Autism and virtual reality head-mounted displays: a state of the art systematic review

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Abstract

Purpose – *The use of virtual reality (VR) technologies in the education of autistic children has been a focus of research for over two decades. It is argued that this form of technology can provide authentic "real world" contexts that target social and life skills training in safe, controllable and repeatable virtual environments. The development of affordable VR head-mounted displays (HMD), such as Google cardboard and Oculus Rift, has seen a renewed interest in their use for a wide range of applications, including the education of autistic individuals. The paper aims to discuss these issues.*

Design/methodology/approach – *A systematic search of electronic databases focussing on empirical studies on the use of VR-HMD for children and adults on the autism spectrum was undertaken.*

Findings – *A review of the literature identified a limited number of studies in this field characterised by differences in the type of application, technology used and participant characteristics.*

Research limitations/implications – *Whilst there are some grounds for optimism, more research is needed on the use of this technology within educational settings to ensure robust recommendations can be made on the implementation, use and sustainability of this approach.*

Originality/value – *This paper is the first to consider the evidence base for the use of VR-HMD technology to support the needs of the autistic population.*

Keywords *Autism, Assessment, Learning, Education, Virtual reality, Head-mounted display*

Paper type *Literature review*

Introduction

> Despite nearly twenty years of research, the potential of VR for autism education still remains an aspiration rather than a reality (Parsons, 2016, p. 1).

Autism or autistic spectrum disorder (ASD)[1] is a neurodevelopmental condition characterised by core differences in social communication, interaction and repetitive behaviours across a variety of contexts (American Psychological Association, 2013). The last few decades (1990s–2010s) have seen an increase in educational and health-based application studies designed to identify effective support for this population (Pellicano *et al.*, 2014). Despite this research, the academic, social-economic and mental health outcomes for children and adults on the autistic spectrum remain poor (Eaves and Ho, 2008). As a result, finding more effective ways to improve outcomes for autistic individuals through effective, and appropriate, applications and approaches remains a research priority for individuals and their families (de Bruin *et al.*, 2013). With approximately 1 in 100 children in the UK (Brugha *et al.*, 2012) and 1 in 68 in the USA (Baio, 2014) receiving a diagnosis, this remains an important issue that needs addressing by a range of stakeholders; education being just one.

Virtual reality (VR) and education

The rapid growth in the development of VR technologies over the last ten years has seen a strong argument made for its use as an educational tool for children, young people and adults (Newman and Scurry, 2015). Virtual environments (VE) enable users to experience

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representations of imaginary or "real word" settings produced in 3-D by digital technology (Cheng *et al.*, 2015). The development of immersive computer-generated environments has been enabled through combining educational and entertainment environments, immersive technologies (e.g. head-mounted displays (HMDs)), advanced input devices (e.g. gloves, trackers and brain-computer interfaces) and computer graphics (Parsons *et al.*, 2017). The type of technology used impacts on the degree to which VE can replicate features of real-world settings and experiences and thus whether, and how, behaviours and interactions take place (Parsons and Cobb, 2011).

The use of VR in educational contexts has tended to focus on two interrelated areas of research: investigating social interactions and its use as a methodological tool (see Parsons, 2016). VE can be used to create authentic and ecologically valid environments which means experimental conditions can be replicated across different studies and participants can be randomly assigned to conditions of the experiment, thus increasing generalisability effects (Blascovich *et al.*, 2002).

As discussed by Parsons (2016), the use of VR to investigate social interactions is based on the fundamental belief that VEs provide realistic and authentic experiences (i.e. veridicality) that mirror the response and behaviours of individuals in the real world. Parsons (2016) goes on to conclude that the assumption of veridicality (i.e. VR being authentic and realistic) has provided a strong argument for the use of VR-based applications in various educational and health disciplines. This includes such diverse areas as: psychotherapy for the treatment of phobias and social anxiety (Gega *et al.*, 2013) and supporting the physical rehabilitation of individuals with motor disabilities (Holden, 2005).

