact in the virtual environment can modulate the participant's performance. Indeed, users are more efficient with point and click than drag and drop. This is the case for children (Inkpen 2001), adults (MacKenzie et al. 1991) and the elderly (Chen and Or 2017; Gonçalves and Cameirão 2016). In these studies, the target size tends to influence time completion and precision on the tasks positively in a pointing task (faster execution and lower error rate) and negatively for dragging-and-dropping task (slower realization and higher error rate). Moreover, the cognitive load associated to drag and drop or to point and click seem to be more cognitively challenging for the elderly (Gonçalves and Cameirão 2016).

Our literature review shown a limited number of studies related to VR interfaces. The simple use to generate interaction with the system could impact the participant's performance in VR and overlord their cognition. In that sense, VR could be more complex than real life and this requires a nuancing approach to the ecological validity and reliability of data coming from virtual environments. More studies are needed to understand how HCI could modulate workload during VR tests. Indeed, several interaction techniques were compared in a virtual supermarket (Verhulst et al. 2016).

Participants collected 7 items in the supermarket using gamepad or a natural gesture interface where motions were recognized by the Kinect. Results showed that participant took less time to complete the task using the gamepad (they could look around them thanks to head tracking) than other conditions using the Kinect. The workload associated to the use of these interaction techniques was higher for the Kinect conditions, especially for the effort scale. Indeed, to interact in the virtual supermarket participants were physically involved with real gesture such as walking-in-place whereas no physical involvement is required for the gamepad use. These results suggest that the use of the interaction technique can impact the participants' performance. Moreover, recording and analyzing physiological signal during the realization of VR test could help to better understand the performance of the participant. Indeed, the heart rate could be rising during difficult VR task (Banville et al. 2017). Moreover, Kubota et al. (2016) showed that after an error or when they experienced difficulties using the mouse, participants with mild cognitive impairment (MCI) took more time to recovery from the error than the elderly without MCI. Therefore, MCI participants would need more time to detect the error and to correct it. These errors could be associated to change in low and high frequency (LF/HF) of the heart rate variability signal. Indeed, the LF/HF peak increase when the time to recovery from the error is long. This physiological demonstration suggests that the participant is aware of the error and may feel difficulties in the task realization.

Virtual environments could involve more cognitive resources than real situations. Allain et al. (2014) using a virtual non-immersive coffee task shown that both participants (healthy control and with Alzheimer's disease) performed differently within virtual environment compared to the same task in a real environment. In this case we need to consider if VR is an ecological tool because the participant's performance seems to differ in real and in virtual situation. If the interactions with virtual environments generate an extra workload, the participant may take longer time to complete the task or commit attention errors because of their lack of available cognitive resources. For instance, during multitasking tasks, because HCI involve an additional workload, the system should be able to identify what is the real performance of executive functions by extracting the overload provoked by the hardware manipulation. This is the case of normal aging, where slowdown could be more apparent (Banville et al. 2017; Verhulst et al. 2017a). It is primary to have a good understanding of the impact of the use of the interaction technique on the participants' performance especially during assessment with VR tests. Indeed, a long completion time could be associated with cognitive deficits and/or to difficulties encounter using the interaction devices. To help investigators to distinguish cognition scores from interaction scores, we could break down activity patterns of the participant and visualize it with diagrams (Verhulst et al. 2017a). The point of this method is to understand where participant presented difficulties independently of the interaction technique. To do this, investigators could show activity by activity the plan of the participant especially during multitasking tests. For example, the first participant did activity one, then activity two and return to activity one. In addition, this thinking force researcher to consider that virtual situation could not always be closer to the real context because virtual environment cannot reproduce the same complexity as the real world. On another hand, some VR assessment (e.g., virtual supermarket) could be less complex than real one because the user is not wearing the produces picked up, there are less customers, less audio stimuli and so on. To sum up, the ecological validity of VR tests is still unclear and must be thinking according HCI and psychometry.

The workload associated to virtual environment can depend on the scale of the virtual environment and on the complexity of tasks (Banville et al. 2017). In the study of Allain et al. (2014), participants committed more errors in a virtual kitchen tasks than during the same task in a real environment whereas participants are more efficient in a virtual supermarket than in a real one (Greenwood et al. 2015). The second study replicated a more complex task than the first one and the workload associated with the use of the interaction could replicate the same workload as in real situations whereas in a less complex task as in virtual kitchen, the use of interaction technique seems to lead to higher workload than in a real kitchen. It is primary to understand the impact of the user of the interaction technique on the participant's workload to better adapt the VR tools. A hypothesis is to propose the easiest interaction for situations with low complexity in real life (e.g., single tasks, few stimuli) and to propose more difficult interaction for more complex situations like in a supermarket. According to this hypothesis, to better replicate the world, VR test should modulate interaction technique in terms of facility to use it. Indeed, if VR technologies cannot replicate the entire stimuli from reality the workload associated with these stimuli could be compensated with quite a complex interaction technique.

As shown in the literature review, cognitive functions are assessed in an independent manner to detect issues in a specific domain (e.g., memory) and traditional tests are able to isolate these several cognitive functions very well. In everyday life situations, cognitive functions are in interaction and create a kind of network to help the individual to act for the good behaviour depending on the context generates by the test. To use VR as an efficient tool, we may argue that we shouldn't focus only on specific cognitive functions but make pay attention to behavioural data during multitasking. Virtual environments can simulate naturalistic tasks and record very precisely behavioural data (e.g., completion time, type of errors, navigational patterns). Moreover, with VR testing, an infinity of variables can be recorded. These variables could give the finest measure those in real situations and variable associated with the use of the interaction technique (e.g., mouse movement) could give a new interpretation of the participant's performance (Verhulst et al. 2017b) . Mouse movement and inputs (e.g., mouse click) were analyzed during web searching tasks and results showed that when participants are cognitively involved in a task, they make long mouse movements whereas and when they are focusing on information, they make quick movements (Guo and Agichtein 2008). Verhulst et al. (2017b) propose to do a parallel between these results found during web searching and those during a virtual naturalistic task. Having a good understanding of interaction technique data such as mouse movements could help to discriminate the workload associated with the HCI and to the task itself.

Conclusion

In order to conclude with the literature review synthesized in this chapter, other limits, already highlighted in previous publications, compromise the widespread use of data from studies done in VR with TBI patients. The first limit of previous work is their methodological design. A case in point would be the often restricted number of participants as it was the case for our three studies presented in this discussion section. Other limitations address the technical and ergonomic aspects of VR systems that are used. Great variability between devices and immersion techniques (joystick, mouse, HMD, 3D glasses, video-capture, flat screen, immersive or non-immersive techniques, etc.) limit the generalization of the studies because there are too few with the same conditions to reach valid conclusions.

For future studies, a relative importance should be accorded to the discrimination of the cognitive workload generated by the task itself from what is generated by HCI. Consequently, a truly ecological assessment could be obtained by using VR. The necessity to consider the effect of technology on the cognitive load is appearing as an important aspect to consider in the making of new measures. Thus, it appears necessary to: (a) continue research on all kinds of cognitive functions; (b) develop research designs that will validate the hypothesis that the VR is an ecological approach; (c) compare VR environments with classical and standardized tools to establish their validity and reliability; (d) evaluate the possibility that VR can generate a cognitive overload by itself and can be more difficult to use for older than younger adults; (e) creation of dynamic virtual environments, which can adapt to the characteristics of participants on the basis of age or deficiency, while still remaining sensitive to subtle changes, predictors of current or future conditions, would overall be an innovative way of addressing neuropsychological assessment and to use technology. To conclude, all this highlights the importance of further scientific and clinical work in this emerging field.

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Chapter 16
Developing Virtual Environments for Learning and Enhancing Skills for the Blind: Incorporating User-Centered and Neuroscience Based Approaches

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Introduction

As humans, we rely heavily on our vision to interact with the world. Therefore, it is not surprising that individuals who are profoundly blind must make remarkable adjustments in order to pursue education, secure employment, and remain socially integrated. According to the World Health Organization (WHO), approximately 285 million people are visually impaired worldwide; 39 million of whom are considered profoundly blind (WHO 2012) see also (Frick and Foster 2003). While significant progress has been made in eye care delivery and treatment, in developed countries (such as the United States), there are approximately 10 million visually impaired and 1.3 million legally blind individuals; a significant proportion of which are children (estimated at 55,200) (AFB 2013a, b).

Legislative support (e.g. the Americans with Disabilities Act; ADA) has been instrumental in helping blind individuals achieve independence and secure employment. However, the majority of blind individuals, unfortunately, do not reach their full potential for achieving academic and professional success. Currently, the unemployment rate for blind adults stands between a staggering 70–80% (AFB 2013a, b). Along with concerns regarding decreasing rates in Braille literacy, there are other important factors that appear to be contributing to the overwhelmingly high unemployment rate among the blind. One example is the inaccessibility of the academic

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and workplace settings as well as overall misconceptions on behalf of the sighted community regarding the abilities of blind people. In fact, blind students often encounter the presumption that many subjects such as mathematics and science can only be conceptualized visually (Moon et al. 2012). There are also numerous barriers to educational access, including logistical challenges associated with the production of relevant tactile graphs and diagrams as well as a lack of active hands-on participation in visually-oriented laboratory activities. Such barriers place blind students at a significant academic disadvantage when compared to their sighted peers. As such, many aspiring blind students lack the proper academic foundations in the subjects of science, technology, engineering, and mathematics (collectively referred to as STEM disciplines) in order to pursue competitive employment in these rapidly developing fields (Moon et al. 2012; Kell et al. 2013).

Advancements in assistive technology have helped blind individuals overcome some of these barriers by providing nonvisual access to computer interfaces and printed materials. Noteworthy examples include text-to-speech (TTS) and screen reading programs, optical character recognition (OCR) software, and electronic refreshable Braille displays (Fig. 16.1). While modern technological innovation has provided the blind with a hitherto unprecedented level of access to information, such advancement has, at the same time, created new and substantial challenges which current assistive technologies have been unable to resolve. As modern technology continues to grow in complexity, the development of assistive technologies fails to match this astonishingly rapid pace of evolution. Most mainstream computer and device interfaces are designed without the nonvisual access needs of blind users

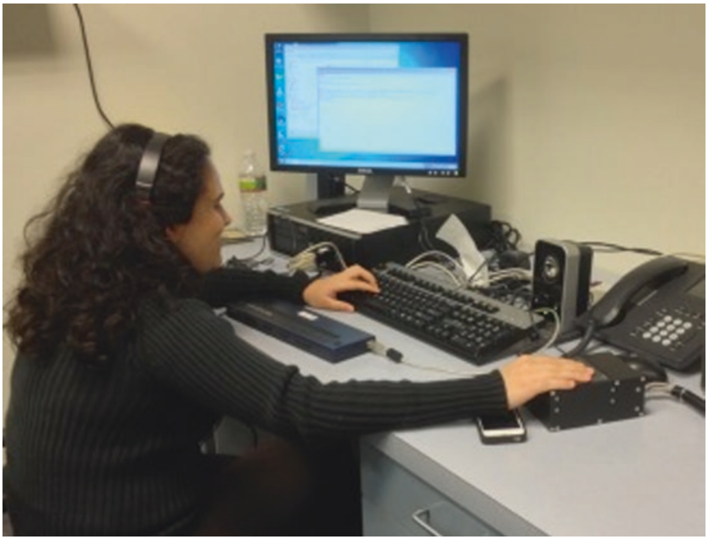

Fig. 16.1 Blind individual with assistive technology typically used to operate a desktop workstation. Screen reader software allows content presented on a monitor to be explored auditorily (headphones). Refreshable Braille display and tactile graphics display allow for Braille text and graphics to be accessed through touch

in mind and therefore incorporate visual elements which assistive technologies are unable to convey to the user in a meaningful way. As a result, a blind end-user regularly encounters the all-too-common trend of accessible technologies lagging behind technology and information access designed exclusively for sighted users (e.g. complex web page designs) which are either incompatible with assistive technologies or otherwise difficult to access. This barrier of nonvisual access can have detrimental consequences for the blind, especially in the areas of education and employment. Thus, while screen readers, Braille-print, and OCR technologies have revolutionized information access for the blind, they still fail to adequately address the many access barriers which result from the suboptimal designs of technologies built exclusively for sighted users.

