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# Virtual Reality and ADHD: Clinical Assessment and Treatment in the Metaverse

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## WHAT IS VIRTUAL REALITY?

Virtual Reality (VR) technologies offer new opportunities for clinical research, assessment, and intervention. This vision evolved from the long history of general simulation technology being usefully applied and adding value in aviation training, military planning, automotive/equipment/architectural design, and robotic surgery practice (Jentsch & Curtis, 2017; Virtual Reality Society, 2017). Thus, it should come as no surprise that similar simulation technology strategies can provide the foundation for creating powerful and engaging virtual tools for clinical applications, but in a form factor that can deliver VR experiences within a clinicians' office, hospital, research laboratory, or the subject's home. Over the last 25 years, intrepid researchers and clinicians have pursued this dream of using VR as a tool to advance clinical assessment, intervention, and scientific research (Hoffman et al., 2001, 2019; Riva, 1998; Riva et al. 2019; Rizzo & Buckwalter, 1995; Rizzo & Koenig, 2017; Rothbaum et al. 1995, 2014; Slater & Wilbur, 1997; Slater et al., 2019). This dream was further grounded by the many lines of reasoning that make the intuitive case for why VR is well matched to address the challenges for providing effective clinical strategies for mental health, rehabilitation, and general medical purposes (Rizzo & Buckwalter, 1995; Rizzo et al., 2004; Rizzo & Koenig, 2017; Rizzo et al., 2021). Since the mid-1990s, VR-based testing, training, teaching, and treatment approaches have been developed that would be difficult, if not impossible, to deliver without leveraging the power of modern computing, 3D graphics, body tracking and novel 3D user interfaces, gaming/narrative principles, big data analytics, and artificial intelligence. Such VR enabling technologies allow for the creation of highly realistic (and sometimes surreal), interactive, engaging, and systematically controllable digital stimulus environments. Users can be immersed in VR simulations and interact with content for human performance measurement and training, and by extension for the clinical purposes of assessment and intervention. This perspective makes VR well matched to the requirements of various experimental and clinical targets and supports its use in healthcare contexts. Thus, at its core, VR technologies, along with other related

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simulation-based formats (e.g., augmented/mixed reality), offer capabilities that simply did not exist with the traditional methods that were available back in the bygone days of the 20th century.

In support of the quest for establishing the evidence base in the field generally referred to as C*linical VR* (aka Medical VR or Therapeutic VR), a large and evolving scientific literature has emerged regarding the outcomes and effects from the use of VR applications (Liu et al., 2022; Rizzo & Koenig, 2017). This research has targeted cognitive, psychological, motor, and functional impairments across a diverse range of clinical health conditions/topics including Anxiety Disorders, Posttraumatic Stress Disorder (PTSD), Depression, Emotional regulation, Stress management, Substance use/addiction, Functional skill training, Traumatic brain injury (TBI), Cerebral Palsy, Autism, Attention Deficit Hyperactivity Disorder (ADHD), Alzheimer's disease, Stroke, and for many other mental health and wellness objectives. Moreover, continuing advances in the underlying enabling technologies for creating and delivering Clinical VR applications have resulted in its widespread availability as a consumer product, sometimes at a very low cost, and this will likely support the wider adoption of systems that have been empirically validated.

## WHAT IS VIRTUAL REALITY (VR) TECHNOLOGY AND HOW CAN IT BE USED IN ADHD ASSESSMENT?

The concept and definition of VR has been subject to debate by scientists and clinicians over the years. VR has been very generally defined as a way for humans to visualize, manipulate, and interact with computers and extremely complex data (Aukstakalnis & Blatner, 1992). From this baseline perspective, VR can be seen as an advanced form of human-computer interaction (Rizzo et al., 1997) that allows a user to more naturally interact with and become immersed within computer-generated 3D graphic or photographic simulations of real or imaginary environments beyond what is typically afforded with standard mouse and keyboard interface devices. However, VR is not defined or limited by any one technological approach or hardware set up. The creation of an engaged VR *user experience* can be accomplished using combinations of a wide variety of interaction devices, sensory display systems, and content presented in the virtual environment.