VR and autism

Key features of VEs have been cited as having potential benefits for autistic individuals as they can be individualised, controllable, predictable and offer "safe spaces" for users to learn new skills (Parsons and Cobb, 2011; Kandalaft *et al.*, 2013). This means that autistic individuals can practice interactions and behaviours within a realistic environment that can be programmed to reduce sensory and social inputs to a manageable level.

The publication of several conceptual and state of the art reviews in recent years has focussed the debate more widely on issues relating to the use of VR by, and with, autistic individuals (see Bellani *et al.*, 2011; Parsons and Cobb, 2011; Parsons, 2016). In addition, the immersive nature of VE has been shown to enable a sense of presence for autistic adolescents (Wallace *et al.*, 2010) as well as providing a motivating tool for learning (Parsons and Mitchell, 2002). There is also evidence that the ability to individualise, rehearse and repeat social scenarios across different contexts has afforded opportunities for the generalisation of social skills learned in VE to everyday life interactions (Didehbani *et al.*, 2016; Parsons and Cobb, 2011; Tzanavari *et al.*, 2015).

The previously reviewed studies mainly cover either screen-based media types (i.e. monitors/TV screens) or more immersive systems that involve projections of animations being displayed on the walls and ceilings of a screened space (i.e. Wallace *et al.*, 2010). However, and as a direct result of the positive findings related to these VRTs, there has been growing interest in the potential of HMDs as a form of VE for autistic groups (see Adjorlu *et al.*, 2017; Newbutt *et al.*, 2016). This format (i.e. HMDs) is the focus of this paper and we aim to shed some light on the state of the art in this field.

It is important to stress that there remains a limited evidence base within this field and a lack of studies exploring the use of the VR across all age ranges (Boucenna *et al.*, 2014; Parsons and Cobb, 2011) or population characteristics (i.e. diagnosis, IQ or educational setting). Other researchers have cited concerns that VR could increase social isolation and that its high cost and lack of general availability were potential barriers to more widespread adoption by schools or educational settings (Parsons and Mitchell, 2002). The issue of cost and availability has become lessened by recent developments in technology hardware that has made the use and research of VR both more affordable and increasingly diverse; hence the need for this state of the art review. The following section looks in more detail at the findings from the research literature in this field, i.e., the use of VR-HMD technology in the education of individuals on the autistic spectrum.

VR-HMDs and autism

The past decade has seen an increased focus on the development of VR-HMD display technology for education, training and leisure. HMDs have been used to increase the feeling of immersion in VE with the advantage that they are lightweight and small, increase the field of view and can present a range of interactive spaces (e.g. using virtual theatres). Users typically wear HMD that consist of two small monitors attached to a high-speed computer with integrated head-position sensor controls, controlling the direction from which the VE is viewed (Osterlund and Lawrence, 2012) (see Plate 1 as an example).

These technological developments have led researchers to study the use, effects and applicability of HMDs in a range of different disciplines, including educational contexts. Regarding autistic individuals, this has been identified as both an emerging and important area of research where: "questions surrounding the acceptability and practicality quickly need to be addressed if we are to develop a sustainable line of inquiry surrounding HMDs and VRTs for this specific (autistic) population" (Newbutt *et al.*, 2016, p. 3166). We suggest there are two major reasons to study the potential of VR-HMDs for autistic groups. First, there is a fast and growing market for VR and HMDs in both commercial and educational settings. For example, Chang and Chen (2017) suggest "people are ready for VR […] and 2017 will witness a quantum leap in user numbers, from around 200,000 in 2014 to 90 million […]" (p. 385). In similar findings Jeon *et al.* (2017) report that "with the development of computer graphics and VR technology as well as HMDs, users can access realistic VR content at a low cost" (p. 27). These examples provide emerging trends for the consumer potential of VR HMDs; thus making this form of media both affordable and portable for using in a range of settings that have not been possible before. Second, the potential for VRTs (in the broadest sense; i.e. VE, virtual worlds, virtual simulations) has been shown to align well to autistic individuals in developing specific outcomes that can support

Plate 1 Example of a VR-HMD in 2018 (HTC Vive) being used in controlled conditions by an autistic adolescent in school

educational, social and learning gains (as they can be controlled, designed in a bespoke manner and provide ecologically valid spaces that enhance presence and immersion, see Wallace *et al.*, 2010, 2017; Newbutt *et al.*, 2016). Therefore, we suggest that research already addressing the potential of VRTs for autistic groups should be extended to the use of HMDs to help highlight the gaps in knowledge, potential, possibilities and educational benefits. In providing this state-of-the-art review now (2018) we believe that there could be a greater chance for a more targeted approach to emerge that addresses areas of importance at a more rapid rate than the development of VEs before.