One of the underlying reasons why mainstream technology poses such tremendous access challenges for blind end-users may be related to differences in ways in which blind and sighted individuals cognitively process information. For instance, sighted people access much of their sensory information through vision, and typically construct mental representations or "mental models" of the world largely based on visual experience. In comparison, blind individuals (particularly those blind from birth and who do not possess visual experience or visual memories) construct mental models based on information gathered from remaining senses such as hearing and touch (Landau et al. 1981; Gaunet et al. 1997; Vecchi et al. 2004; Tinti et al. 2006; Cattaneo et al. 2008). The mode of processing specific to each sense (e.g. the parallel and rapid capture afforded by vision, as opposed to the slower, more sequential processing of touch) has important implications for how blind and sighted people conceptualize the world. An enhanced understanding of how the blind mentally represent and interact with the world could serve as a crucial step towards a much-needed paradigm shift in information access, interface design, and mental manipulation of information (Sánchez and Hassler 2007; Sánchez 2008). The idea of considering the cognitive representations of intended users to new technology is not a new one. In fact, this user-centered approach is often necessary for widespread dissemination and acceptance of new technology to take place. Consider, for example, the rising popularity of the personal computer: prior to this period, computer interfaces were predominantly driven by command lines, meaning that users were required to interact with these exclusively text-based interfaces using line-by-line coding. Mastery of command-line interfaces required that one memorize numerous sequences of syntactically-complex text strings. Today, the serial nature of entering code and strong demand on syntax required of command-line-based interfaces could be viewed not only as counterintuitive, but even daunting for the average would-be computer user. However, a key breakthrough in opening the world of computing to a much broader population was the development of the virtual desktop environment designed to facilitate common tasks such as desktop publishing. Originating in the 1980s with the advent of Apple Computer, Inc.'s Macintosh system (and later refined with the introduction of Microsoft Corporation's Windows operating system), the virtual desktop environment featured a high-resolution on screen graphical user interface that allowed a typical user to intuitively access, organize, and manipulate large amounts of information.

Relating back to our discussion, blind computer users (who rely on alternative access solutions which do not make use of direct interaction with an on-screen interface) experience a similar cognitive challenge. As with command-line interfaces, screen readers and Braille displays present information in a serial fashion, and require users to memorize complex syntax in order to drive modern computer interfaces. Blind computer users must therefore rely on an often counterintuitive approach to accessing complex information and concepts, a task which their sighted counterparts can accomplish with ease using a visual based desktop environment. Similarly, blind users could benefit from a nonvisual access solution similar to this analogy of a desktop or workspace environment to facilitate access, interaction, and manipulation of information in a parallel and intuitive manner. Such a solution could allow for greater and simplified compartmentalization of tasks and concepts. Thus, developing accessible technology to allow blind people to compete on an equal playing field with their sighted peers and colleagues remains a substantial, unmet need. In this chapter, we will discuss the development of virtual environment-based approaches as a unique opportunity to address this issue.

How is Sensory Processing and Cognition Carried out in the Absence of Vision?: Mental Models in the Absence of Vision

When interacting with our environment, we are continuously acquiring new sensory information that is analyzed, stored, and compared to our previous experiences, perceptions, and understanding of the world. This internal cognitive representation of the external world, referred to as a "mental model", serves as the framework for reasoning, decision-making and behavior (Sánchez 2008). While mental models are unique and personal, shared experiences enable people within a group or culture to develop a common schema, thereby creating cultural meaning to perceive and relate to the world. Because an individual's ability to represent the world with perfect accuracy is inherently limited, mental models are conceptualized as personal and incomplete representations of reality (Sánchez 2008). There exists a common consensus among researchers that people form mental models through analogy; creating mental representations of unfamiliar domains by drawing on knowledge of more familiar domains believed to be similar. Such models must be highly dynamic, adaptable, and able to evolve over time through learning (Sánchez and Hassler 2007; Sánchez 2008). Beyond a mere philosophical discussion, one can posit the nature of mental models in an individual born without visual experience, and the extent to which this representation differs (if at all) from that of a sighted person. Specifically, one could ask the following: "what is the effect of the absence or loss of vision (i.e. from birth or later in life) on the development of mental constructs"? This question has become the subject of intense multi-disciplinary research involving neuroscientists, educators, and sociologists (see (Cattaneo and Vecchi 2011;

Pasqualotto and Proulx 2012) for complete discussions). From a technological standpoint, this subject also has implications in terms of whether it is most beneficial to create custom-made interfaces for the blind *de novo* or to adapt current approaches for the sighted so as to render them more accessible. The answer to this question certainly possesses important repercussions from an education and rehabilitation standpoint. In reality, the blind may, in certain respects, structure, order and perceive the world in a completely different manner from their sighted counterparts. Thus, the assumption of a singular mental model constitutes a major premise that necessitates validation, particularly for the development of assistive technology for the blind.

At a basic level, some accessible technology initiatives have incorporated approaches based on the assumption that simply supplying information through non-visual means is sufficient to render technology fully accessible to blind users. For example, the technology mentioned above such as screen readers, voice synthesizers, and text-to-speech (TTS) software enables written information to be interpreted through hearing. These access methods, while undoubtedly indispensable in the daily lives of many blind people, possess a common underlying problem. Namely, the core applications that these accessibility tools support are designed for sighted users, whose visual mental model may differ substantially from the mental model of blind computer users. The primary issue in developing technology without considering the mental models of the intended users is the proper design of a dialog between the user and the interface, which, if not appropriate, can render such technology unusable. We argue that in the case of blindness, it is therefore usually not sufficient to add audio to an existing application or to use screen reader tools to facilitate the use of technology. These solutions, while currently popular, require blind users to make sense of interfaces designed exclusively for sighted users, forcing them to undertake the counterintuitive demand of adapting to a mental model which may differ substantially from their own (Sánchez and Hassler 2007). Current scientific evidence supports the idea that mental models of blind and sighted people do in fact possess key similarities as well as differences (De Beni and Cornoldi 1988; Bedny et al. 2009; Dodell-Feder et al. 2011; Bedny and Saxe 2012). One particularly noteworthy domain in which a disparity between the mental models of blind and sighted people manifests is spatial cognition. In spatial cognition, vision allows for the simultaneous capture of spatial relationships between an object and its background. The auditory and haptic modalities, in contrast, are less suited for this parallel processing of information, and instead receive sensory inputs in a more sequential fashion. The idea that blind people lack access to the parallel information afforded by vision, and instead must rely on the serial information provided by their intact modalities is believed by some researchers to be responsible for the mixed performance of blind subjects on a number of cognitive spatial tasks (Cornoldi et al. 1979; 1993; Morrongiello et al. 1995; Noordzij et al. 2006; Cornoldi et al. 2009) and further suggests that lack of access to information presented in parallel renders the construction of high-level knowledge, global concepts, and overview more difficult (De Beni and Cornoldi 1988; Cornoldi et al. 1993; Pasqualotto and Proulx 2012).

An Approach Inspired from Neuroscience and Sensory Substitution

Leveraging neuroscience and behavioral research, the assistive technology design process can be greatly improved. In the absence of sight, the blind rely heavily on non-visual senses (e.g. touch and hearing) and other cognitive functions (e.g. verbal memory) to perceive and interact with the environment. Indeed, touch and hearing remain the principal modalities not only for sourcing information for learning, knowledge and awareness, but also for enabling a blind person to remain integrated in society. In fact, extensive research has demonstrated that blind individuals show superior non-visual skill performance to their sighted counterparts on a variety of tasks such as sound localization (Lessard et al. 1998), tactile processing (Van Boven et al. 2000), short-term memory (Pasqualotto et al. 2013) and auditory processing (Gougoux et al. 2004; Voss et al. 2004). Intriguingly, profound structural and wiring changes at the level of the brain (such as brain regions responsible for sound and touch processing) are believed to support these compensatory behaviors (Bavelier and Neville 2002; Pascual-Leone et al. 2005; Merabet and Pascual-Leone 2010). Perhaps most dramatic, however, has been the demonstration that regions of the brain normally responsible for the processing of visual information appear to be functionally recruited for the purposes of non-visual tasks (e.g. Braille reading, identifying sounds, language processing, and verbal memory (see (Uhl et al. 1991; Kujala et al. 1992; Uhl et al. 1993; Sadato et al. 1996, 1998; Roder et al. 1999; Weeks et al. 2000; Burton et al. 2002; Roder et al. 2002; Amedi et al. 2003; Burton 2003; Kujala et al. 2005)). This dramatic reorganization at the level of the visual brain raises interesting questions relating to the nature of mental models in the absence of visual experience. Could it be possible that the visual brain may be well suited for the integration of spatial and temporal information and support parallel processing regardless of the nature of the sensory modality input (Pascual-Leone and Hamilton 2001; Pascual-Leone et al. 2005)?

The development of sensory substitution devices (SSDs) for the blind has in many ways served as a platform to test these ideas and has been borne out of the concept that our senses provide information with a certain degree of functional overlap and redundancy. Indeed, several groups have developed sensory substitution approaches as an attempt to restore perception normally carried out via the visual modality by utilizing information gained through sound and touch, as well as by channeling the sensory-motor processing inherent in the brain (Benjamin 1974; Bach-y-Rita 2004; Johnson and Higgins 2006; Chebat et al. 2011). In the case of SSD development, these studies have shown that blind individuals are able to integrate visual cues captured through sound and touch in order to carry out complex sensory tasks such as identifying objects and navigating obstacles in unfamiliar environments (Bach-y-Rita 2004).

Non-visual Virtual Environments for the Blind

The communication and entertainment industries have driven many technical advances (e.g. sound cards, joy sticks, and camera-based, motion-sensing input devices), which create highly realistic representations of sound and touch, leading to a greater immersive sense for the user. Many of the software approaches discussed in this chapter take advantage of blind users' ability to identify and differentiate between ambient sounds in order to orient themselves in space. They have also shown to contribute to the improvement of cognitive development and spatial concepts such as egocentric position (up, down, left, and right). As with real life experience, spatial sound is an important source of contextual information in virtual environments, and serves as a critical aspect of a blind individual's development, ultimately widening the scope of learning and cognition via greater utilization of the senses. Thus, through an ample variety of audio stimuli, users can remain alert and motivated during their interaction with the software.

While spatial sound constitutes a powerful vehicle for mapping information and creating a rich immersive experience, on the tactile side, there has been a growing interest in developing force feedback interfaces that allow blind and visually impaired users to access not only two-dimensional (2D) graphic content (such as from a tactile display), but also information presented in three-dimensional (3D) virtual-reality environments. The use of force feedback joysticks has introduced a more realistic means of tactile sensory interaction that provides information including temperature, texture, and pressure, with real-time feedback. For example, several research projects have been conducted which implement the Logitech WingMan, a force feedback mouse, for the support of visually impaired people in virtual environments (Yu et al. 2003). Also, recent work has focused on using a different haptic device, the CyberGrasp, to capture shapes and forms through a force feedback data glove (McLaughlin et al. 2000). Perhaps the device that has gained the most attention is the PHANToM (developed by Sensible Technologies), which is a pointer device that provides force feedback information in such a way that the user can feel volume and force in his or her hand. This functionality provides greater feedback during the interaction with objects for certain applications such as identifying regular and irregular geometrical figures of different shapes, reliefs and textures. The PHANToM has also been used as a "virtual cane," allowing for the navigation and exploration of virtual environments (e.g. corridors, streets, rooms, buildings, etc.) (Lahav 2006; Lahav et al. 2011). For this same application, the Wiimote (Nintendo) has also gained recent interest, allowing for the exploration of virtual environments (e.g. by using the "rumble" feature when an obstacle is detected) (Evett et al. n.d.).

