Towards a Conceptual Model for Consideration of Adverse Effects of Immersive Virtual Reality for Individuals with Autism

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Abstract. Interest in the use of virtual reality (VR) technologies for individuals with autism has been increasing for over two decades. Recently, research interest has been growing in the area of immersive virtual reality (IVR) technologies thanks to increased availability and affordability. Affordances and theorized benefits of IVR for individuals with autism are quite promising, with the majority of research reports overwhelmingly presenting positive outcomes. Notably absent in the dominant research discourse, however, are considerations of how leveraging the affordances of IVR might lead to unintentional, unexpected, and perhaps deleterious outcomes. This is a particular concern in light of documented adverse effects associated with IVR, such as cybersickness, increased anxiety, and sensory disturbances. Given known characteristics of autism, the impact of adverse effects potentially could be even more pronounced for people with autism than for the general population. In the current paper, we present a conceptual process model for minimizing potential adverse effects of IVR for individuals with autism. Specifically, we highlight the notion of gradual acclimation and detail how gradual acclimation unfolds in a stage-wise manner across implementation contexts and technologies. When working with vulnerable populations, researchers have a special ethical obligation and greater responsibility to actively take precautions to help minimize real or potential risks. Correspondingly, we assert that application of the implementation procedures detailed in the current paper can contribute to researchers minimizing and controlling for potential adverse effects of IVR for individuals with autism.

Keywords: Autism · Immersive virtual reality · Head-mounted displays · Implementation · Adverse effects

1 Introduction

The promise of virtual reality (VR) technology has long been acknowledged for education and training [1, 2]. VR can promote learning along cognitive, affective, and psychomotor dimensions in a manner that is particularly motivating and engaging [3, 4]. Further, VR can provide learners highly realistic experiences in potentially dangerous, impossible, counter-intuitive, or expensive situations (DICE) [5] without potential real-world consequences [6–8]. VR also can situate learners in contexts that would not be

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possible in the real-world, such as exploring space, experiencing the inside of a painting, examining the interior of a human heart, or taking a tour of neural connections within a human brain [9, 10]. VR environments have been effectively implemented across a multitude of learning domains, including medicine [11], nursing [12], engineering [13], second language acquisition [14], and vocational training [15].

The increasing rate of technological advancement in the area of VR introduces profound opportunities to create highly engaging and effective educational, training, and therapeutic interventions [16]. However, VR technologies are typically developed by and for people who are neuro- and physio-typical—not for those with disabilities [17]. Technology features and affordances that might lead to effective learning experiences for Abled people could have unanticipated effects when used with disabled people, particularly when disabled people are not included in the design and evaluation of the technologies. This is especially relevant when working with autistic people. Autism is a lifelong condition that is characterized by differences in social communication/interaction and restricted, repetitive patterns of behavior [18]. As a spectrum condition, manifestations of autism present substantial heterogeneity across affected individuals [19]. Therapeutic supports have been shown to lead to improvements in quality of life [20]; however, access to and consistency of these supports are known barriers. As such, viable and effective supports are in high demand. One potential support modality is VR, which has been steadily gaining attention in the field [21, 22].

VR is considered to be a promising and useful technology for autistic people due to technological affordances which align closely with instructional needs [23], including abilities to encounter and practice useful skills in highly realistic and customizable contexts, have input stimuli intentionally manipulated, and have real-world consequences mitigated or removed. Early research studies on the acceptability and possibility of VR for autistic people suggested that the technology could hold tremendous potential for delivering training, education, and therapy [24]. However, the prohibitive costs of fully immersive VR head-mounted displays (HMD) and the nascent state of VR technologies in the mid-1990s hindered subsequent research from focusing inquiries specifically on the use of headset-based VR [25]. As a result, the field focused for nearly two decades on more readily available immersive technologies, such as virtual worlds like Second Life or bespoke desktop-based VR experiences and interventions [26]. More recently, and largely due to the increasing availability and affordability of high-quality HMD (e.g., Oculus Quest 2, Valve Index, Playstation VR), research on fully immersive VR (IVR) for individuals on the autism spectrum has begun to see a resurgence [27].