In addition to the timeliness of this review, we also suggest that it is important to recognise the potential concern using HMDs with autistic populations. Here we specifically refer to: sensory problems and cybersickness. With revisions to the DSM criteria for diagnosing autism conditions (currently revision 5; American Psychiatric Association (APA), 2013) specifically referring to sensory issues, we suggest that there should be an urgent need for investigating wearable technologies for autistic groups; ensuring that sensory concerns related to wearing technology (in this case HMDs) are appropriately addressed. Within the DSM-5 diagnosis criteria there are specific mention of sensory issues including: "odd responses to sensory input" and "hyper-or hypo-reactivity to sensory input or unusual interest in sensory aspects of environment, such as apparent indifference to pain/heat/cold, adverse response to specific sounds […]" (APA, 2013, p. 50). These criteria, coupled with heightened visual/auditory stimuli that can be part of HMD VR experiences, provide a timely need to investigate, carefully, HMD use by autistic groups. The second point, related to cybersickness, is also timely and important to explore in the extant literature as there have been reports of HMD inducing a feeling of sickness in users—albeit mainly typically developing (non-autistic) groups to date. For example, Park *et al.* (2017) reported high levels of cybersickness in participants using a HMD, while Almeida *et al.* (2017) and Reiners *et al.* (2014) reported high levels of withdrawal (related to cybersickness) in their HMD studies. Similarly, Bashiri *et al.* (2017) suggest that: "studies have indicated that cybersickness is a barrier to the use of training or rehabilitation tools in virtual reality environments" (p. 338), and Polcar and Horejsi (2015) reported that when present, cybersickness influenced learner attitudes towards technology negatively. So with several HMD studies warning of either: cybersickness symptoms; suggesting cybersickness as a barrier to HMD use; highlighting issues that can influence learning; or likelihood of withdrawing from using HMDs, we feel highlighting cybersickness as part of a review into HMD VR use by/for autistic groups is important.

However, and as such, there is a justification for a review of research on the use of VR-HMD with autistic groups that both pulls together findings to date in addition to negative effects (cybersickness) and sensory concerns reported for autistic groups. This paper is the first to assess how this technology has been used in practice and to establish the current state of the art in the field.

Approach to the inclusion of literature in the review

The methodology employed for the review of the literature was based on the NCSE International Review of the Literature of Evidence of Best Practice Provision in the Education of Persons with ASD (Parsons *et al.*, 2009).

The review's two key tasks were as follows:

1. to provide a review of available international empirical studies on the use of VR-HMD technology with autistic children, young people and adults; and
2. to draw on the findings and make recommendations on future directions for research and practice in this field.

A systematic search of electronic databases focussing on empirical studies on the use of VR-HMD for autistic individuals was undertaken. Inclusion criteria (see Table I) were identified and translated into related search terms: HMD (and) VR (and) autism, autistic spectrum, ASD (and) education.

Definitions of terms were identified to enable the scope of the review to be established (see Table AI). The definitions were translated into related search terms (see Table AII) that were systematically

Table I Criteria for search of empirical studies

Inclusion criteria—studies included met all the following	
Scope	Focus on autistic children, young people and adults Focus on educational assessment, approaches and interventions using VR-HDMs
Study type	Are empirical, that is, include the collection of (quantitative or qualitative data) or systematic reviews of empirical data in peer-reviewed journals
Time and place	From 1990 onwards Are written in English

applied to six main databases using "AND" and "OR" Boolean combinations: ERIC, British Education Index (BREI), Research Autism Database, Google Scholar, and the ISI Web of Knowledge. Finally, inclusion criteria were established for studies to be considered under this review (see Table I).