The development of enhanced tactile and audio user interfaces has contributed substantially to the increased feelings of immersion one encounters in virtual environments. When thinking of the implications of learning and skill development, however, the immersive characteristic of virtual environments supersedes enhancement of sensory experience. Rather, one must consider the design of interactive environments for the development and construction of mental representations of space, as well as for the development of cognitive abilities.

By learning through simulation, virtual environments can provide exposure to novel situations which may be otherwise too dangerous, too expensive, or simply physically impossible to carry out in real-world situations. The success of flight simulators for pilot training or military combat simulations serve as prototypical examples (Rizzo and Buckwalter 1997). For the blind, the approaches used in virtual environments have been generally audio-based, spanning from simple alert sounds (hitting a door or wall, or changes in pitch to approximate distance from an object) to a more sophisticated and complex variety of sounds (such as stereo and 3D audio to localize and identify objects). The content used in virtual environments generally focuses on navigation through the representation of a real physical space or a labyrinth, and the interaction with objects inside such space. Based on this premise, virtual environments can potentially constitute a novel method for learning and interacting with complex information by exploiting information that can be acquired through multiple sensory modalities. For example, navigating through virtual environments can exploit different methods of accessing spatial information and allow for both the simulation of travel and the playing-out of hypothetical scenarios.

In this direction, virtual environments have been designed to create interactive interfaces for the blind (particularly children), and have proven to be a highly innovative approach to enhancing cognition. Crucial for success has been the development of systematic usability evaluations. Through implementation of a user-centered design, these evaluations better ensure the environments are simultaneously intuitive and useful for blind users. For example, key interface issues are highlighted early in software development in order to characterize the blind user's needs and ways of interacting with information (Sánchez 2008). At the same time, the growing popularity of video games has sparked new interest within the educational domain as an adjunctive form of teaching basic curriculum as well as for specialty training of skills (Klopfer and Yoon 2005; Shaffer et al. 2005; Stone 2005; Deubel 2006; Prensky 2006; Gros 2007; Proserpio and Viola 2007; Clarke and Dede 2009; Dede 2009). Today, as technology continues to rapidly evolve and computer costs continue to decrease, the potential flexibility and accessibility of "smart" computer devices are becoming increasingly incorporated into our daily activities. This convergence of factors has proved a fertile ground for the development of specialized computer and video-game based educational strategies. The very nature of video games provides appealing characteristics for learning that can serve as a platform for interaction with subject material in novel ways (Kuppersmith et al. 1996; Cho et al. 2012; Lange et al. 2012) and in particular, for children with disabilities (Strickland 1997; Salem et al. 2012). In fact, a growing body of research supports the idea that virtual environments, such as video games, can facilitate learning. In 2012, The Alliance for Excellent Education suggested an educational shift from a "teacher-centric" to a "learner centered" environment in which students receive an array of educational content in the form of face-to-face interaction, such as in the classroom setting, combined with the use of virtual environments (AEE 2012). In this ideal "blended learning" approach, students must be able to find, synthesize, and evaluate information from a wide variety of subjects and sources.

Crucial to success of a viable video-game approach is the demonstration that acquired knowledge and skill can be transferred from the virtual to the real physical world. Thus, the challenge of creating virtual environments for educational purposes is not to create a new video game which merely simulates experiences in the real world, but rather to leverage potential educational strengths and tailor the instructive components of a game to allow for learning which may not be as robust or as feasible in the outside world. Specifically, if gaming is tailored to develop individual skills within scenarios coupled with real life instruction, users can potentially achieve significant gains (Shaffer et al. 2005; Dede 2009), particularly specialty populations that may show limited learning using more traditional didactic teaching methods. For example, video game-based learning environments are typically designed to promote student's self-exploration and self-monitoring strategies resulting in an increased ability to integrate and elaborate on new concepts (Chung et al. 1999) and to problem solve (Bixler 2008).

More recently, this strategy of leveraging video games for learning has been pursued with "brain training games". Unfortunately, only limited skill transferability and overall cognitive improvements across the general population have been shown (Mahncke et al. 2006a; Mahncke et al. 2006b; Bavelier et al. 2011). Other studies involving action video game play (particularly first-person shooter games) have demonstrated selective improvement outside of general gaming skills such as in the areas of visual-attentive processing and visual contrast sensitivity (Achtman et al. 2008; Green and Bavelier 2008; 2012; Wu et al. 2012). As a result, the subject of nonvisual virtual environments for the blind, with the interest and neuroscience-based scientific research it has generated, remains an exciting area of exploration and development (Spence and Feng 2010; Bavelier et al. 2011; Bryck and Fisher 2012).

Virtual Environments for Learning in the Blind

A number of audio-based virtual environments have helped to improve learning and cognition, particularly in blind children and adolescents. By taking into account both blind individuals' specific needs and cognitive developmental trajectory, virtual environments have reinforced a number of skills such as spatial-temporal processing, haptic perception, and abstract memory.

One example of these virtual environments is AudioMemorice (Sánchez and Flores 2004). This game is based on the well-known children's board game "Memory," and places cognitive emphasis on the practice and improvement of short-term memory skills. The tasks embedded in the software require the exercise of audio/oral, visual/oral, audio/image and visual/image memory. The software includes several levels of difficulty, and embeds mathematical concepts such as position value, sequences, additive decomposition, multiplication, and division. By opening pairs of tokens on a board, a blind child must find the corresponding token pair that agrees with displayed mathematical content.

AudioVida is a virtual environment-based game designed to assist with the development of problem solving skills in blind children (Sánchez and Saenz 2006). AudioVida emphasizes the implementation of different routes for movement within a complex, audio-based virtual environment so that users can reach a specific destination and locate a particular object. To achieve this goal, the learner must analyze and interpret the virtual space by applying notions of spatiality and temporality. Use of such cognitive strategies favors abilities needed to recognize different possibilities for navigation through a virtual environment and create a mental representation of the virtual space. The learner's immersion in the virtual environment is induced through spatial sound effects that indicate the player's position and provide references about walls, doors, elements with which the player can interact and intersections within the labyrinth. Users are informed about contextual changes through variations in sound pitch and the location of sound sources. When contexts change, learners receive an audio signal that defines the direction and closeness of the various software components, motivating learners to walk through the virtual labyrinth in the same manner as they would through a real-life, physical environment.

On a larger scale, AudioChile was introduced in an attempt to promote the development of strategies for problem identification, planning and execution for subsequent verification (Sánchez and Saenz 2006). This software encourages users to develop a capacity for verification, reflection and strategies for problem solving. Once immersed in the game's 3D world, the user adopts a main character and interacts with three different virtual regions of the country of Chile. Information relevant to specific regions of the country is provided by hidden clues that allow users to visit and learn about aspects of Chilean geographic traditions. In order to travel between different zones, users must achieve certain objectives that are required for future tasks. Navigation in the virtual world is defined by predetermined paths that allow for the character's mobility and freedom within certain parameters. Interactions occur through actions such as taking, giving, opening, pushing, pulling, looking, speaking, using, traveling, checking the backpack, and making movements and turns. These actions are performed by using a force feedback joystick and a computer keyboard. All actions performed in the software (such as accessing the menu and taking actions during the story itself) utilize audio feedback such as stereo sounds so that the user can understand events taking place in the story.

These examples of software applications have shown that significant improvements in learning and cognition in blind children can be achieved using audio- and tactile-based games specially tailored as a medium for interaction through user-centered technology. Preliminary findings from a number of early studies by one of the authors (J.S) indicate that designing user-centered software for blind children can help develop their intellectual capabilities and thus help to close the cognitive developmental gap between sighted and blind children (Sánchez 2008). Additionally, children were also readily able to learn the software with only minimal outside supervision. However, further research is necessary to determine the impact of this software on the development of higher-order cognitive functions, such as spatial representation, strategies for complex navigation, and problem solving.

Social Development

Historically, blind people have found themselves socially isolated; a trend which persists even in today's world, where modern technology has made it easier for people to remain more connected than ever before. Much of this social isolation begins early in development, when children learn acceptable norms and behaviors required for social interaction. While sighted children learn social cues implicitly through observation, there is concern that blind children do not pick up on such crucial social information as quickly. Moving into adulthood, many blind people are further barred from potential social opportunities because of restrictions such independent travel (Carroll 1961). Even for largely independent travelers, the lack of access to transportation, particularly the scarcity of public transportation in most geographic areas, prevents many blind people from traveling, thereby further decreasing opportunity for social contact and interaction. Socialization is further impaired through blind people's lack of access to the symbolic world, which refers to the use of symbols such as writing and pictures to represent language, ideas and information. Society heavily utilizes symbols to facilitate the exchange of goods, services, and ideas. Much of the symbolic world is conveyed visually, and as a result, blind people are often excluded from this network of information exchange, thereby impeding interactions between blind and sighted people. Blindness myths and stereotypes, negative expectations and perceptions, lower standards, and fears or apprehensions on the part of both sighted and blind people further exacerbate this social divide. Attempts to level the social playing field often involve creating contrived roles that impose artificial disadvantages on sighted participants, as opposed to maximizing the capabilities of all players regardless of visual status. The increasingly widespread adoption of virtual environments has the potential to greatly reduce or eliminate these barriers to full social inclusion. One example of such a potentially inclusive interface are the widely popularized multi-user virtual environment (MUVE) games. The appeal of MUVE games is that they bring people from across the world together in a single virtual environment and have potential applications for online social, business and recreational activities. MUVEs also possess added benefits for blind users. For one, because a user plays the game on a computer, these virtual environments eliminate the barriers related to independent travel which impede socialization in real physical environments. Second, because each user assumes a character represented by an "avatar", the challenges blind people encounter on a day-today basis during face-to-face interactions are lessened. Unfortunately, due to the complex nature of the interactive environments, MUVEs still remain largely inaccessible to blind users (White et al. 2008). However, recent attention has been called to adapting these games for blind users. A prime example of a MUVE game which could be rendered accessible (but which currently presents significant limitations) is the very popular game Second Life (SL). In SL, users exist in a large-scale virtual world, most of the contents of which are created and customized by the users themselves. SL boasts a robust economy, which overlaps with real economies so that goods and services created in the game can be bought and sold with real-world currency. At this time, SL is largely inaccessible to profoundly blind computer users, and is only partially accessible to users with residual vision. In one study, eight blind and visually impaired expert users were able to elucidate the accessibility challenges present in SL while engaging in semi-structured interviews about their personal experiences with accessibility in real and virtual environments (White et al. 2008). This study found that accessibility barriers in SL exist in important domains such as content creation, economic exchange, and communication which have important implications for the social nature of the game. In order to create content in the game, players must use an exclusively visual modeling process, which involves constructing objects using geometric figures as building blocks. The ability to customize one's avatar, and to leverage this same modeling functionality for creating content, enables users to compete with other players in the virtual economy. Active participation in a virtual economy could open up valuable opportunities for otherwise unemployed individuals to independently generate their own income. Unfortunately, the fact that there exists no nonvisual alternative to accessing this visually-dominant component of the game still makes such a prospect unfeasible. In addition, much text-based information in this game is communicated graphically, and standardization of this information in an accessible format is difficult to enforce. Blind users therefore miss out on much of the text-based and graphical information available to their sighted counterparts, which is analogous to the inaccessibility of symbolic information. Furthermore, the inaccessibility of content creation combined with the incompatibility of SL with screen readers renders it impossible for blind players to communicate with other players within the game. These social aspects of the game are considered to be critical by sighted players. Despite these virtual barriers to SL and similar virtual environments, there is reason to believe that social inclusion in this arena is possible if the correct strategies for maximizing usability are put in place. The authors of the aforementioned study discuss several approaches to enabling access not only to SL, but also to other similar virtual environments. First, screen readers must be able to effectively convey information specific to 3D environments, a challenge which is the subject of their current investigations. Examples of such accessible interfaces include self-voicing TTS, text-based clients, and the use of a conventional screen reader combined with immersive 3D audio. Additionally, the use of haptic force feedback devices could resolve another current limitation pertaining to screen readers; the incapacity to provide a smooth method of navigating continuous spaces. These innovative technological solutions, far from simply making individual games accessible to the blind, serve the far greater purpose of ensuring that blind and sighted people can compete equally in an increasingly virtualized world. As a result, blind users must have access to the full range of content available to their sighted counterparts; without complete access to this exchange of ideas, dialogue, and other resources, maximum social integration is rendered impossible. Blind people will be able to more fully enjoy and appreciate the powerful interactive capabilities of virtual environments through a combination of innovative audio interfaces, haptic feedback, and novel screen reader designs. Meanwhile, increased support for existing assistive technologies by mainstream applications can further narrow the existing accessibility gap. Together, these access strategies have the potential to create a climate of social inclusion in the virtual world.

