Chapter 15
NeuroVirtual 3D: A Multiplatform 3D Simulation System for Application in Psychology and Neuro-Rehabilitation

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Abstract In the last decade the use of Virtual Reality platforms in psychology and neurorehabilitation increased thanks to a higher availability of low-cost technology and a wider acceptance from the clinical world. Nonetheless multiplatform taking into consideration the combined use of innovative low-cost technologies are still missing. This chapter will extensively discuss the opportunities offered by the NeuroVirtual 3D platform in term of technologies innovations for the clinicians. After an overview of the state of the art in the field, a comprehensive discussion will focus above all on the low-cost stereo cameras and the Eye-Trackers, both more and more used in the assessment and neurorehabilitation of motor and cognitive abilities.

15.1 Introduction

The use of virtual reality (VR) in psychology and neurorehabilitation has continued to increase. However, it seems likely that VR can be much more than just a tool to provide exposure and desensitization.

In this sense virtual reality has great potential for use in the rehabilitation of everyday life activities, involving cognitive and motor functions. The use of simulated environments, perceived by the user as comparable to real world objects and situations, can overcome the limits of the traditional tests employed to assess, by keeping intact its several advantages.

VR systems in stroke neurorehabilitation both cognitive and motor are rapidly expanding and a large number of interesting platforms are currently being developed

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and tested. Morganti et al. [41] and Ma and Bechkoum [38] proposed a combination of standardized paper and pencil neuropsychological tests and a virtual reality-based assessment (VR-Maze test and VR-Road Map) for the evaluation of spatial orientation in brain injured patients. Compared to a control group, 4 male patients with brain damage revealed significantly shorter times and greater errors in solving a virtual spatial task. In a recent review, Tsirli et al. [61] described past and ongoing research of VR applications for unilateral neglect post-stroke evaluation: they suggested that VR could improve existing assessment methods by providing information about head and eye movements, postural deviations, and limb kinematics.

The use of Virtual Reality systems in motor rehabilitation provides the opportunity to create tailored interventions in which the duration, intensity and feedback can be manipulated according to the specific patient's needs. In the last decade, many investigators have developed and tested the effectiveness of VR-based platforms for rehabilitation of the arm [7, 15–17, 34, 55] or hand [6] in stroke patients. Arm motor deficits are, in fact, prevalent post stroke: for example, 55–75 % of stroke patients are affected by upper limb (UL) at 3 and 6 months [43, 31]. Merians et al. [40] verified the effectiveness of VR training of the hemiparetic hand on 8 post-stroke patients using a system that provides repetitive motor re-education and skill reacquisition. Results showed that patients improved in fractioning, range of motion and speed and these changes translated to improvements in the real-world measures. They suggested the use of VR environments in movement re-education since they have the potential to improve existing rehabilitation therapies. A recent meta analysis published on Stroke [57], which included 12 studies (for a total of 195 patients) highlighted that rehabilitation protocols that include VR are the most effective. These studies support the hypothesis that virtual environments are very useful in motor rehabilitation since they increase the efficacy of actual therapies.

15.2 NeuroVirtual 3D Platform: Main Issues and Aims

If, on the one side, the use of VR in rehabilitation represents a consolidated and rising scientific trend, the use of this tool in clinical practice is very limited, especially on a national level. According to recent reports, in Italy and Europe VR is employed especially within clinical research projects while its professional use is extremely limited. This finding cannot be explained by the immaturity of technological components, which have been developed thanks to the huge growth of the videogames market, nor in terms of the lack of scientific evidence about the efficacy of this approach.

A more suitable explanation of the absence of diffusion of VR in the rehabilitative field is related to two specific problems: (a) the lack of easily usable, low cost and high reliability tools; (b) the limited availability of rehabilitative contents, which provide interactive simulations aimed at practice and therapeutic stimuli.

Another problem is represented by the absence of integrated solutions between research and clinic: often therapists are interested not only in taking care of the patient through the use of VR but also in collecting important data for the improvement of the efficacy of the therapeutic solutions.

Finally, the need to assess the so called "transfer of training" (that is to establish to which extent the results obtained through the virtual reality exposure can be transferred to daily life activities) should not be overlooked. In this perspective, an emerging need is to effectively use the possibilities offered by the new mobile technologies (smartphone, wearable sensors) to permit the patient to carry on exercises also at home and to give to the therapist important indications related to the level of compliance with the therapeutic instructions.

Starting from these premises, the NeuroVirtual 3D platform aims at addressing these challenges by designing, developing and testing a low-cost integrated virtual reality solution for applications in clinical psychology and neuromotor rehabilitation.