The literature search resulted in the following number of articles per database: Research Autism Database = 13; BREI = 8; ISI Web of Knowledge = 7; ERIC = 10; Google Scholar = 14. In total, this produced 51 articles for possible inclusion. The results for each database were then cross-referenced and the duplicates removed which meant the remaining total of article summaries (titles and summaries) requiring closer inspection was 27. Most of these studies had used desktop, laptop or touch screen-based technology to provide VE for the users. Only six studies had used VR-HMD technology with autistic participants. The results are shown in Table II. This shows the limited number of studies in this field and the diversity of participants, design and conditions under which VR-HMD have been used (e.g. different VE, users completing different tasks under different constraints and over differing time periods).

Overview of studies

The six studies identified in the literature review are reflective of the two main uses of VR in autism research. First, as means of assessing and monitoring the responses of autistic individuals to authentic VE in experimental conditions (i.e. Mundy *et al.*, 2016), with a view to understanding core social, cognitive and neurological differences. Second, to support the learning of skills in a VE that can be applied to "real world" contexts and be generalised as such. Strickland *et al.* (1996) were the first to study the potential of VR-HMD as a learning tool to with autistic children. This early VR technology was used to enable two primary aged autistic children to identify cars and colours in three different virtual scenarios, leading to safely crossing a road. The intervention integrated practice and principles from the TEACCH methodology, including the use of schedules, a structured learning environment and the parents of the children acting as "co-therapists" (Schopler, 1987). Results demonstrated the ability of the children to use and tolerate an HMD and to meaningfully interact within a VE. The study recommended using adjustable VE and HMD tools with autistic children, to help participants understand virtual scenarios and the virtual world.

There was a gap of almost two decades between the work of Strickland and the next published examples of research using VR-HMD with an autistic population. Exploratory research by Newbutt *et al.* (2016) focussed on understanding the user experience of a VR-HMD in different VE. This study was conducted over two phases. Phase 1 explored user acceptance of the technology, whilst Phase 2 investigated negative effects, immersion, sense of presence and ecological validity. The first phase indicated that most participants (95 per cent, $n = 25$), adults on the autistic spectrum, were accepting of wearing the HMD through three separate and different VE experiences. Though there were no increased levels of user anxiety or sensory issues identified, there was some negative feedback on the technology used. This included comments by participants that the HMD made them feel dizzy, was not comfortable to wear and that the graphics were not smooth enough. Participants in Phase 2 had been selected from the Phase 1 group and were exposed to two different VE experiences over a longer period (15–20 mins). A key finding from this phase was that the users felt their experience of the VE using the HMD

Table II Empirical papers relating to the use of VR-HDMs with autistic populations: learning, assessment and intervention