Virtual Environments for the Purposes of Developing Navigation and Way Finding Skills

User-centered virtual environments have also been employed as a method to help for the specific purpose of helping blind individuals develop navigation and way finding skills, as well as spatial reasoning abilities. For the blind, navigating independently and safely is an important skill to master and presents a significant challenge. Orientation and mobility (O&M) training remains a mainstay in blind rehabilitation, and with systematic and rigorous training, individuals with visual impairment can gain a certain level of functional independence (Ashmead et al. 1989; Blasch et al. 1997). It is important, however, that training strategies remain flexible and adaptable (Long and Giudice 2010). Rather than focusing exclusively on providing students with explicit instruction for navigating a specific environment (i.e. learning a specific route to reach a given destination), training must also promote the development of extensible navigation skills which blind individuals can generalize to unfamiliar situations. Further, training must be tailored to a person's own strengths and weaknesses to address an individual's particular challenges, needs and learning strategies. The creative use of interactive virtual environments may provide for this flexibility and supplement current O&M training curricula. In this section, we describe how user-centered, audio-based virtual environments afford a safe, immersive, engaging, and highly interactive setting that allows a blind user to interact with context-relevant spatial information that can be used for the purposes of learning the spatial layout of a complex environment and the development of navigation skills.

One of the earliest programs developed for the exploration of non-visual navigation skills in blind children was AudioDoom (Sánchez and Lumbreras 1999) which was based loosely on the popular first person shooter video game "Doom". In this game, a player must navigate through a predetermined labyrinth of walls and corridors, while locating various items and avoiding monsters, so as to find an exit portal and begin the next level. Crucial to a player's success is the ability to create a spatial mental (or "cognitive") map (Strelow 1985) of objects and rooms found in the labyrinth and continuously update this map while moving through the environment. AudioDoom operates in much the same way, except that it uses iconic and spatialized sounds to provide contextual information regarding one's surroundings during game play. A player can use a joystick, keyboard or mouse to move in any direction and interact with the virtual environment in a step-by-step fashion. Since the environment is constrained by the use of corridors (as opposed to wide-open spaces), users can readily keep track of their orientation and heading. Played out in the context of a three dimensional environment, the user can build a mental spatial representation through the sequential and causal encounters within a goal-directed navigation framework. Early studies with AudioDoom reported positive outcomes in terms of educational and spatial reasoning skills. For example, blind children found the game highly enjoyable and engaging, and supervising teachers reported that blind gamers demonstrated increased cognitive abilities, problem solving skills, and overall sense of self-confidence transferring to other areas of their coursework (Sánchez and Lumbreras 1999). Perhaps even more interesting, children who played AudioDoom were able to accurately construct tactile representations of the encounters and routes they followed within the game, as demonstrated by the concrete models they created (e.g. using Lego pieces or other materials). Visual inspection revealed a high degree of consistency between the children's tactile representations and the target labyrinth navigated in the game, suggesting high fidelity of the spatial cognitive maps generated following game play.

These preliminary results from AudioDoom show how virtual environments can leverage spatialized auditory information to provide reliable cues that describe spatial environments and the relationships between objects. Furthermore, they also demonstrate that profoundly blind children can generate accurate spatial cognitive maps using auditory information alone through an immersive and interactive virtual environment. The interactive and immersive nature of this game not only provides a strong, motivating drive for players, but demonstrates that spatial cognitive constructs can be learned simply and implicitly through causal interaction with the software.

As a next step of scale, AudioMetro was one of the first audio-based software interfaces developed with the goal of assisting users with visual impairment to organize and prepare a travel route before riding on an actual subway. This interactive software is based on the urban subway system of the city of Santiago, Chile (though in principle, virtually any subway system can be rendered) (Sánchez and Maureira 2007). Interaction with AudioMetro utilizes a metaphor of simulating travel aboard a subway car. This interactive model considers notions of consecutive, transfer, and terminal stations and allows the user to simulate the experience of the entire journey from start to finish. As with most urban subway systems, travel between two stations is sequential and occurs along specific subway lines which are bi-directional. Transfer stations consist of different levels with each specific subway line having its own level. In a typical session of game play, the user first chooses the departure and arrival stations of the chosen journey using an interactive menu (keyboard input and TTS interface). The software then automatically calculates the optimal route from the departure to the arrival station. In the second stage, the user travels virtually through the subway network starting at the departure point, passing through consecutive stations, and making appropriate transfers until finally arriving at the desired destination. The software has an inherent sequential and unidirectional flow, allowing the user to explore the subway network and associated landmarks through audio feedback. As a result, users can familiarize themselves with the basic organization of the subway system and reinforce important spatial knowledge such as the relative distance between stations, appropriate transfer points, and platforms associated with each line as well as key landmarks and facilities present at various stations. Sánchez and Maureira (2007) conducted a study with seven legally blind participants (aged between 15 and 32), and found that users of AudioMetro were able to initially plan their journey as well as construct a mental representation of the overall organization and layout of the subway system, including the interconnections of the various lines (as verified by tactile model construction). Furthermore, users were able to implement the knowledge they gained from interacting with AudioMetro by travelling independently throughout a series of test scenarios without the need of a guide present. Users also reported a greater sense of autonomy and competence in using the subway network (assessed using subjective rating scales) (Sánchez and Maureira 2007). The results from AudioMetro suggest that audio-based interactive software can provide access to useful navigational information as well as simulate and play out hypothetical scenarios in a meaningful way, which, taken together, can potentially translate into enhanced navigation skills. Furthermore, the resultant mental representations generated can be large-scale and correspond to real-world environments.

Building upon and combining the strengths of the aforementioned software approaches, it was hypothesized that profoundly blind users who interact with a reconstruction in a virtual environment can not only create an accurate spatial cognitive map of that space, but may also transfer this acquired spatial information to a large-scale, real-world navigation task. Key to demonstrating this premise would be to develop a flexible and modifiable software platform that leverages the advantages associated with both gaming metaphors and interactive virtual navigation. Following through with these notions, the authors of this chapter are currently investigating the feasibility and effectiveness of using an audio-based virtual navigation software called Audio-based Environment Simulator (AbES) (Sánchez et al. 2010; Merabet et al. 2012) (Fig. 16.2). This software is similar to those previously described in terms of its audio-based navigation and interactive capabilities and can be used to generate virtually any physical space desired including open rooms and corridors, multiple floors, furniture and obstacles. The software also incorporates various data-collection methods that can be used to assess behavioral performance (e.g. reconstruction of the route travelled including the time taken to navigate to target, distance traveled and errors made). A user explores the building virtually via keyboard input, moving through the environment and listening to appropriate spatial audio cues after each step taken (e.g. a knocking sound in the left stereo channel is heard as the player walks past a door on the left and walking up stairs is associated with sequential steps of increasing pitch). Orientation is based on cardinal compass headings (i.e. north, east, west, south) and the user also has a "where am I?" key that can be pressed at any time to access TTS-based information that describes their current location in the building, orientation and heading as well as the identity of objects and obstacles in their path (for complete details, see (Connors et al. 2013)).

In a recent study, we demonstrated that after approximately 60–90 min of interacting with AbES, users were able to virtually survey and explore the layout of a building and locations of the target objects within it (Merabet et al. 2012). Furthermore, subjects were able to demonstrate a transfer of their cognitive spatial

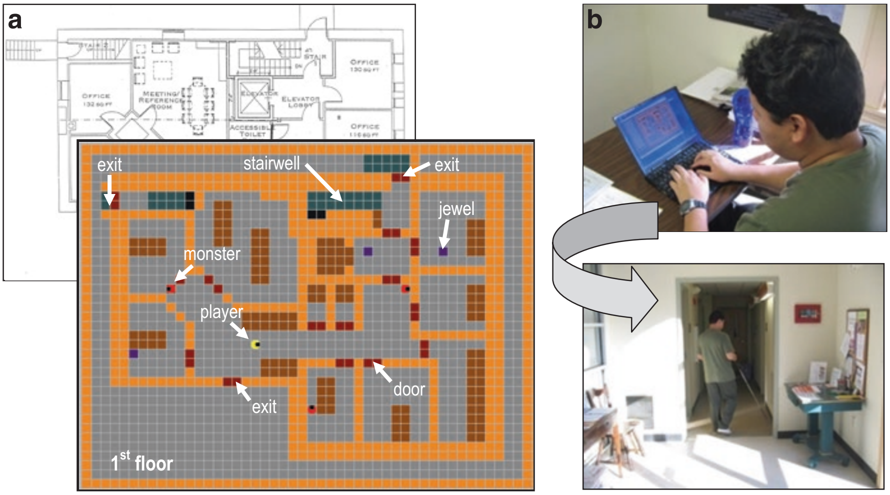

Fig. 16.2 (**A**) The spatial layout described in a floor plan (background) of a real physical building is converted into a virtual representation in the software AbES (foreground). Scaling is such that one step in AbES is roughly one step in the real building. (**B**) Participants (previously unfamiliar with the building) explore their surroundings through the use of spatial audio cues and the causal interactions with the objects located in the virtual environment (top photo). Once trained in the virtual environment, users are then tested on navigation task within the real physical environment represented in AbES (lower photo)

knowledge in a real-world navigation task by carrying out a series of path integration tasks in the actual physical building corresponding to the building rendered in the virtual environment.

Another unique feature of AbES is that it can be played in two distinct modes. In "directed navigation" mode, a facilitator leads the user through a predetermined route within the virtual world, creating a virtual rendition of a traditional O&M lesson. In the "game" mode, the user independently interacts with the virtual environment (i.e. without a facilitator) with the goal of exploring the entire building in order to collect hidden gems while avoiding roving monsters Thus, in either mode, users interact with the virtual environment to gain spatial information and generate a cognitive map of the spatial surroundings. However, given the implicit nature of acquiring spatial information through gaming, we have speculated that the construction of these spatial cognitive maps may prove to be different depending on the mode of play. In other words, AbES played in game mode is designed to promote full exploration of the building, thereby maximizing creativity and encouraging players to develop "higher level" spatial skills and cognitive representations (Blasch et al. 1997). By comparison, we hypothesized that individuals who interact with AbES in directed navigation mode would lead to spatial mental constructs that were limited to the actual routes encountered and as defined by the facilitator. It would be reasonable to assume that individuals who have a more "robust" cognitive spatial map of their surroundings would be more likely to be flexible in their spatial thinking and thus be better able to construct alternate routes for navigation, as opposed to relying on rote memory alone. Current work is aimed at investigating these hypotheses by assessing individual's ability to transfer the acquired spatial information from the virtual to real physical environment.