For the purposes of this article, *Immersive VR* is of central focus. Immersive VR can be produced by the integration of computers, head-mounted displays (HMDs), body-tracking sensors, specialized interface devices, and 3D graphics. These set-ups allow users to operate in a computer-generated simulated world which changes in a natural or intuitive way with head and body motion. Using an HMD that occludes the user's view of the outside world, an engaged immersive virtual experience employs head and body-tracking technology that senses the user's position and movement and sends that information to a computing system that can update the sensory stimuli presented via high resolution visual display inside of the HMD, to the user in near real-time, contingent on user activity. This serves to create the illusion of being immersed "in" a virtual space, within which users can interact. When immersed within computer-generated visual imagery and sounds of a simulated virtual scene, user interaction produces an experience that corresponds to what the individual would see and hear if the scene were real. The key aim of these immersive systems is to perceptually replace the outside world with the virtual world to psychologically engage users with simulated digital content designed to create a specific user experience. Immersive VR is typically the choice for applications where a controlled stimulus environment is desirable for constraining a user's perceptual experience within a specific synthetic world. This format has been often used in Clinical VR applications for delivering exposure therapy for anxiety disorders and PTSD (Difede et al., 2007, 2019; Rothbaum et al. 1995, 2014; Rizzo & Shilling, 2018; Rizzo et al., 2021), analgesic distraction for patients undergoing acutely painful medical procedures (Hoffman et al., 2001, 2019) and in the cognitive assessment of users to measure performance under a range of systematically delivered challenges and distractions (Rizzo et al., 1999; 2006; Stokes et al., 2022).

Viewed from this perspective, the added value for such VR systems can be seen in the technology's capacity to create systematic human testing, training, teaching, and treatment environments that allow for the precise control of complex, multi-sensory, dynamic 3D stimulus presentations. Within such simulations, sophisticated behavioral interaction is possible and such physical activity can be precisely tracked, recorded, and analyzed to study human performance and behavior. Much like an aircraft simulator serves to test and train piloting ability under a wide variety of controlled conditions, VR can be used to create relevant simulated environments where the assessment, study, and treatment of cognitive, emotional, social, and sensorimotor processes can take place under stimulus conditions that are not easily deliverable and controllable in the physical world. When combining VR's stimulus control features with the ability to immerse users in functional and ecologically relevant virtual environments, early clinical VR scientists envisioned a fundamental advancement in how human assessment and intervention could be addressed. It could also be conjectured that this "Ultimate Skinner Box" perspective was what human experimental researchers and clinicians had always strived for but were limited by the constraints imposed by the laws of physics that govern physical reality. Clinicians and scientists who were drawn to the idea of VR during this time were often guided by the belief that its core features and assets could support the development of innovative clinical approaches that were not possible with existing traditional therapeutic methodologies.

Recent advances in VR technology afford new opportunities to develop and test VR assessment tools and interventions for ADHD. VR immersion makes the child an active participant in the virtual setting and tests or teaches a skill in a virtual setting where distractibility can be the most impairing, *the classroom*. In this use case, a VR HMD and earphones can support a 3-dimensional interaction between the child and a virtual classroom. The child "moves" through the virtual world in space and real time by a head tracking system following the child's movement in the real world to move correspondingly in the virtual world. The HMD component of the VR therapy appears to be critical for its effectiveness (Gershon et al., 2004). Comparisons between VR immersion with a HMD versus therapy without that VR component report that the VR component increases effectiveness in behavioral and physiological response (Gershon et al., 2004) and may be more effective than in vivo exposure (Powers & Emmelkamp, 2008). These studies suggest the immersion aspect of the VR equipment and HMD are critical factors and point to an advantage of VR for assessment and treatment of ADHD versus traditional computerized tests and training. Newly designed and available low cost HMD headsets (e.g., PICO) also include eye-tracking capability as a method to improve visual resolution via a fovea rendering approach for the delivery of VR content (cf., PICO and HP Omnicept), adding to the technology's ability to assess attention. Headsets also automatically track head movement, which can serve as another source of data for tracking attention. The assessment of distraction on performance in simulation (e.g., VR) methods has been pioneered and validated in a simulated classroom for children. A game changer for the field of VR is the availability of low-weight and affordable consumer VR headsets (e.g., Oculus 2, PICO, Samsung). Individuals are purchasing the headsets for gaming, working out and other forms of entertainment and with the increased use of the term "Metaverse" in the public consciousness, the awareness of VR as a tool for clinical purposes has been amplified.

