Applications of Virtual Reality (VR) in Autism Research: Current trends and taxonomy of definitions

In the 1980s, Jaron Lanier coined the phrase Virtual Reality, or VR (Lanier, 2017). Virtual Reality's initial popularity peaked in the 1980s and 1990s, but it quickly faded due to a lack of technology and exorbitant expenses. Engineering, aeronautics, and visual perception were the main areas of research at the time (Sheridan, 1992; Robinett & Rolland, 1992). However, in 2014, Facebook (now, Meta) purchased start-up business Oculus (BBC, 2014), ushering in a new era for Virtual Reality. Technology has grown much more affordable and accessible in recent years. As a result, there has been a surge in interest in immersive technologies, such as augmented reality (AR) and mixed reality (MR). Now, Virtual Reality (VR) is a term used to describe a range of technologies, including, but not limited to, virtual worlds (VW), massive multiplayer online role-playing games (MMORPGs), virtual (collaborative) environments, cave automatic virtual environments (CAVE), static VR (using smartphones) and Head-Mounted Display (HMDs) (Newbutt, Bradley & Conley, 2020).

Virtual Reality is as difficult to define as the experience itself. VR systems are a sophisticated interplay of technology and human perception. VR is often described as an artificial environment that is controlled (at least partially) by user interactions and is experienced through computer-generated sensory cues (such as sights and sounds). However, a more basic definition of VR is an artificial environment experienced through a range of senses that is manufactured by a computer and accessed via a display, most commonly a Head-Mounted Display (HMD) (Mandal, 2013). A HMD is a set of big glasses that display a virtual environment by projecting two separate images, one to each eye, producing the captivating illusion of a three-dimensional scene all around them. A VR system usually includes one or more input devices (such as controllers, gloves, or motion trackers) in addition to cutting-edge graphics (Newbutt, Bradley & Conley, 2020).

The capabilities of virtual reality systems vary substantially depending on the device's capacity and the quality of the three-dimensional world that has been created. Immersion, interaction, and a sense of presence are three key features of all VR systems (Alcaniz-Raya et al, 2020). The degree to which the technology isolates the user from reality is referred to as immersion, which means the user can engage with objects in the virtual environment in real time. Hardware capabilities are inextricably tied to immersion (Slater & Sanchez-Vives, 2016). Immersion and interaction result in a sense of being present. It can lead to the psychological sensation of being there in a virtual environment, despite the fact that you are actually present in the real world (Alcaniz-Raya et al, 2020). Virtual Reality technologies can create highly immersive surroundings that are both realistic and safe in nature. Many disciplines of psychology have embraced this new technology in the last decade to conduct easily regulated and ecologically valid experiments. In this review, we will look at the use of VR in autism research to identify key emerging trends and to use this area of research as an illustration of the requirements for specific terminology in the future research.

VR and Autism

Social difficulties, repetitive/restrictive behaviours, and sensory processing differences are all core features of autism (APA, 2013). In the UK, the prevalence of autism is at least 1% of the population, according to recent estimates and is one of the most common neurodevelopmental conditions across the globe. The latest report by the Centers for Disease Control and Prevention (CDC), estimated the prevalence in the United States is close to 2%. (Baio et al., 2018). Clinical heterogeneity has long been rrecognised across the autism 'spectrum', with autistic individuals experiencing a range of daily living difficulties. In particular, autism is characterised by a variety of connected socio-cognitive traits , which include (but are not limited to) cognitive differences, delayed or atypical language production, and differences in social development (Miller, Wiederhold, Miller & Wiederhold, 2020). These traits can adversely impact aspects of personal independence, health, and quality of life (Lord et al., 2018).

Dorothy Strickland published one of the first accounts of Virtual Reality in autism in 1997. Since then, many empirical research have identified VR as a significant therapeutic tool (Kandalaft et al, 2013; Halabi et al, 2017; Wang & Reid, 2011). VR has been recognised as a useful tool with controllable stimuli that allows for the safe adjustment of the environment, which generally consists of a visual and aural world, as well as the potential for personalised situations (Strickland, 1997). Stimuli might be presented gradually, managed, and adapted for attentional difficulties in autism. An organised and adaptable setting could help individuals maintain their focus and manage sensory processing difficulties. Furthermore, participants may interact with the objects around them while remaining aware that they are in a virtual environment. Autistic individuals have also been found to respond well to interventions provided by computer systems (Strickland, 1997; Maskey et al, 2014).