It is important to consider that substantial differences between the behavioral gains obtained through virtual compared to real-world navigation may certainly exist (Magliano et al. 1995). For example, virtual navigation training within a controlled environment allows for the opportunity to play out multiple scenarios while potentially alleviating stress and risk issues associated with comparable real-world scenarios. Conversely, there may exist inherent advantages associated with the actual execution of physical movements in real-world situations that ultimately translate into enhanced motor planning and eventual consolidation of O&M task-related skills. It is important to realize that virtual reality software approaches are not meant to replace current rehabilitative techniques and programs. Indeed, traditional O&M training used in conjunction with virtual environments parallels the highly beneficial "blended" learning approach mentioned above. What we propose is that virtual environments can serve as an adjunctive strategy that not only draws upon the benefits of high motivational drive, but also provides a testing platform to carry out more controlled and quantifiable studies including neuroscience-based investigations.

Virtual Environments as a Platform for Behavioral & Neuroscience Investigations

The manner in which the brain learns and ultimately transfers skills gained from game- and virtual environment-based learning remains a matter of intense investigation (Bavelier et al. 2010; Bavelier et al. 2011, 2012). An important, yet unresolved, question relates to identifying the underlying brain mechanisms responsible for learning and transfer of skills acquired within virtual environments. Combining virtual environments and game-based learning with modern techniques of brain imaging (e.g. functional magnetic resonance imaging; fMRI) may help us to come closer to answering this crucial question. Virtual environments provide a tractable testing platform for the collection of quantifiable metrics such as performance outcome measures and the monitoring of learning and progress.

In this section, we give an example of ongoing research investigating the neuroscientific basis of navigation skill by leveraging the technical advantages offered by virtual environments. Navigation is a complex mental process that draws upon a number of cognitive skills and functions including the construction and retrieval of a mental map of the environment, the assessment of one's current position within that map, memory of past events, heading, re-routing around obstructions, and planning future movements. Our collaborative group has been using virtual environments to help uncover the neural correlates of how blind individuals can carry out this task in the absence of sight. Furthermore, within a virtual environment, it is possible to compare brain activation on a variety of behavioral tasks as well as the strategies used to perform the tasks under study. Navigation performance in virtual environments also has importance within the clinical setting. Orientation and mobility (O&M) training in the blind traditionally utilizes the instructor's clinical intuition as to which techniques and strategies are best used to proceed with training. Each individual may respond best to different types and forms of instruction. Thus, exploiting the flexibility of virtual environments in the fMRI brain scanner can be used to compare, head-to-head, the learning strategies which lead to optimal behavioral performance as well as the neural networks associated with this performance.

We have recently adapted our audio-based virtual navigation system AbES to be used in an fMRI scanner. We asked blind participants (as well as sighted controls) to navigate within the virtual environment, starting from one room and ending in another. In a pilot study, we compared brain activity of a blind individual to that of a blindfolded sighted individual carrying out the same navigation task. We found that activation during auditory-based navigation in the blind participant was very similar in pattern to that observed in the sighted control. Specifically, we found activation within areas of the brain normally ascribed to navigation (referred to as the action and route planning network; see (Maguire et al. 1999; Spiers and Maguire 2007). This includes regions of the brain including frontal cortical areas (implicating with planning), parietal cortex (implicated with spatial processing) and regions of the hippocampus (important for memory and route finding). Intriguingly, regions of the brain responsible for the processing visual information (i.e. the occipital visual cortex) were also highly active in both the blindfolded sighted control and blind participants despite the fact that no visual information was provided during the navigation task (Fig.16.3). Certainly, one may argue that the visual cortex activation observed in the blindfolded sighted participant could be related to mental processes related to visual mental imagery. Indeed, many studies have demonstrated that visual perception and visual mental imagery share common brain processing machinery (Ganis et al. 2004; Pearson and Kosslyn 2013). The activation of visual cortical areas in the sighted participant may correspond to mental visual exploration and manipulation of spatial cognitive maps for the purposes of virtual navigation. However, what does activity in the visual brain correspond to in an early blind individual and presumably does not have visual memories? Do these similarities in activation patterns suggest that blind individuals have the same mental spatial constructs as sighted individuals? Once again, this raises an intriguing (and critical) discussion regarding the nature of mental models in the blind and how they relate to learning and cognitive processing (Aleman et al. 2001). Future studies leveraging the gains afforded by carrying out well designed and controlled behavioral experiments with virtual environments coupled with insights gained by modern day brain imaging techniques may help solve this important question.

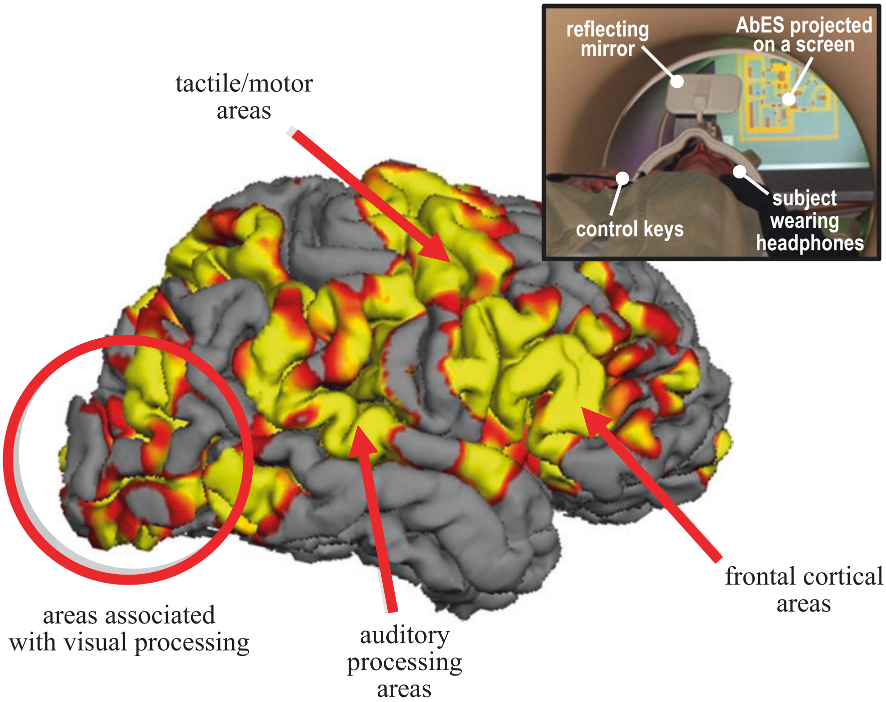

Fig. 16.3 Exploring patterns of brain activity (using functional magnetic resonance imaging; fMRI) associated with navigating within a virtual environment. The AbES software is adapted so that virtual navigation can be carried out inside the scanner (inset figure - sighted participant). Brain activation associated with a congenitally blind individual carrying out a virtual navigation tasks reveals cortical regions including frontal, auditory, sensory-motor (tactile/motor) areas as well as regions of the occipital cortex typically associated with the processing of visual information (for simplicity, the lateral surface of the right hemisphere is shown)

Conclusions

We have discussed the role and importance of virtual environments for the development of cognitive skills in the blind. Efforts in this direction have led to a variety of innovative and promising approaches, which still necessitate considerable development and further research. This novel paradigm is completely in line with the belief that blind individuals merit facilitation and improvement in their training, education, and employment opportunities. Coupled with reality-inspired and goal-directed rehabilitation, the use of virtual environments may serve as a powerful vehicle for improving the quality of life for the blind.

We have described a series of interactive non-visual computer based software and virtual environments designed to serve as novel rehabilitative approaches for the improvement of spatial navigation, problem solving skills, and overall confidence in individuals with visual impairment. We continue to investigate the feasibility, effectiveness, and potential benefits of learning to interact with virtual-based environments. In parallel, we are developing methods of quantifying behavioral gains, as well as uncovering brain mechanisms associated with learning skills through this approach. A key direction of future research will be to understand what aspects of the acquired information ultimately transfer from virtual to real environments and the conditions that facilitate this transfer (Thinus-Blanc and Gaunet 1997; Waller et al. 1998; Farrell et al. 2003; Chrastil and Warren 2012). This research affords us the opportunity to gain a greater appreciation for the real-world challenges faced by blind individuals, as well as to develop a greater scientific understanding of how mental models in the blind compare with those of sighted people. Furthermore, understanding how the brain creates spatial cognitive maps over time as a function of both learning approaches and an individual's own experience and motivation will have potentially important repercussions for how blindness rehabilitation training is carried out, and at the same time, directly contribute to an individual's overall rehabilitative success. In the area of orientation and mobility, for example, a significant number of blind children and adults do not independently travel outside of familiar areas, such as their schools or neighborhoods, which they usually learn via formal instruction or sighted assistance. Fortunately, however, blind individuals regularly demonstrate the ability to successfully navigate almost any novel environment using a combination of robust spatial strategies, real-world problem solving skills, and confidence in their travel abilities. Virtual environments show significant promise in providing valuable tools for improvement in these key areas.

Currently, many solutions already do exist which have enabled blind individuals to overcome a number of the existing barriers to accessibility. Virtual environments represent a unique avenue for further development of skills not readily available through assistive and accessible technology alone. The implementation of universal interface designs may help users to overcome the cognitive constraints imposed by design flaws in current technologies. In the midst of this exciting innovation, one must not lose sight of the fact that technology, no matter its groundbreaking potential, cannot substitute for the persistence, creativity, and high motivational drive which have enabled so many blind individuals to attain personal and professional success thus far. Only by possessing these qualities initially can blind individuals hope to leverage technology to its fullest extent as a tool for achieving maximum independence and integration in a predominantly sighted world. Parents and educators can largely facilitate blind children's development by setting high expectations and embodying positive outlooks on the abilities and potential of blind people. With STEM careers constituting a substantial proportion of the job market, it is imperative that blind students have access to opportunities in order to pursue these fields of study (Moon et al. 2012; Kell et al. 2013).

Through creative innovation and a core belief in the inherent abilities of blind people, we can work together with the blind community to empower the next generation of individuals who are blind in their effort to achieve full independence and inclusion in society. Moving forward, future work in this arena should continue to employ a multi-disciplinary approach drawing in expertise from instructors of the blind, clinicians, and technology developers as well as neuroscientists, behavioral psychologists and sociologists. By leveraging the utility of virtual environments, we are in a better position to understand the compensatory abilities of the blind and the remarkable ability of the brain to adapt to a wide variety of experiences.

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Chapter 17
Virtual Human Standardized Patients for Clinical Training

Thomas Talbot and Albert "Skip" Rizzo

A virtual revolution is ongoing in the use of simulation technology for clinical purposes. When discussion of the potential use of Virtual Reality (VR) applications for human research and clinical intervention first emerged in the early-1990s, the technology needed to deliver on this "vision" was not in place. Consequently, during these early years VR suffered from a somewhat imbalanced "expectation-to-delivery" ratio, as most users trying systems during that time will attest. Yet it was during the "computer revolution" in the 1990's that emerging technologically-driven innovations in behavioral healthcare had begun to be considered and prototyped. Primordial efforts from this period can be seen in early research and development (R&D) that aimed to use computer technology to enhance productivity in patient documentation and record-keeping, to deliver cognitive training and rehabilitation, to improve access to clinical care via internet-based teletherapy, and in the use of VR simulations to deliver exposure therapy for treating specific phobias. Over the last 20 years the technology required deliver behavioral health and medical training applications has significantly matured. This has been especially so for the core technologies needed to create VR systems where advances in the underlying enabling technologies (e.g., computational speed, 3D graphics rendering, audio/visual/haptic displays, user interfaces/tracking, voice recognition, artificial intelligence, and authoring software, etc.) have supported the creation of low-cost, yet sophisticated VR systems capable of running on commodity level personal computers. In part driven by digital gaming and entertainment sectors, and a near insatiable global demand for mobile and networked consumer products, such advances in technological "prowess" and accessibility have provided the hardware and software platforms needed to produce more usable and hi-fidelity VR scenarios for the conduct of human research and clinical intervention. Thus, evolving behavioral

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health applications can now usefully leverage the interactive and immersive assets that VR affords as the technology continues to get faster, better and cheaper moving into the twenty-first Century.