1.1 Accelerating Interest in IVR

IVR systems are high-fidelity VR systems that have the potential to immerse users along spatial, sensorimotor, cognitive, and emotional dimensions [28]. IVR presents interesting and novel opportunities for researchers to continue and extend a research tradition that until recently has been conducted predominantly in the domain of desktop-based immersive technologies. These VR technologies are advancing at an exponential rate. According to Moore’s Law, computing power doubles every 1.5 years, meaning that the processors that power the current generation of VR devices could be superseded by processors that are up to 16 times more powerful in just 6 years. Correspondingly, Kurzweil's Law of Accelerating Returns suggests that the increasing rate of technological advancement itself leads to even more rapid technology acceleration, resulting in increased efficiencies, economies of scale, and reduced costs in ever-decreasing timespans. Extrapolating from Moore's Law and Kurzweil's law regarding technological progress in VR, it seems reasonable that advances of the past 20 years will be eclipsed multiple times over in just the next few years, and that highly sophisticated IVR systems soon will be widely available at a fraction of their current cost.

The user experiences and interaction possibilities provided by modern, hyper-realistic, deeply immersive IVR systems present fertile ground to explore and test how these more modern technologies might be leveraged to influence the lives of autistic people in positive and productive ways. However, given the exponential rate of technological advancement, it is simply not feasible for researchers to keep pace. As such, it is very likely that technologies will be adopted and implemented by and for autistic people before those technologies are fully understood. Compounding this is the limited attention to and understanding of how to best implement IVR for individuals with autism [22]. Further, researchers seeking to design studies using IVR are presented with an apparent quandary in that the majority of extant research has been performed using technology tools with considerably different features and affordances than contemporary IVR systems. That is, research evidence suggesting VR is a particularly promising technology for autistic people [26, 29, 30] draws primarily from studies that use rather primitive VR tools. Questions of how autistic people might perceive and react to the hyper-stimulating, immersive experiences provided by modern IVR systems remain largely unanswered.

1.2 IVR, Autism, and the Risk of Adverse Effects

Implementing technologies with vulnerable populations before those technologies are well understood introduces a number of risks. Of particular concern when working with autistic groups is the risk of adverse effects associated with HMD usage [31]. These adverse effects include, but are not limited to, negative effects such as sweating, nausea/motion-sickness, dizziness, headache, eye fatigue, safety concerns (e.g., static balance, transient reduced depth perception), increased anxiety, sensory disturbances, and disorientation [32–35]. The literature exploring VR for individuals on the autism spectrum largely ignores potential adverse effects, with consideration being cursory at best [21, 30, 36–38]. This is perhaps because the majority of research studies have been conducted using less immersive or non-immersive VR systems, which are less likely to cause adverse effects [39]. Further consideration is therefore warranted, as people with autism could be more likely to experience adverse effects in fully immersive VR systems, and with greater severity, than neuro- and/or physio-typical individuals.

The question of how individuals with autism might be particularly impacted by adverse effects is informed by sensory conflict theory and postural instability theory. According to sensory conflict theory, humans gather sensory cues from multiple channels to present a continually updated model of the world and one's body [40]. However, the use of VR can introduce conflicts between what is experienced and what is expected, and this mismatch can lead to adverse effects such as nausea and dizziness [41]. Such mismatches could be even more pronounced for individuals on the autism spectrum due to diminished multisensory integration [42] and hyper-reactivity to sensory input

[43]. Sensory processing and sensory integration differences in individuals on the autism spectrum could potentially generate conflicts between visual and proprioceptive information in a virtual environment, which would increase the potential for adverse effects to present. Adding to this are the difficulties that many autistic people have maintaining postural stability—referred to as atypical postural reactivity [44]—due to reduced perceptions of body movements and shifts relative to their body's orientation and equilibrium. According to postural instability theory, extended postural instability in VR environments can lead to adverse effects [45, 46]. Since some individuals on the autism spectrum can have difficulties related to postural stability, adverse effects may be particularly acute for them when using IVR. Perceived adverse effects are well established in the VR literature for general users; however, given the known characteristics of autism, adverse effects could be particularly acute.

2 Towards a Conceptual Model for Minimizing Adverse Effects

Problematically, researchers have yet to meaningfully and systematically approach questions related to people with autism experiencing adverse effects when using immersive VR [27]. Assuming a continued trend of interest in IVR for individuals with autism, we argue that consideration of the affordances of the technology must include systematic attention to potential adverse effects and how to mitigate them. According to Kellmeyer [33], "very little systematic discussion of the neurophilosophical and ethical challenges from the clinical use of these new VR systems is available" (p. 2). These issues raise ethical concerns, as when working with vulnerable populations, researchers have a special obligation and greater responsibility to actively take precautions to help minimize real or potential risks [47, 48]. This extends to possible adverse effects associated with the use of IVR for individuals with autism. A significant gap exists, therefore, related to exploring and reporting potential adverse effects [27]. We argue that with rapid technological advancements in this area, professionals working with people with autism have an urgent responsibility to confront these issues [49].