The platform, which includes the features of the software NeuroVr 2.0 (http://www.neurovr.org/neurovr2/) [51], will be expanded as follows:

- development of a software interface for integrating into NeuroVirtual 3D commercially-available peripherals that support neuromotor rehabilitation (es. dataglove, haptic devices, Kinect);
- integration with eye-tracking devices;
- enable support for multi-users interaction and communication through virtual humans;
- development of 3D contents for mobile devices (android, iPhone/iPad);
- development of a web repository of 3D scenes for allowing researchers and rehabilitation professionals to share their virtual environments and protocols.

The development of the platform will be done on the basis of specific ergonomic and clinical trials based on the proposed platform.

15.3 The Scientific-Technological State of the Art

In the last decade, the use of VR in neurorehabilitation rose in a significant way and an increasing number of experimental findings suggested that this technology can positively impact upon cognitive and motor functional recovery [1–3, 33, 37, 52, 57]. The rationale for the use of VR systems in the rehabilitation field is based on a series of advantages widely documented in the scientific literature:

- Neuroplasticity: VR allows the use of scenarios based on principles that regulate and facilitate neuroplasticity (for example: exercise intensity, exercise frequency, "enriched stimulation", etc.) that provide a neuro-biological basis for the recovery of cognitive and motor functions.
- Personalized training: VR is based on highly automated functioning mechanisms that require a minimal contribution by the rehabilitation professional, who may make use of the possibility to customize the intensity and the difficulty of the training based on the specific necessities of the patient.
- Involving tasks: in the VR, the content of rehabilitative exercises may be planned to the extent of defining some tasks oriented to re-train specific abilities (for example, to reach an object), and in the same time integrating in some

recreational scenarios to maintain a high level of involvement and compliance in the patient in the execution of exercises. In particular, a lot of studies evidenced the role of VR in augmenting the sense of Presence [49, 50] and the optimal experience [25] in the rehabilitative process.

- Tracking and objective/quantitative measure: thanks to the sensors integrated in VR systems (for example: cranial movements tracking sensors, sensors for superior limbs, dataglove etc.) it is possible to record a high quantity of data with regard to actions executed by the patient inside the virtual scenario and to use these data to create some indexes of performance in order to measure in a quantitative and objective way the improvement in performance observable in the course of the rehabilitative process.
- Transferring of the training in ADL: many studies that investigated the use of VR in the neurorehabilitative field evidenced the potential offered by this methodology to transfer the results of the re-learning of cognitive and motor abilities that were damaged in the activity of day living (ADL). The positive impact of VR on ADL is documented by many studies and is explained by the fact that VR offers the possibility of including rehabilitative exercises in real life context simulations (for example: buying an object in a virtual supermarket may help to rehabilitate executive functions in patients with frontal lesions).

These advantages, documented by an extensive literature and clinical case record in different pathological fields (from mental diseases to neuropsychological, from acquired brain injury to neurodegenerative diseases and ictus) increased the interest of sanitarian organizations and rehabilitation professionals in this innovative methodology. This increasing interest is documented by the increase in the number of studies, by the proliferation of conferences and scientific publications, the increase in public and private finance for research into clinical applications of VR. From a commercial point of view there is a limited and varied offering of VR systems for rehabilitation (neurological or psychological). The main goal of the NeuroVirtual 3D platform is to design and develop a low-cost VR platform for applications in the fields of mental wellbeing and neuromotor rehabilitation. The specific technical innovations provided by the platform are described in the following sections.

15.4 Interfaces Development for Input/Output Hardware Devices for Applications in Neurorehabilitation (e.g. Dataglove, Haptic Devices, Kinect)

Recently, there has been a progressive diffusion on the home gaming market of advanced game technologies (such as Microsoft Kinect, Nintendo Wii) that allow the use of a large series of interactive devices at a low cost [26, 27, 35, 47]. Most of these devices, in addiction to their low cost (due to the fact of being targeted at the consumer market), make available Software Development Kits (sdk) to integrate third-part software. The NeuroVirtual 3D platform aims to use such commercial