While such advances have now allowed for the design and creation of ever more believable context-relevant "structural" VR environments (e.g. combat scenes, homes, classrooms, offices, markets), the next stage in the evolution of Clinical VR will involve populating these environments with Virtual Human (VH) representations that can engage real human users in believable and/or useful interactions. This emerging technological capability has now set the stage for the next major movement in the use of VR for clinical purposes with the "birth" of intelligent VH agents that can serve the role of virtual standardized patients (VSPs) for clinical training. One problem in trying to understand VSPs is that there are several quite distinct educational approaches that are all called a 'virtual patient.' Such approaches include case presentations, interactive patient scenarios, virtual patient games, human standardized patients, high fidelity software simulations, high fidelity manikins and virtual human conversational agents. The emphasis of this chapter is on virtual human conversational agents and the reader is referred to Talbot et al., (Adamo 2004) for a very clear detailing of the salient features of the wide variety of approaches that are commonly referred to as virtual patients.

The Rationale for Virtual Standardized Patients

An integral part of medical and psychological clinical education involves training in interviewing skills, symptom/ability assessment, diagnosis and interpersonal communication. In the medical field, students initially learn these skills through a mixture of classroom lectures, observation, and role-playing practice with standardized patients--persons recruited and trained to take on the characteristics of a real patient, thereby affording medical students a realistic opportunity to practice and be evaluated in a simulated clinical environment. This method of clinical training was first attempted in 1963, when Dr. Howard Barrows at the University of Southern California trained the first human standardized patient (Artstein et al. 2008). Since that time, the use of live actors has long been considered as the gold standard medical education experience for both learning and evaluation purposes (Babu et al. 2006; Barrows and Abrahamson 1964). Human standardized patients (HSPs) are paid actors who pretend to be patients for educational interviews and provide the most realistic and challenging experience for those learning the practice of medicine because they most closely approximate a genuine patient encounter. HSPs are also a key component in medical licensing examinations. For example, the United States Medical Licensing Examination (USMLE) Step 2 Clinical Skills exam uses SPs and is mandatory for obtaining medical licensure in the United States [cf. http://www.usmle.org/]. HSP encounters engage a number of clinical skill domains such as social skills, communication skills, judgment, and diagnostic acumen in a real time setting. All other kinds of practice encounters fall short of this because they either do not force the learner to combine clinical skill domains or they spoon feed data to the student with the practice case that turns the learning more into a pattern recognition exercise, rather than a realistic clinical problem solving experience. The HSP is the only type of encounter where it is up to the learner to naturalistically pose questions to obtain data and information about the case that then needs to be integrated for the formulation of a diagnostic hypothesis and/or treatment plan.

Despite the well-known superiority of HSPs to other instructional methods (Benedict 2010; Bickmore and Cassell 2005), they are employed sparingly. The reason for this limited use is primarily due to the very high costs to hire, train and maintain a diverse group of patient actors. Moreover, despite the expense of standardized patient programs, the standardized patients themselves are typically low skilled actors and administrators face constant turnover resulting in considerable challenges for maintaining the consistency of diverse patient portrayals for training students. This limits the value of this approach for producing realistic and valid interactions needed for the reliable evaluation and training of novice clinicians. Thus, the diversity of clinical conditions that HSPs can characterize is limited by availability of human actors and their skills. HSPs that are hired may provide sub-optimal variation control and are typically limited to healthy appearing adult encounters. This is even a greater problem when the actor needs to be a child, adolescent, elder, person with a disability or in the portrayal of nuanced or complex symptom presentations.

The situation is even more challenging in the training of students in clinical psychology, social work, and other allied health professions. Rarely are live standardized patients used in such clinical training. Most direct patient interaction skills are acquired via role-playing with supervising clinicians and fellow graduate students, with closely supervised "on-the-job" training providing the brunt of experiential training. While one-way mirrors provide a window for the direct observation of trainees, audio and video recordings of clinical sessions is the more common method of providing supervisors with information on the clinical skills of trainees. However, the imposition of recording has been reported to have demonstrable effects on the therapeutic process that may confound the end goal of clinical training (Bickmore and Giorgino 2006) and the supervisor review of raw recordings is a time consuming process that imposes a significant drain on resources.

In this regard, VSPs can fulfill the role of human standardized patients by simulating diverse varieties of clinical presentations with a high degree of consistency, and sufficient realism (Bickmore et al. 2007; Bitzer 1966), as well as being always available for anytime-anywhere training. Similar to the compelling case made over the years for Clinical VR generally, VSP applications can likewise enable the precise stimulus presentation and control (dynamic behavior, conversational dialog and interaction) needed for rigorous laboratory research, yet embedded within the context of an ecologically relevant simulated environment. Toward this end, there is a growing literature on the use of VSPs in the testing and training of bioethics, basic patient communication, interactive conversations, history taking, clinical assessment, and clinical decision-making and initial results suggest that VSPs can provide valid and reliable representations of live patients (Adamo 2004; Bitzer 1966; Bogolub 1986; Campbell et al. 2011; Cheek 2012; Collins and Harden 1999; Cook and Triola 2009; Dev and Heinrichs 2012; Dunne and McDonald 2010).

Virtual Human Conversational Agents

Recently, seminal research and development has appeared in the creation of highly interactive, artificially intelligent and natural language capable virtual human (VH) conversational agents. No longer at the level of a prop to add context or minimal faux interaction in a virtual world, these VH agents are designed to perceive and act in a 3D virtual world, engage in face-to-face spoken dialogues with real users (and other VHs) and in some cases, they are capable of exhibiting human-like emotional reactions. Previous classic work on virtual humans in the computer graphics community focused on perception and action in 3D worlds, but largely ignored dialogue and emotions. This has now changed. Artificially intelligent VH agents can now be created that control computer generated bodies and can interact with users through speech and gesture in virtual environments (Gratch et al. 2002). Advanced virtual humans can engage in rich conversations (Traum et al. 2008a, b), recognize nonverbal cues (Morency et al. 2008), reason about social and emotional factors (Gratch and Marsella 2004) and synthesize human communication and nonverbal expressions (Thiebaux et al. 2008). Such fully embodied conversational characters have been around since the early 90's (Bickmore and Cassell 2005) and there has been much work on full systems to be used for training ((Evans et al. 1989; Kenny et al. 2007; Prendinger and Ishizuka 2004; Rickel et al. 2001); Rizzo et al. 2011a, b), intelligent kiosks (McCauley and D'Mello 2006), and virtual receptionists (Babu et al. 2006).

In this regard, Virtual Standardized Patients (VSPs), a specific kind of virtual human conversational agent, can be used in the role of standardized patients by simulating a particular clinical presentation with a high degree of consistency, credibility and realism (Stevens et al. 2005), as well as being always available for anytime-anywhere training. There is a growing field of researchers applying VSP's to training and assessment of bioethics, basic patient communication, interactive conversations, history taking, clinical assessments, and clinical decision-making ((Bickmore and Giorgino 2006; Bickmore et al. 2007; Kenny et al. 2007; Lok et al. 2007; Parsons et al. 2008); Rizzo et al. 2011a, b). Initial results suggest that VSPs can provide valid and reliable representations of live patients ((Triola et al. 2006); Andrew et al. 2007). VSP applications can likewise enable the precise stimulus presentation and control (dynamic behavior, conversational dialog and interaction) needed for rigorous laboratory research, yet embedded within the context of ecologically relevant simulations of clinical environments (Kenny et al. 2007; Parsons et al. 2008).

VSP systems require a complex integration of technologies. A general VSP architecture can be created to support a wide range of verbal interaction levels from simple question/ answering to more complex approaches that contain cognitive and emotional models with goal-oriented behavior. Such architectures are modular distributed systems with many components that communicate by message passing. Each module may contain various sub- components. For example, the natural language section is divided into three components: a part to understand the language, a part to manage the dialog and a part to generate the output text.

This is all combined into one statistical language component. Interaction with the system might require that user enters text as input or talks into a microphone that records the audio signal that is sent to a speech recognition engine. With voice recognition, the speech engine converts that into text. The text is then sent to a statistical response selection module. The module picks an appropriate verbal response based on the input text question. The response is then sent to a non-verbal behavior generator that selects animations to play for the text, based on a set of rules. The output is then sent to a procedural animation system along with a pre-recorded or a generated voice file. The animation system plays and synchronizes the gestures, speech and lip-syncing for the final output to the screen. The user then listens to the response and asks more questions to the character.

Due to strengths of their dialogue system AI, VSPs excel at interview and counseling skills applications. Additionally, VSPs can be constructed so that they provide features not found in human standardized patients such as reliable, bias free assessments with detailed reports for the learner, and the possibility of repeated performances. Extensive work has been conducted on full feature VSPs by the USC Institute for Creative Technologies MedVR group (Rizzo et al. 2011a, b). The Virtual Experience Research Group (http://verg.cise.ufl.edu) at the University of Florida also builds dialogue AI systems and virtual patients (Rossen et al. 2010).

USC Efforts to Create Virtual Standardized Patients

Early Work in Psychiatry

The USC Institute for Creative Technologies began work in this area in 2007 with an initial project that involved the creation of a virtual patient, named "Justin" (see Fig. 17.1]. Justin portrayed a 16-year old male with a conduct disorder who was being forced to participate in therapy by his family. The system was designed for novice clinicians to practice asking interview questions, to attempt to create a positive therapeutic alliance and to gather clinical information from this very challenging VSP. Justin was designed as a first step in our research. At the time, the project was unfunded and thus required our lab to take the economically inspired route of recycling a virtual character from a military negotiation-training scenario to play the part of Justin. The research group agreed that this sort of patient was one that could be convincingly created within the limits of the technology (and funding) available to us at the time. For example, such resistant patients typically respond slowly to therapist questions and often use a limited and highly stereotyped vocabulary. This

Fig. 17.1 "Justin"

allowed us to create a believable VSP within limited resources for dialog development. As well, novice clinicians have been typically observed to have a difficult time learning the value of "waiting out" periods of silence and non-participation with these patients. The system used voice recognition technology to translate speech to text, upon which the system would match questions to a limited bank of VSP responses. We initially collected user interaction and dialog data from a small sample of psychiatric residents and psychology graduate students as part of our iterative design process to evolve this application area. The project produced a successful proof of concept demonstrator and generated interest in the local medical community at Keck School of Medicine at USC that subsequently led to the acquisition of funding that supported the development of our next VSP.

Following the Justin proof of concept, our 2nd VSP project involved the creation of a teenage female sexual assault victim, "Justina" to more formally assess student views towards interacting with a VSP in a training context (see Fig. 17.2). We also aimed to explore the potential for creating a clinical interview trainer that could evaluate students in terms of their ability to ask questions relevant for assessing whether Justina met the criteria for the DSM-4r diagnosis of PTSD based on symptoms reported during the clinical interview. The interaction were also informally reviewed to get a sense as to whether students would interact with the VSP in a "sensitive" fashion as one would expect with a real-life clinical interaction with someone who had experienced significant personal trauma.

Fig. 17.2 “Justina”

For the PTSD content domain, 459 questions were created that mapped roughly 4–1 to a set of 116 responses. The aim was to build an initial language domain corpus generated from subject matter experts and then capture novel questions from a pilot group of users (psychiatry residents) during interviews with Justina. The novel questions that were generated could then be fed into the system in order to iteratively build the language corpus. We also focused on how well subjects asked questions that covered the six major symptom clusters that can characterize PTSD following a traumatic event. While this approach did not give the Justina character a lot of depth, it did provide more breadth for PTSD-related responses, which for initial testing seemed prudent for generating a wide variety of questions for the next Justina iteration.