## A BRIEF HISTORY OF THE VIRTUAL CLASSROOM CONCEPT FOR ATTENTION PROCESS ASSESSMENT

Over the last 20 years, the virtual classroom approach has been studied to determine its usefulness for differentiating children with ADHD from typically developing children (TD) on multiple measures of attention and motor activity (Adams et al., 2009; Bioulac et al., 2012; Díaz-Orueta et al., 2014; Parsons et al., 2007; Pollak et al., 2009; Rizzo et al., 2006). The original VR Classroom project began in 1998 as part of a larger Clinical VR research program aimed at developing VR technology applications to improve our capacity to understand, measure, and treat the cognitive/functional impairments commonly found in clinical populations with Central Nervous System (CNS) dysfunction (Rizzo et al., 2000). Within this context, the VR Classroom was initially designed as an HMD VR system for the assessment of attention processes in children. Efforts to target this cognitive process were supported by the widespread occurrence and relative significance of attention impairments seen in a variety of clinical conditions that effect children. Notable examples of childhood clinical conditions where attention difficulties are seen include ADHD, Traumatic Brain Injury, and Fetal Alcohol Syndrome. With these clinical conditions, VR technology provides specific assets for assessing attention that are not available using existing methods.

The first project with the VR Classroom focused on attention assessment in children with ADHD. The heterogeneous features of ADHD, a behavioral disorder marked by inattention, impulsivity, and/or hyperactivity, have made consensus regarding its diagnosis difficult. Moreover, traditional methods for assessing ADHD in children have been questioned regarding issues of reliability and validity. While behavior rating scales should be included in a thorough evaluation for ADHD as they enable a perspective of the child's behavior over an extended time period they are also associated with concerns about bias and may also be an inconsistent predictor of ADHD. Correlations between concordant measures of ADHD, such as parent and teacher ratings of hyperactivity, have been repeatedly shown to be modest at best and frequently low or absent (Barkley, 1990; Colegrove et al., 1999; Murray et al., 2018; Narad et al., 2015). Standard neuropsychological test results also have limitations, due to their relatively poor relationship with ADHD rating scale outcomes (Barkley, 2019). Limitations with these tests may be in part due to the limited ecological relevance of traditional neuropsychological tests to actual performance required in relevant everyday contexts (i.e., school settings). Due to the complexity of the disorder and the limitations of traditional assessment techniques, diagnostic information is required from multiple types of ADHD measures and a variety of sources in order for the diagnosis to be given (American Psychiatric Association, 2013). Thus, in the area of ADHD assessment where traditional diagnostic techniques have been plagued by subjectivities and inconsistencies, it was believed that an objective and reliable VR strategy might add value over existing approaches and methods.

The research version of the Virtual Classroom scenario evolved between 1999 and 2003 and consisted of a standard rectangular classroom environment containing desks, a female teacher, a blackboard across the front wall, a side wall with a large window looking out onto a playground and street with moving vehicles, and on each end of the opposite wall, a pair of doorways through which activity occurred. Within this scenario, children's attention performance was assessed while a series of common classroom distracters (i.e., ambient classroom noise, activity occurring inside the classroom or outside the window, etc.) were systematically controlled and manipulated within the virtual environment. The child sat at a virtual desk within the virtual classroom and on-task attention was measured in terms of reaction time performance and error profiles on a variety of attention challenge tasks that were delivered visually using the blackboard or auditorily via a virtual teacher's voice.