Current Research Trends and Issues

VR and psychology research has grown at an exponential rate over the last few decades, as previously discussed. According to Parsons' (2016) assessment, VR is veridical (genuine and realistic) and has strong ecological validity, although further research into the various aspects that influence individual perceptions is needed. VR is often referred to as a 'bridge to the real world,' and it has the potential to revolutionise education, particularly for autistic people (Parsons, 2016). One of the major elements of VR, a sense of presence, is critical for autistic people since it allows for realistic simulations of social settings. Therefore, it is not surprising that the majority of work in VR for autism is focused on social skills training and interventional components. Selected samples are limited to small populations (mainly children), and the majority of studies are undertaken in Western societies (Savickaite et al, 2022). While recommendations for more varied samples and interventions are clearly significant, there are other issues that have recently emerged in the literature that have been raised but have not been previously investigated.

In a recent scoping review on this topic, Savickaite et al (2022) assessed research from the onset of VR 'renaissance' in 2015 until the end of 2020. Many of the publications during this period focused on training, intervention studies and experimental work. The authors also identified an exponential growth in papers published on VR applications in autism research and concluded that this unique research field was just starting to gain clear momentum. Conference papers were excluded in this analysis by Savickaite et al (2022) as journal publications were clearly overtaken by the computer-themed conference proceedings (Valencia et al, 2019). This meant that the review focused on journal publications only, and that the work published was predominantly in the clinical (autism and neurodiversity) domain. Nevertheless, it was clear that VR applications in autism research are still in their infancy and that the intersection between technology focused and psychology focused publications is limited.

Dechsling et al (2021) reviewed work specifically on VR applications for social skills interventions in autism. Here, a number of key gaps in the literature were identified, which closely mirror those identified in other related reviews (e.g., Savickaite et al, 2022; Valentine et al; 2020). These include: limited accessibility to data and open source materials, a lack of diversity in study methodologies and sample demographics (e.g. due to very small sample sizes), a paucity of research in autistic adults, a clear lack of definitions and the use of fully immersive HMDs (also what type of technology is used). Lorenzo, Newbutt and Lorenzo-Lledo (2021) further add that potential negative effects of VR are underreported in the field. Interestingly, a lot of studies document low negative effects expressed by participants and through observational reports, and so these recent concerns require urgent investigation.

Recent work could further improve the use of VR technology by advocating the use of psychological theories in task design and highlighting certain properties of VR configurations and human–VR interactions (Karami et al, 2021; Harris et al., 2020). For instance, Karami et al (2021) discuss how the variety of VR technology used in the trials prevent us from establishing a systematic relationship between the technology type and its effectiveness. As such, more research is needed to study this link (see related discussion in Savickaite et al., 2022). Furthermore, restricted and repetitive behaviour, which is one of the main characteristics of autism, is hardly ever addressed by VR-based investigations, therefore more experiments in this area are urged in future research.

Linked to this point above, a large proportion of the research exploring how VR can be used for autistic populations has traditionally focused on social skill interventions and training. To explore recent developments in the field, we followed the procedures of scoping review by Savickaite et al (2022) and included publications from 2021 and 2022. Detailed summary of these recent publications is available at online supplementary materials (https://osf.io/qtfp7/). In this updated analysis, it was clear that the research themes emerging over the last two years were similar to those identified by Savickaite et al (2022) between 2015 and 2020. Social training and intervention work still dominates the research area, in spite of recent calls from the autism community to broaden our scientific understanding of neurodivergent experiences and daily living behaviours (e.g., see Cusack & Sterry, 2016). Although, autism is often characterised by difficulties with social interactions, it is just one part of the presentation. Sensory differences, motor difficulties and repetitive behaviours are also important facets of the condition, as well as various wider aspects of health, wellbeing and quality of life. However, many of these topics appear to be understudied in research on VR applications for autism.

An increasing number of research publications have focused on vocational training with children and adolescents (e.g., Johnston et al, 2020; see online supplementary materials for a full list). For example, Simoes et al (2020) and Miller et al (2020) investigated the effectiveness of virtual travel training for autism, and highlighted several promising avenues for potentially fostering independence through future technology-based programmes. Cognitive training in VR research has also become the focus of attention over the last few years (Didenhabi et al, 2016; Moon et al, 2020), along with the design and adoption of education-based VR technologies. For example, Schmidt and Glaser (2021) investigated the usability and learner experience of VR adaptive skills intervention for autistic adults. The same research group are also one of the leaders of research on minimising adverse effects of HMDs for autistic participants (Schmidt et al, 2021). Finally, it must be acknowledged that a fair body of literature on VR applications for autism research cannot currently be categorised into any one discipline or area. In the online supplementary materials, we have labelled this research as 'miscellaneous', and we include work on the integration of VR with biomarker and eye-tracking technology (Alcaniz et al, 2020) and inclusion of virtual avatars (Burke et al, 2020).