In the initial test, 15 Psychiatry residents (6 females, 9 males, mean age = 29.80, SD 3.67) participated in the study and were asked to perform a 15 min interaction with the VSP to take an initial history and determine a preliminary diagnosis based on this brief interaction with the character. The participants were instructed to speak normally, as they would to a live standardized patient, but were informed that the system was a research prototype that uses an experimental speech recognition system that would sometimes not understand them. They were instructed that they were free to ask any kind of question relative to a clinical interview and the system would try to respond appropriately, but if it didn’t they could ask the same question in a different way.

From post questionnaire ratings on a 7-point Likert scale, the average subject rating for believability of the system was 4.5. Subjects reported their ability to understand the patient at an average of 5.1, but rated the system at 5.3 as frustrating to talk to due to speech recognition problems, out of domain answers or inappropriate responses. However most of the participants left favorable comments that they thought this technology will be useful in the future, and that they enjoyed the experience of trying different ways to talk to the character in order to elicit an relevant response to a complex question. When the patient responded back appropriately to a question, test subjects informally reported that the experience was very satisfying. Analysis of concordance between user questions and VSP response pairs indicated moderate effects sizes for Trauma inquiries (r = 0.45), Re-experiencing symptoms (r = 0.55), Avoidance (r = 0.35), and in the non-PTSD general communication category (r = 0.56), but only small effects were found for Arousal/Hypervigilance (r = 0.13) and Life impact (r = 0.13). These relationships between questions asked by a novice clinician and concordant replies from the VSP suggest that a fluid interaction was sometimes present in terms of rapport, discussion of the traumatic event, the experience of intrusive recollections and discussion related to the issue of avoidance. Low concordance rates on the arousal and life impact criteria indicated that a larger domain of possible questions and answers for these areas was not adequately modeled in this pilot effort.

Social Work Standardized Virtual Patients

The next USC VSP project involved collaboration with the USC School of Social Work, Center for Innovation in Research (CIR). This MSW program is novel for its focus on preparing social workers for careers working with military Service Members, Veterans and their families. This project resulted in the creation of a VSP named "Sgt. Castillo" (see Figs. 17.3a and b) designed to help social work trainees gain practical training experiences with VSPs that portray behavior more relevant to military culture and common clinical conditions that Service Members and Veterans experience. This work also supported our first effort to create a limited authoring system that would allow for the creation of new VSP dialog that would support the flexible modification of the training goals. The vision was to build an interface that allowed clinical educators to create a virtual patient with the same ease as creating a PowerPoint presentation. If such authoring could be done by clinical educators, it would be possible for subject matter experts (social work educators in this case) to create VSPs that could represent a wide range of clinical conditions with the ability to manipulate the intensity and complexity of the clinical presentation and subsequent training challenge. Unfortunately, the resulting authoring system was somewhat difficult to learn without a deeper understanding of dialog management. Consequently, the authoring system was poorly adopted by our collaborators in social work and only a few VSP instantiations were created. A sample video

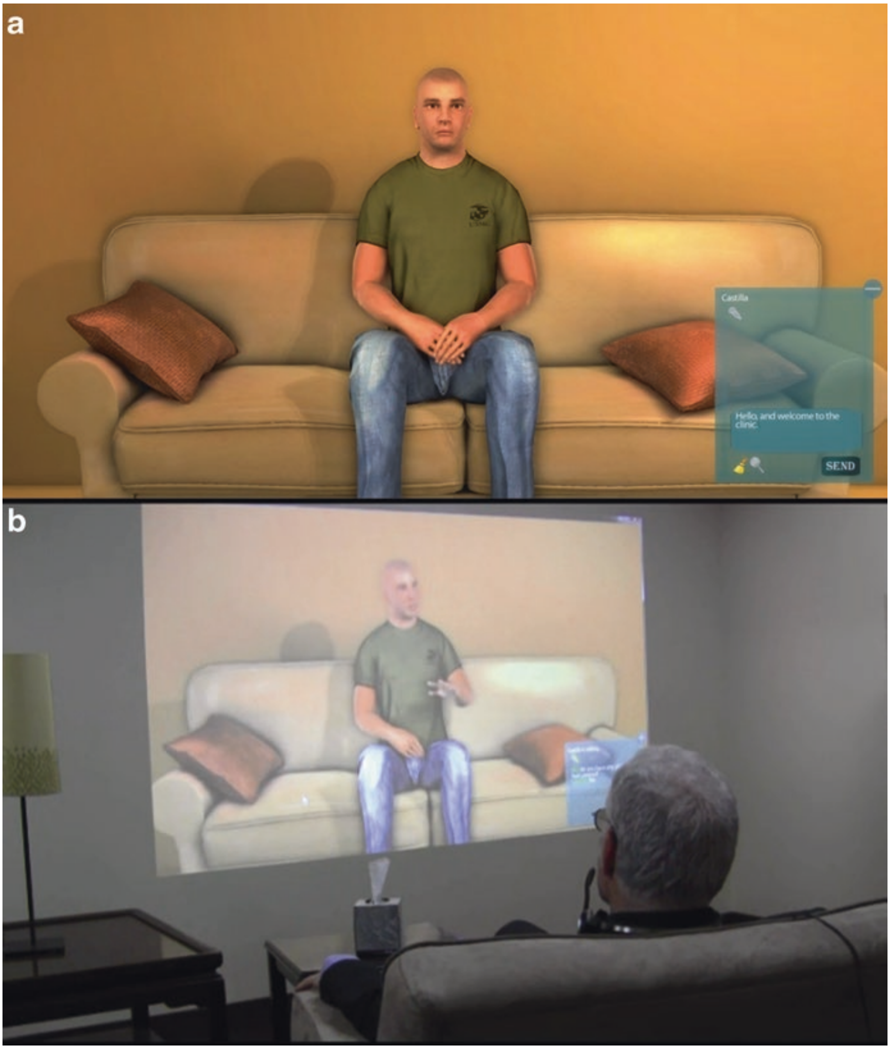

Fig. 17.3 **a**. Sgt. Castillo military VSP. **b**. in use, projected on wall with trainee

of a social work trainee interviewing one of these military VSPs can be found here: http://www.youtube.com/watch?v=PPbcl8Z-8Ec.

In view of these difficulties with authoring, the ICT/CIR project changed direction in order to meet the immediate need to provide clinical training to social work students currently enrolled in the CIR program. Instead of a focus on authoring and modification of the characteristics of the VSP, the emphasis shifted to training a specific psychotherapeutic approach that could involve concurrent individual and group/classroom practice. This resulted in the development of the Motivational Interviewing Learning Environment and Simulation (MILES) to provide future social workers with the opportunity to practice Motivational Interviewing (MI) skills in a mixed-reality setting with a VSP. MILES was designed as an instructor-facilitated experience that enables an individual student to practice a MI-oriented interaction with a military veteran VSP while a classroom of students observes real time video of the student/client interaction. The individual student trainee "speaks" to the virtual human through a microphone, selecting what he or she says from a multiple-choice list of carefully constructed statements. The MILES VSP (see Fig. 17.4) has the ability to understand the spoken dialog and responds to the student in a lifelike, natural manner with realistic voice, body language, gestures and facial expressions. As the single student progresses through the scenario, a branching dialog system can lead to various successful and unsuccessful outcomes depending on the response options selected by the individual trainee. At the same time, the rest of the class follows along viewing the real time video and selects their choice of the dialog options at each interaction juncture via individual response "clickers". An instructor control station captures performance data, including the answers selected by the lone student and their fellow classmates, to support of instructor awareness of the class's knowledge status to facilitate feedback in the form of an After Action Review (AAR) following an interaction. This system is currently in classroom use and learning evaluations are ongoing. A sample video of the MILES project can be found here: http://www.youtube.com/watch?v=Sg8x1rttBho&feature=youtu.be

Fig. 17.4 MILES virtual patient

Standardized Virtual Patients for Medical Training

After a number of prototypes and experiments conducted by the Authors and elsewhere, it had become clear that a plateau had been reached in VSP applications and technology that left progress short of the threshold required for broader adoption of interactive conversational characters for training. The primary factors limiting further improvement in experimental VSP systems were many, with the primary cause being the considerable effort required to create a single VSP encounter. Generally, it required a team of experts about 6 months to create a VSP, including up to 200 h of expert language training (Kenny et al. 2010). Additional factors included the low performance of natural language understanding (NLU) systems needed to understand the learner's questions and the effort involved in animating, creating voices, lip syncing and scheduling motion of a virtual human avatar. The Justina prototype had a maximum NLU accuracy of 60% (Kenny et al. 2007), with other systems achieving about 75%. That level of performance resulted in frustrating encounters, whereas NLU accuracy nearing 90% is more likely to result in a more positively received interaction that flows well as a clinical interview.

One strategy around the NLU accuracy problem is to avoid NLU altogether. Virtual human conversations are possible that include an avatar that responds to pre-selected choices; such an interview is called a structured encounter. There are many kinds of structured encounters. They may be linear, branching, unlocking style and state-machine/logic-based. Structured encounters can be employed for patient interviews, surrogate interviews, counseling sessions, difficult conversations, persuasive conversations and many other purposes (Figs. 17.5 and 17.6). Learner choices are

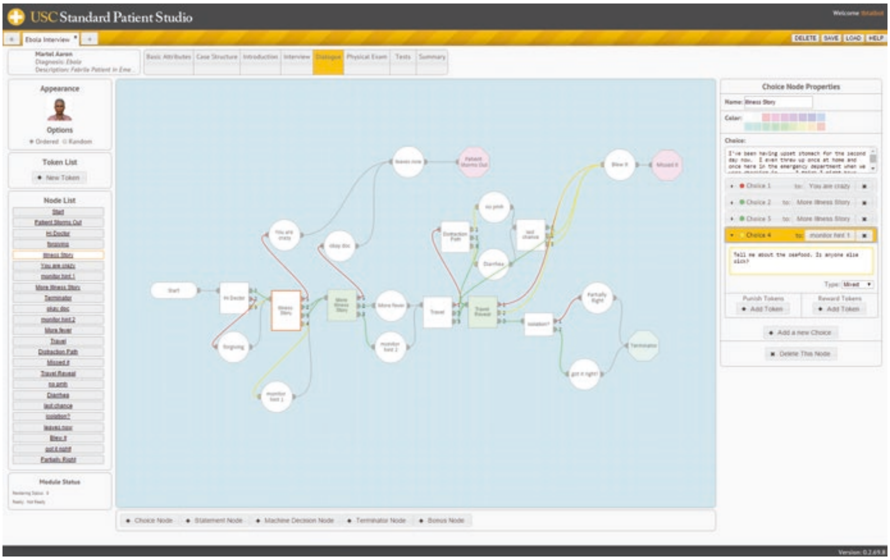

Fig. 17.5 USC Standard Patient "Select-a-Chat" structured virtual human encounter authoring tool

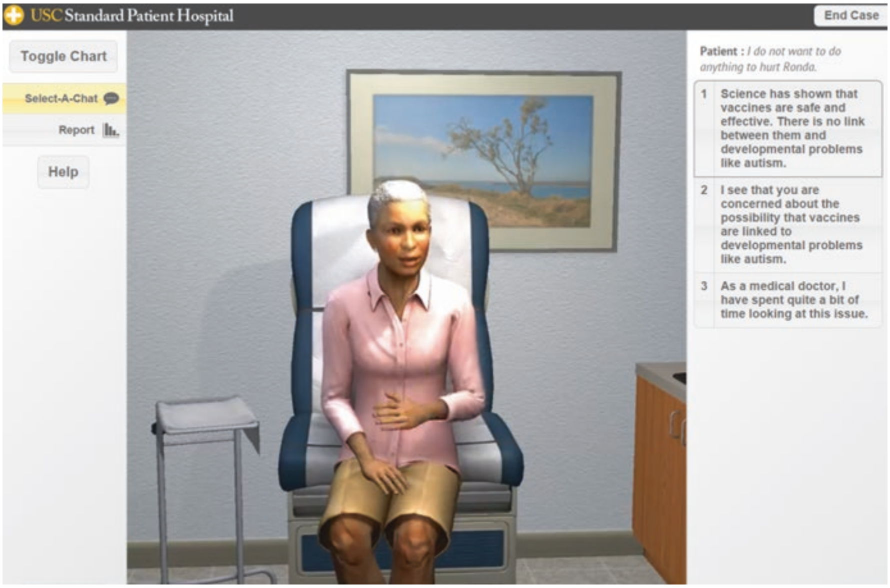

Fig. 17.6 A structured virtual human encounter depicting a vaccine resistant parent. (USC Standard Patient)

definite and appropriate responses are guaranteed. Assessments are based on accurate data and have no potential for assessment bias.