2.1 Proposed Conceptual Model

In prior published research, we proposed a framework for addressing adverse effects when using HMD-based VR with autistic groups [49]. The purpose of this work was to foreground the need for IVR implementation guidelines to minimize adverse effects for autistic people. This framework came about as a result of two studies [23, 50] synthesizing approaches in working with autistic groups at two different research sites. Our efforts resulted in a synthesis of methods and processes for deploying IVR in a stage-wise manner, with the primary aim of minimizing adverse effects for participants. The methods we used to develop the resulting framework are detailed in the research published by Schmidt and colleagues [49]. In that work, we describe an iterative analysis process in which we collaboratively compared the approaches separate researchers adopted for implementing IVR with autistic groups. By deconstructing our techniques and critically analyzing them, we were able to identify points of convergence and divergence and subsequently distill and synthesize a set of common practices, principles, and procedures.

We present these in a graphical format that is designed to be simple enough that anyone could implement it, including both researchers and practitioners (Fig. 1).

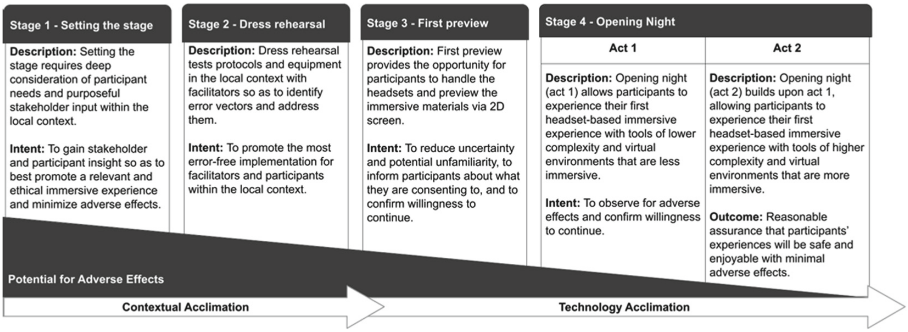

Fig. 1. Stage-wise process model promoting gradual acclimation to minimize potential adverse effects of IVR for individuals with autism.

Central to our stage-wise process is the notion of gradual acclimation, that is, the process through which the VR experience is continually optimized within and across implementation stages. Gradual acclimation begins with contextual acclimation (Stages 1 and 2). Contextual acclimation seeks to identify the local variables that potentially could impact successful implementation. The gradual acclimation process continues through technology acclimation (Stages 3 and 4). Technology acclimation provides opportunities for participants to handle and experience the technology. Importantly, by technology, we refer not only to the VR headset, but also to the virtual environment. Gradual acclimation is utilized due to known characteristics of autistic groups, such as anxiety, a preference for sameness and routine, sensory differences, etc.

Turning now to the specific stages in the model, *Stage 1: Setting the Stage* includes front-end analysis and intervention design. In addition, intentional solicitation of collaborative and meaningful input from all stakeholders during this stage ensures the voices of those who matter the most are heard [17]. *Stage 2: Dress Rehearsal* tests in-situ the IVR technology used to deliver the intervention, thereby allowing teams to collectively examine the space where the technology will be used. Importantly, dress rehearsal is not technology testing; it is preparing for social-behavioral human subjects research [43]. *Stage 3: First Preview* provides structured opportunities to communicate the project to participants. Participants can examine the technology and learn about the virtual environment they will experience. This helps provide concrete and real examples of what they will be experiencing, thereby enhancing communication. An additional benefit of this relates to informed consent, as concrete examples and hands-on activities are well aligned with known autistic traits. In *Stage 4: Opening Night Act 1*, the equipment and experience is delivered in a limited manner so as to promote gradual acclimation. This is achieved by limiting the amount of time that participants engage in the VR experience and using lower tech versions of the technology to reduce complication and promote usability [23, 51], as well as reducing the potential for frustration or confusion [52].

Finally, *Stage 4: Opening Night Act 2* provides opportunities for participants to fully engage in the IVR experience using high-fidelity HMDs (i.e., Oculus Quest, HTC Vive).