Research participants responded to a virtual continuous performance test (CPT), to assess sustained attention They were instructed to view a series of letters presented on the blackboard and to hit the response button only after viewing the letter "X" preceded by an "A" (successive discrimination task). The stimuli remained on the screen for 150 msec, with a fixed interstimulus interval of 1350 msec. The target letter X (correct hit stimuli) and the letter X without the A (incorrect hit stimuli) each appeared with equal probability of 10%. The letters A and H both appeared with a frequency of 20%. The remaining eight letters occurred with 5% probability. Participants were instructed to press the mouse button as quickly and accurately as possible (with their dominant hand) upon detection of an X after an A (correct hit stimuli) and withhold their response to any other sequence of letters. Four hundred stimuli were presented during each of two 10-minute conditions. The two 10-minute conditions consisted of: one without distraction and one with distractions (pure audio-classroom noises, pure visual-chapter airplane flying across the visual field and mixed audiovisual-a car "rumbling" by the window and a person walking into the classroom with hall sounds occurring when the door to the room was opened). Distracters were each displayed for 5 sec. and presented in randomly assigned equally appearing intervals of 10 sec, 15 sec, or 25 sec. and 36 distracters (9 of each) were included in the 10-minute condition. As well, six degrees of freedom tracking from the head, arm and leg was used to produce movement metrics needed to analyze the motor hyperactivity component in conjunction with the cognitive performance. VR performance was also compared with results from standard neuropsychological testing. Results with this system over a series of studies (cf. Parsons & Rizzo, 2019) indicate no significant side effects in child users and users with ADHD produced slower and more variable reaction time, more omission errors in the presence of distracting stimuli, and increased head/body movement during testing compared to neurotypical users.

Mangalmurti and colleagues (2020) used the USC classroom to take a deep dive in assessing the mechanisms underpinning attentional deficits in combination with sophisticated diffusion modeling of a variety of cognitive performance measures associated with ADHD. They assessed the relation between field-of-view (FOV) to ADHD symptoms (i.e., inattention, hyperactivity/impulsivity) and CPT performance in the context of the USC VR classroom testing children with ADHD and a typically developing control group. The researchers captured changes in the FOV based on quantifying head rotations (rather than actual eye-movements) to distractors in the VR classroom. They found that FOV partly mediated the relationship between hyperactive/impulsive (rather than inattentive) symptoms and impaired attentional performance, as well as information uptake. This study is an example of how VR technology can deepen the understanding of distractibility and attention by combining measures from the VR setting and standardized ADHD rating scales.

The USC VR Classroom system has been used in a series of other studies to examine other clinical populations and the impact of medications and cognitive training activities on attention process performance. More detailed information on the rationale, methodology, and research projects can be found in various articles (Adams et al., 2009; Aster et al., in press; Bioulac et al., 2012, 2018; Coleman et al., 2019; Gilboa et al., 2011; Mühlberger et al., 2016; Nolin et al., 2016; Parsons et al., 2007; Parsons & Rizzo, 2019; Pollack et al., 2010; Rizzo et al., 2000, 2006).

The aggregation of the results of these studies supports the idea that the VR Classroom has good potential as an efficient, cost-effective and scalable simulation tool for conducting attention performance assessment that would be difficult to do using traditional methodologies. The system allows for controlled performance assessment within an ecologically relevant environment and the research has shown that it can parse out the impact of controlled distraction manipulations on attention performance. Additionally, the capacity to integrate measures of movement via the tracking technology further added value to this form of assessment when compared to traditional paper/computerized tests and rating scales. Within the classroom if becomes possible to disambiguate target omission errors due to distractibility (user looking away from target at a distracting event) vs. loss of focus (target is in the user's field of view, but no response).

 

Moreover, the system allows for the aggregation of a total head movement measure across the whole test period to inform assessment of the hyperactivity component of ADHD.