The problem of defining the level of immersion in VR is still one of the most significant issues in the literature. Immersion levels of VR systems have been a point of contention since Jaron Lanier invented the term in the 1980s. VR differs from other forms of human-computer interaction in that users actively participate rather than passively observe the virtual world (Slater & Sanchez-Vives, 2016). VR has undergone many changes since the 1960s, and up until recently the level of immersion of the systems was inherently linked to its technological capabilities.

However, new technological variations have since arose (as the demand for interactive VR systems grew), and associated descriptions have arguably become more complex. The search for more standardised and/or specific terminology has been stated on frequent occasions, however, it has perhaps never fully made it into academic circles. A notable contribution was made at the start of the last decade by Mandal (2013), who began classifying technology into distinct stages of immersion. According to this piece of work, non-immersive systems, such as desktop VR, were deemed low-level because they did not require any particular hardware. The potential success of this paradigm in research could then be attributed to its simplicity. LCD shutter glasses, which enabled higher levels of immersion but did not generally support interactive input/output, were termed as semi-interactive systems. Finally, immersive systems were primarily defined as a Head-Mounted Display (HMD) with stereoscopic vision, as well as position and location tracking (Mandal, 2013).

VR stands out from other representational technologies because of its immersion, presence, and interactivity, and has grown into its own niche. Before the second VR 'boom' in 2016, Mandal (2013) alluded to the issue of nomenclature (the body/system of names used in a specialist field). Slater and Sanchez-Vives (2016) also addressed the issue of taxonomy, particularly when new hardware with increased resolution, lower latency, and higher framerates become more widely available. Thus, the question of what constitutes a truly immersive experiences has resurfaced. We can no longer deny that VR has established itself in autism research. As the number of studies continue to grow, it is a perfect time to reconsider and update our notion of definitions of immersion and its reliance on hardware.

At this stage, we wish to emphasise the distinction between the Virtual Reality Experiences (VREs) that a user or participant has and the technology that allows them to have such experiences. It may be argued that we should only be interested in the VREs and not the methods used to attain them. While it is conceivable to have VREs that do not make use of the hardware's capabilities, it is not possible for the VREs to *exceed* hardware capabilities. Although we have aimed to justify this technocentric approach within the context of this review, it must be stressed that we do not think that it is the only taxonomic work required to improve and clarify the reporting of VR-related research. Instead, we hope that this work will stimulate a more transparent and detailed approach to defining levels of immersion within the field. Our proposed breakdown of the immersive technology, and specifically VR, taxonomy is presented in Figure 1.