By following the stage-wise approach, we assert that participants will gradually acclimate to the technology, thereby diminishing the likelihood that adverse effects might unfavorably impact participants. Efforts to minimize risk should continue across the duration of VR experiences; for example timely check-ins with stakeholders to determine comfort and willingness to continue. As we have highlighted above, researchers have a special obligation when working with vulnerable populations to reduce risks. A dearth of guidance exists for researchers and practitioners seeking to harness the promise of VR for individuals with autism. The conceptual model we present here is a first step towards an operational reflection of values that (1) is sensitive to the rapidly advancing technological development of IVR, (2) promotes inclusion of autistic voices, and (3) recognizes our special ethical obligation as researchers when working with autistic populations. However, further work is needed. We discuss this in the next section.

3 Discussion and Implications

The current paper argues and positions the need for considering adverse effects when using IVR with autistic populations. The work is both timely and relevant, as interest in using IVR for individuals with autism is growing in areas such as: supporting attention, communication, daily living skills, emotional skills, and social skills, as well as addressing phobias and fears and promoting physical activity [30]. Although many of the procedures in our stage-wise process model arguably could extend to the general population, they were articulated for autistic populations in particular due to known autistic characteristics. Related to general audiences, 3D virtual learning environments (which include VR) provide a number of affordances that are considered to be particularly beneficial for promoting meaningful learning, including specifically (1) representational fidelity and (2) opportunities for learner interaction [53]. Examples include realistic display of the environment, user representation, embodied actions, and embodied verbal and non-verbal communication. Related to individuals with autism specifically, researchers have further considered affordances of VR that are promising, such as predictability, lack of real-world consequences, ability to experience new places in a safe and structured manner, ability to simplify the environment and tasks, etc. To date, the manner in which VR affordances have been presented in the literature has been overwhelmingly positive. Notably absent in the dominant research discourse, however, are considerations of how leveraging these affordances might lead to unintentional, unexpected, and perhaps deleterious outcomes.

Given known characteristics of autism, many of the affordances presented by others as promising also have the potential to result in adverse effects. We present here examples connected with realistic display of environments and smooth display of view changes and object motion, as well as HMD devices themselves. First, a highly realistic virtual environment can provide concrete representations, which in theory, could promote generalization from the virtual world to the real world [54]. However, the hypersensitivity to visual stimuli that some individuals with autism experience could lead to feeling overwhelmed and overstimulated. Next, IVR can allow for smooth display of view changes and object motion, which can promote a positive and engaging user experience. However, the degree to which this can be achieved is determined by the quality of the IVR system. Even with some of the most advanced HMDs, most end-users will experience some degree of cybersickness [32, 55]. As stated previously, given the sensory differences associated with autism, these virtual experiences could be particularly acute. In addition to this, some autistic users could have difficulties bringing these experiences to the attention of researchers due to known communication challenges associated with autism. Finally, the HMD systems that are believed to make possible these affordances could themselves be problematic for some. Donning HMDs can be an extraordinarily visceral experience, including (1) having someone who is presumably a stranger fit the HMD to the user, (2) physical sensations related to the HMD's weight, size, and the pressure of the tight-fitting straps, and (3) the sudden transition into a high-fidelity, hyper-realistic visual and auditory environment. Taken together, these factors potentially could trigger heightened anxiety and associated behaviors. If researchers and practitioners are to effectively apply IVR technologies with autistic populations, then the known characteristics of autism must be carefully considered alongside potential technology affordances. However, anticipating and accounting for all potentialities a-priori is neither practical nor feasible. Because our process model derives from our own practice, many of the challenges that we have experienced implementing IVR with autistic populations are embedded within the various stages. However, the model is also flexible in that unanticipated contextual or technological challenges that emerge can be identified and minimized or corrected through collaboration with stakeholders and participants.

4 Conclusion

The work presented herein explores an unmet and arguably critical need in the new and emerging field of IVR for individuals with autism concerning the meaningful and systematic consideration of adverse effects. We proffer the stage-wise implementation framework (Fig. 1) as a conduit for both considering and minimizing potential adverse effects associated with these technologies. This framework draws its importance not only because it addresses a known gap in the literature, but also because it could potentially guide future implementation in design of research studies and deployment and utilization in practice of IVR for individuals with autism. While no evidence exists currently to suggest that the proposed framework results in reduced adverse effects, what is presented here is the first phase of framework development—an important first step. Future research will seek to evaluate the framework empirically and incorporate subsequent refinements.

We offer this provisional framework in a space and time when there is very little known about how wearable technology like HMD might adversely affect individuals with autism. Practitioners, researchers and other professionals will benefit from this clear, simple and informed framework for implementing IVR with individuals with autism in a safe and ethical manner.

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