Much of the research cited above was generated with the 2003 version of the VR Classroom that has been in continuous use as a research tool to study attention processing through to 2021. In 2018, a commercial entity (Cognitive Leap Solutions: https://www.cognitiveleap.com/) partnered with author, Dr. Rizzo, to create an updated VR Classroom that could become available as a commercial assessment product in the near future, informed from knowledge gained from the design studies and previous clinical user research with the USC version. This version is currently in use to generate a normative database with neurotypical children aged 7-13 to support its future use as a standardized test. Thus far, 695, non-diagnosed, neurotypical children (female n=321) across the ages of 6-13 years have been tested on a 13-minute VR classroom test to establish normative data for each age group. Children were evaluated (using the standard measures of omission/commission errors, reaction time/reaction time variability, and head movement activity) on an A-K CPT delivered on a white board within the classroom, in the presence of common classroom distractions.

Early results from this normative sample showed clear linear performance improvements on all variables across the ages of 6-13 years, as was predicted to occur across age during this developmental period. For example, when grouped by 2-year intervals, male participants showed a reduction of both omission and commission errors across the age groupings (for ages, 6-7, 8-9, 10-11, and 12-13 years, mean omission errors = 13.6, 6.6, 4.2, and 2.1, and mean commission errors = 22.5, 12.1, 5.4, and 2.9, respectively). Moreover, reaction time (RT) and reaction time variability (RTV) produced similar reductions (mean RT's (in msecs.) = 523, 450, 407, and 402, and mean RTV's = 197, 149, 124, 110, respectively). Results for female participants followed the same linear pattern, but also revealed some observed differences compared to the data acquired from the male sample. The normative data continues to be collected with a target N of 1000, at which time sex differences will be analyzed more rigorously along with comparisons with ongoing data collection with children diagnosed with ADHD, medication-free.

## THE UNIVERSITY OF CALIFORNIA, DAVIS MIND INSTITUTE VR CLASSROOM PROJECT

Most studies using the USC VR classroom have used traditional CPTs in which children identify target versus nontargets on a whiteboard in the center of the classroom, responding on a computer keyboard or handheld controller. However, other tests within the VR Classroom have been developed including traditional attention and response inhibition tasks such as the Stroop test, the Boston Naming Test, and the letter crowding task (Rizzo et al., 2006). More recently, with the parallel development of the University of California, Davis (UC Davis) VR Classroom, Schweitzer, Rizzo and colleagues have continued to add more traditional classroom tasks, such as math fluency problems and an educational nature video with an attention response requirement.

Most information on distractibility in ADHD outside of the laboratory setting is based parent or teacher rating scales which only include one or two items on distractibility and limit our ability to characterize the nature of and quantify distractibility in childhood ADHD. Furthermore, the gross measure of distractibility on rating scales constrains the researcher and clinician's ability to systematically track change in response to treatment effects in clinical trials. Finer grained measures of distractibility should ultimately enhance the identification of targets for treatments and is consistent with the Research Domain Criteria initiative (Insel et al., 2010; Insel & Cuthbert, 2015) which seeks to identify targets across diagnostic categories. Such efforts will hopefully serve to improve assessment and intervention development for significant distractibility, which is currently associated with several behavioral and neurodevelopmental disorders.