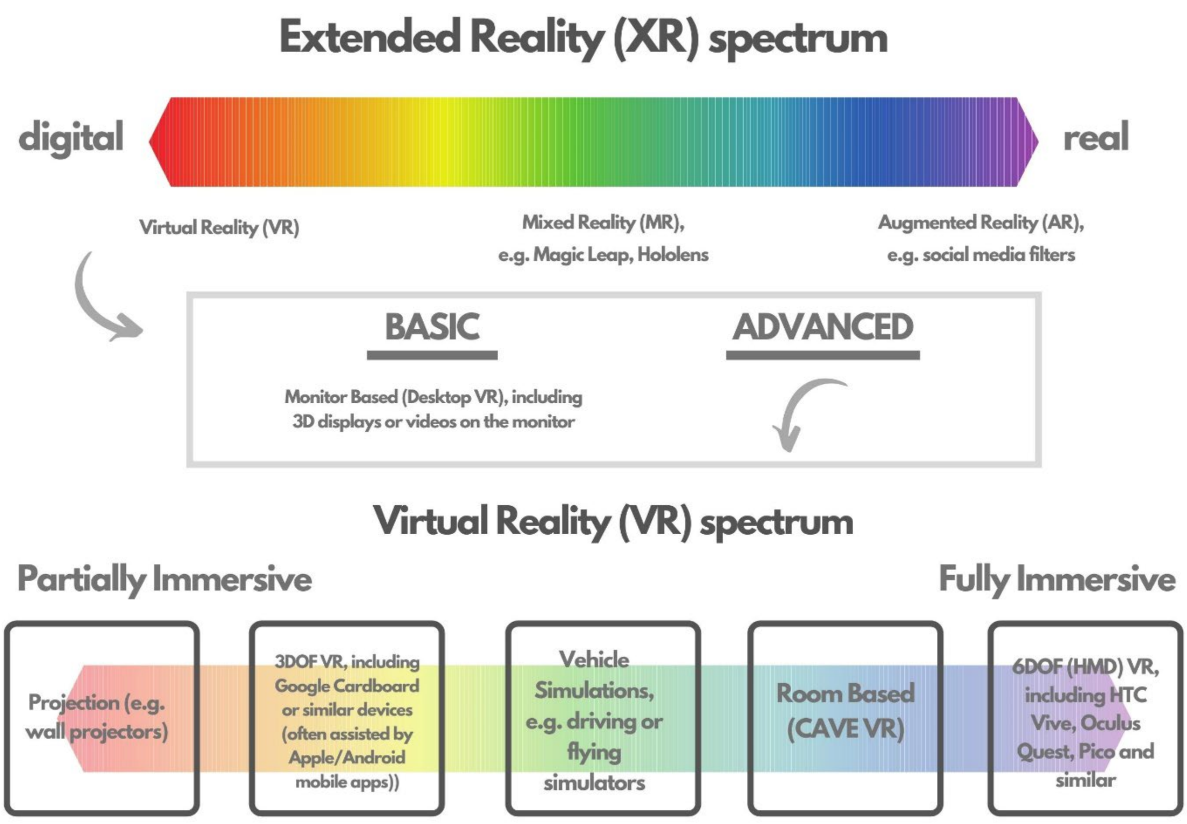

Figure 1. Virtual Reality (VR) definitions within the Extended Reality (XR) spectrum.

Although no single methodology or technology are viewed to be fundamentally flawed, advances in headset technology have resulted in a major stratification in terms of the immersive capability of VR equipment. This shows that fresh definitions in how we refer to the equipment are required. Virtual Reality is now dominated by Head-Mounted Display, and research should account for this at a communicative level. Indeed, in the absence of transparent reporting standards and terminology, readers may be left confused (or unintentionally misled) by manuscripts that use the term "virtual reality" to describe non-HMD devices. Furthermore, additional nomenclature such as augmented reality (AR), mixed reality (MR), and extended reality (XR) is commonly associated with VR. To ensure that future scientific work is adequately replicable and understood across multidisciplinary audiences, a revised set of standards must therefore be developed (so that future trials can see which VR hardware is being used).

For decades, industry and academia have struggled to come up with clear and standardised definitions of immersion levels. In various areas of VR research, several different definitions have evolved. VR applications for autism research is a growing field, and provides an excellent place to start incorporating new criteria that more appropriately represent technology and the level of immersion. Savickaite et al (2022) made the first attempt to systemise the nomenclature and expanded on Mandal's (2013) terminology by including some recent advances as well as the concept of degrees of freedom (DOF). However, our understanding of VR technology and how it relates to immersion has evolved, and it is vital that methodological clarity is upheld within autism research studies.

Figure 1 presents our attempt at summarising technology actively used in the area of autism research and its relationship with the level of immersion. Here, we present a new set of reporting standards that can be incorporated by researchers to ensure that scientific terminology remains consisted and transparent in future work. Moreover, HMDs and other displays are growing in sophistication and the distinction between Virtual Reality and other ‘sister’ technologies (e.g. Augmented Reality (AR) is getting less clear. Therefore, we wish to introduce VR micro-definitions within the broader spectrum of Extended Reality (XR) macro-definitions (Figure 1). This attempt to systemise VR terminology predominantly comes from our scoping review. However, we have also consulted broader literature, including immersive education (Kommetter & Ebner, 2019), urban design (Shakibamanesh, 2015) and even dentistry research (Al-Musawi et al 2017). It is evident that the debate around the taxonomy of VR is not as new as one might expect, however, it evolves and changes continuously. Therefore, we wish to emphasise that our proposed set of VR definitions are not definitive and final.

Each subsequent generation of new VR devices improve the size andusability of the equipment, as well as the user interface and resolution. The Covid-19 epidemic has changed information exchange in academia already, and the scientific world is becoming increasingly reliant on technological innovations. Academics are actively joining social media and conferences are shifting to the internet allowing for faster information flow. As a result, the studies and terminology utilised are constantly evolving. We hope that our review serves as a starting point for a more complete taxonomy and a meaningful dialogue.

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