The use of structured virtual humans for training is established; it has been successfully integrated into routine training with the previously mentioned MILES being an example. Another MILES variant, ELITE Lite has been accredited by the US Army for training. According to the accreditation document (Lamb et al. 2007), ELITE Lite survey feedback reported 88.7% of respondents indicated practice exercises provide a sufficient representation of an informal interaction between a counselor and counselee. Subjects (87%) indicated the training experience was engaging and effective while 77% indicated they have a better understanding of the counseling process after using ELITE Lite. Most users indicated they would rather use ELITE Lite vs. lecture and PowerPoint instructional method (85%).

Another compelling structured encounter prototype is Virtual Child Witness (VCW–Fig. 17.7). VCW is a structured virtual human encounter intended to assess forensic interviewing skills. This effort focused on questioning strategy and compared “experts”, a group of professionals who completed a forensic interviewing course with novices. The study, designed to see if the virtual human encounters could be an effective assessment tool, showed significantly higher performance in the expert group compared with novices. Analysis of the study data also revealed a strong training effect with subjects who unexpectedly played the structured encounter multiple times (Leuski et al. 2006). Of interest, VCW was created with very small budget on the SimCoach virtual human platform. SimCoach shortened

Fig. 17.7 Virtual Child Witness–a structured encounter

the development time because it handled all the tasks required to create animated virtual humans and provided an online delivery mechanism (Bitzer 1966).

Although structured encounters are a useful tool for many training applications, there is still a desire to simulate the medical interview with a VSP. The expense and limited access to human standardized patients coupled with the potential for objective assessments and repeatable, low cost encounters makes a compelling case for the success of VSPs. Fortunately, recent technology advances have succeeded in breaking the VSP plateau to the point where the major problems inhibiting VSP creation and adoption are being addressed.

The USC Standard Patient (USP) project is a freeware open-source VSP community (www.standardpatient.org) that has applied considerable resources to improving natural language random access (NLRA) VSPs – the kind that mimic typical conversations with human patients (Fig. 17.8). The improvements (Leuski and Traum 2010) include creation of an automated online virtual human tool, an improved medical NLU system, a universal VSP taxonomy, and a new approach to assessing human-computer conversations.

An automated online virtual human tool, SimCoach, was created first. SimCoach enables the rapid creation of cloud-based online virtual humans. SimCoach VSPs work on current-generation web browsers and greatly simplify the development burden for virtual human (VH) creation. SimCoach automates speech actions,

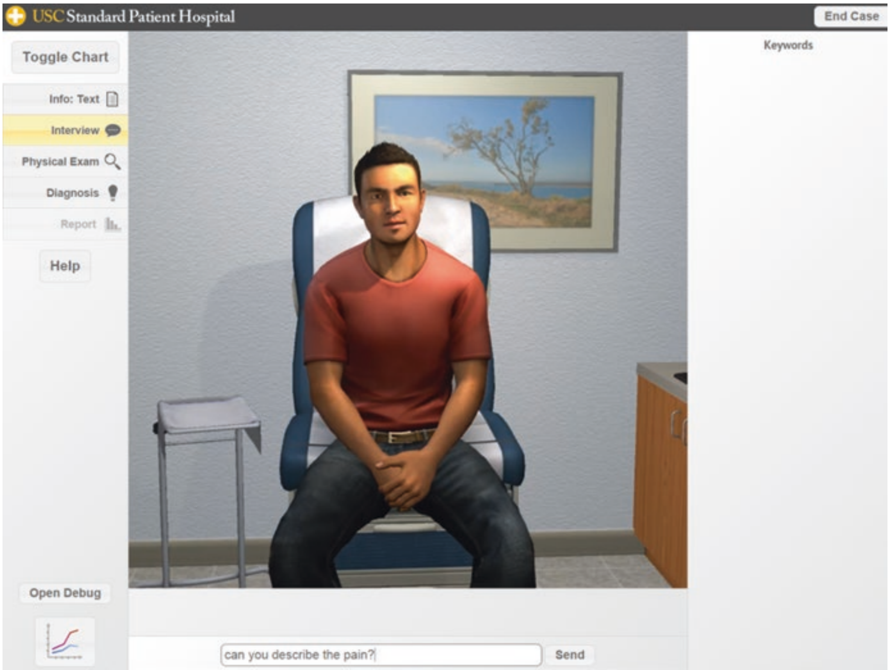

Fig. 17.8 Natural language capable VSPs permit learners to ask questions in a natural manner through speech or typed input. (USC Standard Patient)

animation sequencing, lip synching, non-verbal behavior, NLU integration, and AI processing and interaction management. With assets in place, new VHs can be created by providing text content. SimCoach was initially employed for training for VCW and is now the virtual human technology platform for USP.

The next impediment to be addressed is the fact that most prior NLRA VSPs were authored by creating a language focus around a specific medical problem or diagnosis. Questions would be compiled and answers associated to create a case that receives training data. This labor-intensive process needed for every patient case. Additionally, off-topic questions were poorly handled and caused such VSPs to appear inflexible. The Standard Patient project adopted a unified medical taxonomy (UMT) instead. UMT provides a common patient description regardless of actual patient condition. This makes new patient cases much more easily authorable and provides a fixed NLU training domain. Every Standard Patient VSP is represented by the complete unified taxonomy. Baseline and non-authored case elements are filled in by the UMT system based on age/sex appropriate default responses.

NLU, one main impediment to fluent learner-patient interactions, was addressed through the creation of a new medical NLU system called LEXI Mark 1. LEXI is a vastly improved NLU system specifically developed for medical interactions. The system is closely tied to the UMT and includes lexical assessment, probabilistic modeling and content matching approaches. Lexi is capable of improving performance through human-assisted and machine learning. The implication of an approach that trains the NLU for the UMT rather than a specific case is that NLU training affects improvements in all cases on the system. Lexi has demonstrated better than 92% NLU accuracy in testing with a well-trained taxonomy under training conditions.

A new approach to conversational assessment, INFERENCE-RTS, was then developed. INFERENCE is an advanced game-based assessment engine that is capable of analyzing human conversations in real-time and associating learner speech acts with effects on the UMT. With this system, case authors annotate patient utterances in the case-authoring tool with assessment tags. Such tags are employed to indicate information that is of critical importance or moderate importance to the diagnosis. Tags exist for every UMT taxonomy item. The feedback intervention system encapsulates diagnostic performance and provides learners with concrete improvement tasks, a mind-map case taxonomy visualization (Fig. 17.9) and a learning-curve tool. INFERENCE was designed for deliberate practice at the proximal level of learner development. Future research will establish if such a system is practical and efficacious.

Tagging the universal taxonomy and providing feedback in the form of the mind-map has finally provided a workable solution to automating the assessment of conversational interviews. Such automated assessments can be accurate within a few percent. The use of feedback from this type of display has been employed and has demonstrated a strong training effect in real world use.

The combined effect of all these recent improvements results in a practical system that maintains ease of use, allows content creation in a timely manner, and

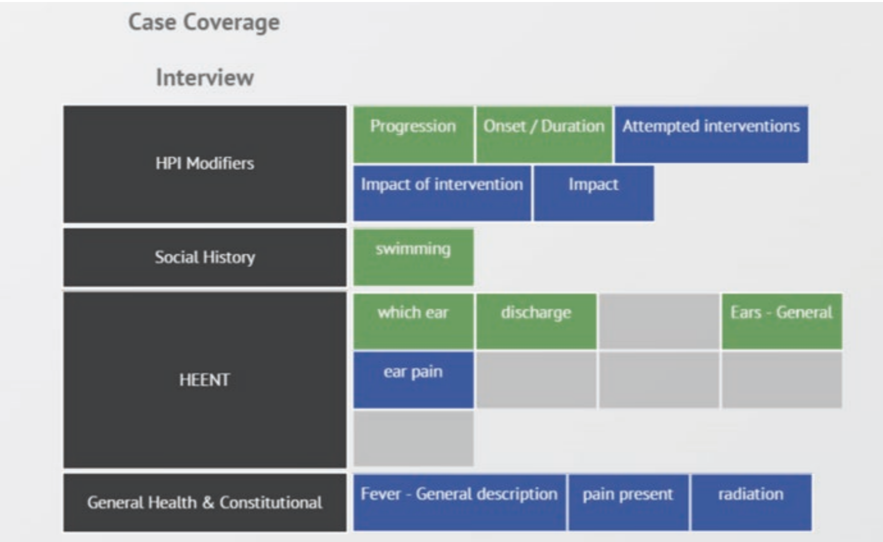

Fig. 17.9 VSP interview mind-map

provides practical assessment feedback to learners and educators. Researchers have yet to conduct the necessary validations to determine the educational impact of VSP systems that employ combinations of these recent advances. In the near future, this information will be available and will determine the next course of action to advance VSPs for medical and psychological education purposes. If these combined technologies prove efficacious, it will be of great interest to see how this influences the milieu of medical and professional training.

Most VSPs attempted to date have been on traditional computers. With the increased prevalence of mobile devices, it is logical to consider the migration of VSP technology to phones and tablets. Regardless, there are significant usability barriers to adoption of VSPs on mobile platforms. The limitations are more human factors-based rather than caused by technical limitations. For example, how will a person interact with a conversational VSP? Will people talk to their phones? Will people type on tablet screens? Computers have excellent keyboards and when speech recognition is performed, this is usually with the benefit of a headset microphone to isolate speech. Phone and tablet microphones capture surrounding sound and this may result in too many speech recognition errors. It may also present a more awkward interaction. Structured encounter-style VSPs do not suffer from these limitations and are much more readily adaptable to mobile device adoption.

Another promising idea is to imbue a manikin or task trainer with VSP capabilities. Such a capability could greatly improve the interactive potential of plastic-based physical training systems. The main technical limitation is similar to the mobile device problem; voice recognition. Specifically, voice recognition system in robots will have to work at a distance. Future distant recognition systems (DSR) will require a high level of individual speaker discrimination and will likely adopt microphone array-based acoustic beamforming technology. (Lok et al. 2007) Unfortunately, DSR technology is not yet at a sufficient level of maturity for effective use with VSPs.

Conclusion

Virtual reality standardized patients have come a long way from faux-interactions on time-sharing mainframes starting half a century ago. Work over the last 15 years; in particular, has produced a wealth of knowledge and practical lessons in both the advance of VSP technology as well as experience with VSPs in clinical training applications. Despite these advances, VSPs have yet to see mainstream adoption in clinical training for a number of reasons. Recent work appears to have advanced sufficiently to ameliorate or overcome the most significant barriers. Thus, the age where VSPs may play a major role in training may finally be upon us. Future success may no longer be rate-limited by the pace of technology, but by the creativity and innovation of educators who will create compelling VSP experiences and curricula.

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Eynat Gal, P. L. (Tamar) Weiss, and Massimo Zancanaro

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