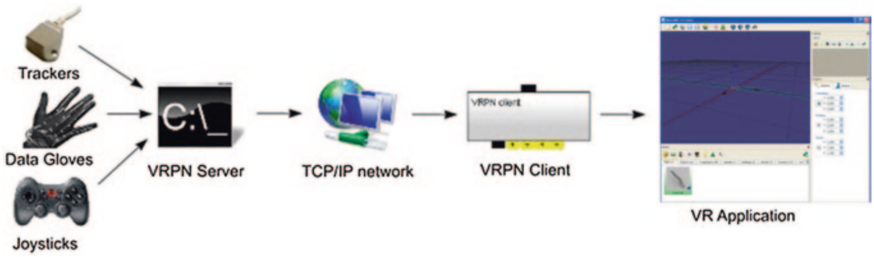

Fig. 15.1 Device- NeuroVirtual 3D interaction interface

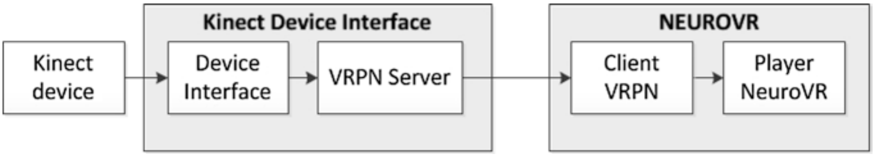

Fig. 15.2 Kinect-NeuroVirtual 3D. Interaction interface

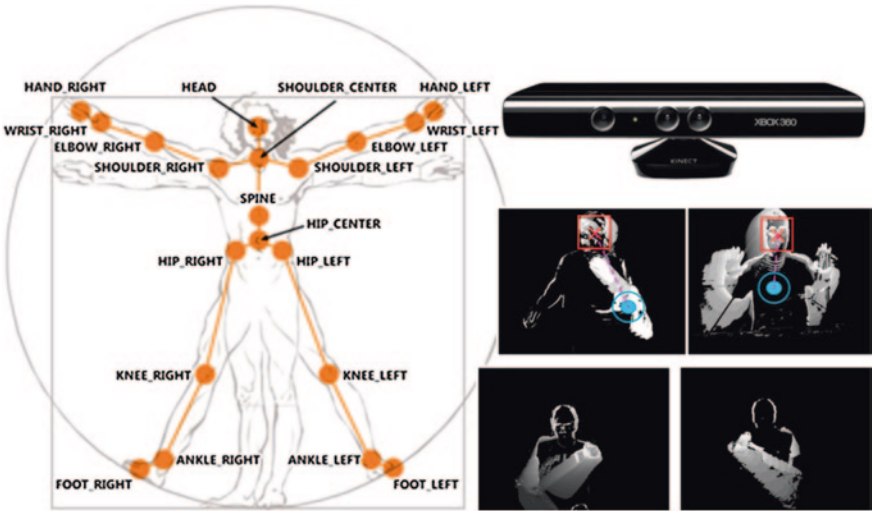

Fig. 15.3 Video signal processing from kinect and Avatar structures

devices to integrate new interactive functionalities in the NeuroVR platform, to be used and tested in a neurorehabilitative framework. This strategy is to obtain a double result: On one hand, to add new interactive features to the VR platform to allow an higher range of content and neurorehabilitative exercises; on the other hand, to take advantage from these technologies to offer solutions based on low cost and high availability (Figs. 15.1, 15.2 and 15.3).

15.4.1 Integration with Eye-Tracking Devices

For many decades the recording and processing of cerebral and oculomotor activity is a relevant methodology for clinical and neuropsychological assessment [19, 30]. In particular, an interesting instrument that has been increasingly used in the past decades for clinical assessment is the Eye-tracker [20, 21, 62]. This advanced device /method is able to track and record, with a high spatial and temporal precision, ocular movements, synchronizing them with the stimuli. Traditionally the standard methodology uses validated paradigms, such as saccadic, anti-saccadic and smooth pursuit [4, 12, 13, 18, 24]. Moreover, recently, the framework of such instruments has been widely extended, moving from the classic clinical assessment to a more active use of such an instrument as input platform. In this sense, the most extensive use is the Alternative and Augmented Communication (AAC), through which it is possible to communicate "by the means of eye movements", also for patients with motor or communication deficit [10, 11]. Through the integration of ocular tracking in the NeuroVirtual 3D platform, it will be possible to obtain an effective methodology to monitor eye-movements during the immersive experience, obtaining useful information on cognitive activity of the participant, such as visual attention, perception, reasoning, information pursuit, and the evaluation of complex environmental stimuli. In particular, the integration of the eye-tracker and of the Brain Computer Interface (BCI) will provide the following advantages:

- Increased accuracy in assessment and diagnostics of ongoing rehabilitation processes;
- Ability to correlate specific mental states with specific activities executed into the virtual environments, through the use of environmental markers that allow the synchronization of the ocular path with the action performed by the user.
- Ability to study the variables related to attention, perception, and cognition in the framework of simulations representing realistic situations and daily contexts, increasing the ecological validity of gathered data.

15.4.2 Development of Multi-User Interaction and Communication Through Avatars

Another innovative technological solution introduced by the NeuroVirtual 3D platform is the development of multi-user functionalities, at the present missing in the NeuroVR platform.

The use of virtual environments in multi-user modality permits an increase the applicability of such a platform in the rehabilitation framework, allowing an extended use of complex paradigms, such as including social situations (e.g., the patient has to learn to manage a social phobia in a virtual environment, such as public speaking) or in rehabilitative situations, where the co-presence of a therapist represents an added value in the patient motivation to perform the exercises (e.g., in telemedicine).