The UC Davis VR classroom was also developed with the expressed goal of studying the underlying mechanisms associated with distractibility in ADHD and integrates eye-tracking equipment within the VR headset to capture eye movements. Eye tracking studies have previously documented impaired attention in ADHD, such as more micro-saccades and longer duration fixations to non-relevant regions, unrelated to target stimuli (Fried et al., 2014; Lev et al., 2020; Vakil et al., 2019). Until recently, however, the combination of using eye-tracking measures within the VR system in ADHD, is relatively rare. Studies that combine VR and eye-tracking have the potential to reveal fundamental issues in attention, saliency of distractors and patterns of engagement and disengagement within a simulated classroom environment. In a recent study at UC Davis (Stokes et al., in press) the team combined eye-tracking in the UC Davis VR classroom along with a CPT task, the Stroop task measure of response inhibition and a traditional academic task (i.e., math fluency) in a proof of principle study characterizing distractibility in children with ADHD. The temporal dynamics of distraction were recorded in this newly designed classroom via continuous eye-tracking measures in 20 children diagnosed with ADHD. The participants performed Math Fluency, Stroop, and an AX-CPT task while a series of "real-world" classroom distractors were presented. The AX-CPT in the UC Davis version used images in place of the typical letters of the alphabet. Participants were instructed to view a series of images and to press the appropriate response button when viewing the "X" image (e.g., dog) if preceded by the "A" image (e.g., bear). Each block featured a separate group of images using developmentally appropriate stimuli such as animals, fruits, and colors. The results found that distractors significantly reduced rates of on-task performance across all tasks and significantly reduced on-task, eye-gaze (i.e., defined as looking at a classroom whiteboard in the front of the room) versus off-task eye-gaze (i.e., looking away from the whiteboard. There were no significant differences, however, between task type in relation to eye-gaze or performance, suggesting consistent effects of the distractors within participants across task type (i.e., AX-CPT, Stroop & Math Fluency). Additional analyses revealed that lower task response rates were related to higher gaze distractibility suggesting that response rates and higher rates of eye gaze away from the whiteboard are indicative of a common cause of distraction. Furthermore, the pattern of eye-tracking revealed that once the distractor served to disengage children from looking at the white board and toward the distractors, they remained disengaged for a significant time period and began looking at other stimuli in the VR classroom, which continued to capture their attention. Frequently, this included looking at the animated avatar children in the classroom, with those sitting closest to the participant, often the most distracting. These laboratory observations are anecdotally similar with what one would find from observing a child in a real classroom while having the ability to systematically manipulate variables within the VR classroom to further our understanding of attention. The VR-eye tracking system also provides quantifiable measures of the challenges children with attention deficits have in returning to tasks once distracted and demonstrate how the system could serve as a sensitive measure of treatment effects.

The UC Davis VR system is currently engaged in developing and testing how VR can be used to increase attention and reduce distractibility in a pilot clinical trial. In this project, research participants have baseline and post-intervention assessments conducted in a laboratory setting, gathering eye-movement, performance and rating scale data. However, the actual intervention is conducted at home, where the children take home a VR headset and are randomized to either a control or active distractibility-exposure condition. Participant data are uploaded to a "cloud" where the research team can monitor session engagement. Children perform a series of the tasks each training session and are permitted to play VR games after completing their training sessions for the day. It is too early in the project to draw conclusions on its effectiveness, however, there is enormous interest in the community for such a treatment. The long-term goal of this project is to enable families to have widely accessible and relatively affordable treatments that while delivered in a VR context, generalize to the real environment.

## INTERVENTION EFFORTS IN VR

As noted above, there is promise for the development of interventions within the VR context to generalize to the day-to-day environment. Limitations in both individual and group traditional clinic-based therapies for ADHD include inadequate opportunities to practice a skill or behavior that can be mitigated by practice in the VR environment. Some of the advantages for VR, whether it be asynchronous, or even synchronous with a "therapist guide" presenting in real time as an avatar, is that it may be less intimidating and the child with ADHD may be more comfortable interacting with an avatar. Of course, youth nowadays spend considerable time interacting with peers online and strategies that teach them to lessen challenges with ADHD (e.g., impulsivity, distractibility) and foster the development of strengths (e.g., prosocial, civil behavior, conflict resolution) on the internet are useful skills. It remains to be seen and of course needs to be tested to see if gains made in the VR environment transfer to the real setting or if training for generalization with a stepped approach is needed for skills to transfer to the real setting. One of the authors, Dr. Rizzo, is currently involved in a program that uses VR, with live therapists embodied in a virtual world as an avatar, to role play having difficult conversations and working through conflict using conflict resolution approaches with justice-involved and disadvantaged teenagers. While the project is still in the early stages of pilot testing, it has been qualitatively been observed that teenagers are more accepting of and interested in using the VR approach and report that they are less intimidated and more comfortable working with therapists in these types of VR activities.