15.4.3 Development of the Ability to Display 3D Content on Mobile Devices

The growing diffusion of mobile platforms, such as smartphones and tablets, represents a meaningful chance in rehabilitation, unfortunately not enough explored yet. Thanks to the progressive raising of computational and memory capabilities, these devices could provide interactive 3D simulation with a high level or realism and complexity, that can effectively be used for rehabilitation, to allow the patient to continue exercises in mobility or at home. The objective is to provide rehabilitative virtual contents and exercises to be used in a hospital environment with the therapist and to be repeated where the patient desires (e.g., at home) through players installed in mobile devices, such as iPhone, iPad and Android.

15.4.4 Development of an Online Repository of 3D Scenes for the Sharing of the Environments Among the Software Users

A further innovation proposed by the NeuroVirtual 3D platform is the creation of an online repository with validated clinical 3D contents, containing also protocols and procedures to share with rehabilitation experts' community, operating with virtual reality or simply interested in experimenting with this approach. The ability to easily access this content will encourage and promote a wider use of the NeuroVirtual 3D platform and will allows users to experiment on a large-scale to obtain a higher number of clinical evidences to reach a critical mass of studies to support the use of VR in research and in the clinical practice.

The evolution of the platform is to allow the translation of the medical therapy principles, through virtual environments, to the psycho-behavioral and motivational training techniques—typically residential—conveying them through new generations distance learning systems, allowing, thanks to the interaction with immersive and interactive 3D environments, a greater emotional involvement, thus overcoming the main limitations of e-learning.

15.5 The Clinical Use of Virtual Reality

The use of virtual reality (VR) in clinical psychology has become more widespread [48]. The key characteristics of virtual environments for most clinical applications are the high level of control of the interaction with the tool, and the enriched experience provided to the patient [58]. Typically, in VR the patient learns to cope with problematic situations related to his/her problem. For this reason, the most common application of VR in this area is the treatment of anxiety disorders, i.e., fear of heights, fear of flying, and fear of public speaking [23, 63]. Indeed, VR exposure therapy (VRE) has been proposed as a new medium for exposure therapy [48] that is safer, less embarrassing, and less costly than reproducing the real world situations. The rationale is simple: in VR the patient is intentionally confronted with the feared stimuli while allowing the anxiety to attenuate. Avoiding a dreaded situation reinforces a phobia, and each successive exposure to it reduces the anxiety through the processes of habituation and extinction.

However, it seems likely that VR can be more than a tool to provide exposure and desensitization [48]. As noted by Glantz et al. [28]: "VR technology may create enough capabilities to profoundly influence the shape of therapy." (p. 92). In particular we suggest that embodiment through VR might have important applications in other fields of rehabilitation, and specifically in the treatment of chronic pain conditions and weight disorders.

Virtual reality (VR) can provide the appropriate experience to support remote rehabilitation [8, 36, 57]. By VR we refer to a set of technologies that attempts to create an immersive computer display that surrounds the participant [22]. VR replaces direct vision and audition of the real environment with synthesized stimuli, and can also integrate haptic (tactile and force) cues representing virtual objects or remote interactions [46, 5]. VR is able to provide real time feedback to the participant [39, 9], comprised of parallel streams of sensory information (visual, sound, or haptics; [1]). The capacity of VR-based systems as a facilitation tool for functional recovery by engaging brain circuits, such as motor areas, has been demonstrated [2].

A recent review study has shown that such systems can be effective and motivating for rehabilitation therapies involving repetition and feedback [33]. It seems that motivation is a key factor for applications based on augmented feedback using VR for rehabilitation of motor skills of patients with neurological disorders [54]. In particular, there is evidence for the effectiveness of such approaches for the rehabilitation of upper limbs in patients with stroke [14, 31, 37, 57].

Apart from immersion and motivation, a critical ability of VR in the context of neurorehabilitation is the possibility to induce ownership of a whole virtual body [60] or specific body parts such as the hand/arm [59] or belly [42].

The fact that a virtual body part can be incorporated into the body schema based on synchronous visuo-tactile correlations has opened new paths for examining the mechanisms of body perception. The strength of the virtual illusion is reinforced when, to the visual co-location, synchronous visuo-motor correlations are provided, e.g., with the person controlling the body movements (arms, legs, etc.) of the avatar, who mimics her movements [29, 56].

In clinical terms, manipulations of a virtual body could have implications not only for motor or sensory rehabilitation but also for psychological treatment in different pathologies involving body perception, such as painful phantom limbs, regional pain syndrome (Llobera et al. in press), eating disorders [45, 53], or burns [32]. Recently, a novel approach following these cognitive principles of body perception has been proposed [44].

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