VR has been shown to improve outcomes in a number of areas relevant to ADHD, including motor functioning (Salem & Elokda, 2014), teaching physicians to learn to ignore distractions during medical simulation teaching (Gershon et al., 2004; Krueger & Gilden, 1999; Lange et al., 2012; Salem & Elokda, 2014) and to reduce anxiety in children with autism (Maskey et al., 2014). Meta-analyses (Opris et al., 2012; Parsons & Rizzo, 2008; Powers & Emmelkamp, 2008) and other reports (Gerardi et al., 2010; McLay et al., 2012; Reger et al., 2011; Rizzo et al., 2013; Rothbaum et al., 2006) suggest moderate to large effect sizes for VR therapy, with long-term efficacy in relatively few sessions (e.g. 4-8 sessions) for anxiety. Research in using VR for treatment of ADHD is still in its infancy. A recent meta-analysis, however, found that training within the VR context for ADHD has potential (Romero-Ayuso et al., 2021) with large effect sizes, including a reduction in omissions in CPT measures and an increase in CPT accuracy on cognitive functioning measures in ADHD. Beyond accuracy the meta-analysis also found a medium effect size for CPT reaction time and fewer commission errors.

While the VR classroom has a lengthy history of use as an initial assessment tool to inform diagnosis, it could also serve as a useful method to assess treatment effects. A preliminary study using a VR classroom in conjunction with functional near-infrared spectroscopy (Jang et al., 2020) showed that the VR classroom can be used to test the effects of pharmacological interventions, in this case, methylphenidate on working memory, in ADHD, while also furthering our understanding of the neural and behavioral effects of medication on ADHD. Ultimately, researchers will have to assess if the VR classroom situation is indeed more closely representative of treatment changes in a real classroom.

## VR VERSUS PREVIOUS COMPUTERIZED COGNITIVE TRAINING PROGRAMS

VR interventions have the potential to differ in important ways from computerized cognitive training approaches (e.g., Cogmed or Lumosity). Cognitive training is based on the rationale that it will improve a domain-general higher-order cognitive function (e.g., working memory) that will be involved in any situation requiring that function and typically involve stimuli unlike what a child would encounter in real life. In contrast, in our pilot trial using VR training we specifically target known distractors that a child would encounter in a real classroom (e.g., other avatar children talking to one another, vehicles driving by a classroom window, avatar children dropping pens or sneezing, cell phone ringing, etc.) and are attempting to train children to ignore distractors while they perform typical classroom tasks. Secondly, while traditional computerized cognitive training makes no effort to train for generalization to the real environment, VR was specifically created to explicitly simulate real world response and thus generalize to actual situations. Because VR environments mimic reality well, they produce physiological and psychological realism, which enhances generalization. This realism is why VR is used to train medical professionals and airplane pilots who require high-fidelity simulations. Similarly, VR is a successful therapy for anxiety disorders because it evokes the same response as in the real world. Thus, the emotions a child with ADHD might experience while trying to control their attention in the classroom while distracted by a classmate, may also emerge while undergoing treatment in the VR scenario. Ultimately, depending on the availability of the VR art programmers, one could develop a simulated environment that could be personalized to the patient/client with ADHD, wherein the patient would select to work in an environment that most closely mimics their real environment, whether that is the classroom for the child with ADHD or the office space for an adult with ADHD.

## FUTURE DIRECTIONS AND CONCLUSION

While the idea of VR applications for ADHD started decades before, the authors are optimistic that its usefulness and potential will soon accelerate greatly. Tech companies appear to be highly invested in developing the "metaverse" which will only grow the potential for utilization for clinical applications as well. This is due to the likely continued acceleration of hardware and generation of new computer art that is necessary to develop the VR and AR worlds. Other resources that are enabling clinical application, include the efforts to amass normative data for the assessment of ADHD, which is quickly progressing.

The possibilities for growth in the ADHD domain are many, including addressing symptoms beyond attention and distractibility in the VR world, such as impulsivity and social skill limitations. The potential to integrate physiological measures within a VR system, such as heart rate variability, provide other methods in which the VR system could be used to track physiological changes relevant to understanding and treating ADHD. Thus far, the predominant studies in ADHD have been in youth, however, adult scenarios for testing and intervention could also be developed, such as working in an office environment, for adults with ADHD. Lastly, while there is great optimism for the future of VR it is possible that intervention scaffolding may be necessary for generalization to occur. The USC and UC Davis VR teams look forward to seeing how the field of VR can grow to help address unmet needs of persons with ADHD.

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