Reference	*Target behaviours /focus (foci) of study*	*Number and autism characteristics/ diagnosis of participants*	*Design and procedure*	*Equipment*	*Setting/ context*	*Negative/side-effects reported*	*Main findings*
Adjorlu *et al.* (2017)	Whether skills learnt in VE could be transferred to a real supermarket (i.e. confidence levels in supermarket shopping, ease of shopping and assistive elements used to identify products)	9 children with ASD Aged 12–15 years Experimental group ($n = 4$) Control group ($n = 5$) Male ($n = 8$) Female ($n = 1$) Diagnosis confirmed by existing educational or medical records IQ not specified	Group-based comparison study 7 sessions over 10 days	Vive HMD and desktop computer	Children's school and community supermarket	Negative effects—not reported Did report positively on ease of use of VR simulation (1–5 self-report scale)	VR simulation helped the treatment group to retain their ability to find products' locations more accurately and confidently
Bozgeyikli *et al.* (2017)	The effectiveness of the VR system for vocational training and the effect of distracters on task performance within this	9 adults with HFASD in experimental group 9 typically developing adults in control group Aged 25–29 years Gender not specified Diagnosis confirmed by existing educational or medical records IQ above 70	Group-based comparison study 2×2 h sessions over 2 days	HMD (VR2200) and desktop computer	University laboratory	Negative effects—reported tiredness. Self-report 5-point Likert scale. 1: not tired at all to 5: very tired. Indicated no negative effects on participant tiredness levels when completing tasks Motion sickness—asked how nauseous/dizzy participants felt on a scale of 0: none to 3: major. Indicated no negative effects on participant motion sickness when completing tasks	Improvement seen in trained skills for the autistic participants and no negative effect of distractors
Cheng *et al.* (2015)	To improve target behaviours of non-verbal communication, social initiations and social cognition for participants	3 children with ASD Aged 10–13 years Male ($n = 3$) Diagnosis confirmed by existing educational or medical records IQ above 80	Single-subject experimental study with multiple probes×3 sessions over a 6-week period	HMD (Model: I-Glasses PC 3D Pro) and laptop with 3D SU system	Children's school	Negative effects—not captured or reported	Participants' targeted behaviours improved, from baseline to intervention through maintenance, following their use of the VE system
Mundy *et al.* (2016)	To investigate whether information processing during joint attention may be atypical in children on the autistic spectrum	32 children with HFASD, 27 children with ADHD and 23 typically developing children Aged 9–13 years Gender not specified ASD confirmed by SCQ and ASSQ IQ above 100	Group-based comparison study	HMD	University laboratory	Negative effects—not captured or reported	An atypical pattern of information processing response to joint attention was observed in the HFASD sample. There was no diagnostic group differences in attention (fixations or duration of study time)
Newbutt *et al.* (2016)	Whether it was safe to use the VR-HMD interface and did participants accept and enjoy their experience in the VE	29 autistic adults Mean age 32.02 years Male ($n = 22$) female ($n = 7$) Diagnosis confirmed by existing educational or medical records	Two phase exploratory case study	HMD (Oculus Rift) and laptop	Community rehabilitation centre	Negative effects—reported tiredness, eye strain, dizziness, feeling nauseous. Self-report 5-point Likert scale. 1: no negative effects to 5: high negative	Participants expressed a general acceptance of wearing VR-HMD. High spatial presence, engagement and ecological validity were reported within the

(continued)

Table II

Reference	Target behaviours /focus (foci) of study	Number and autism characteristics/ diagnosis of participants	Design and procedure	Equipment	Setting/ context	Negative/side-effects reported	Main findings
		ASD ($n = 16$) Asperger's ($n = 10$) PDD-NOS ($n = 3$) IQ (mean) above 80				effects. Participants indicated low negative effects when completing tasks. Use of ITC-SoPI[a] to measure these effects	VE environment. Self-reported anxiety was not increased as a result of using the VR-HMD
Strickland *et al.* (1996)	Level of acceptance of HMD equipment, ability to complete a task and pay attention to the VE	2 mild to moderately autistic children Aged 7.5–9 years Male ($n = 1$) Female ($n = 1$) ASD confirmed by CARS IQ (mean) 76.5	Multiple probe design 14–21×3–5 min sessions	HMD (divisor and provision 100 VR system)	Lab based in university setting	Negative effects—not captured or reported	Participants wore the VR-HMD without difficulty and completed the tasks successfully

Notes: HMD, head-mounted display; VE, virtual environment; VR, virtual reality; HFASD, high-functioning ASD. [a]Independent Television Commission–Sense of Presence Inventory (Lessiter *et al.*, 2001) were authentic and could feasibly happen in real life. Supporting the argument that this technology could be applied for generalising skills into "real world" contexts. The next two studies explored this possibility in more detail.

The first of which studied the feasibility of using VR-HMD for developing the shopping skills of autistic adolescents (Adjorlu *et al.*, 2017). Four students had seven sessions of VR supermarket training following a baseline assessment of behaviour in a real supermarket. At the end of the intervention, they were assessed again in the real supermarket and results compared with five students in a control group who had not received the VR training. The intervention was led by a teacher at the student's school which was a specialist setting. Though the results indicated a positive effect on the treatment groups' ability to find products' locations more accurately and confidently in the real supermarket, there was a negative development in their self-reported confidence levels during the post-treatment assessment. Furthermore, it was reported that the treatment group self-satisfaction levels decreased over the period of the intervention, indicating that they were not sufficiently stimulated by the supermarket VE.

The second study by Bozgeyikli *et al.* (2017) explored the use of VR-HMD technology to support vocational training for adults on the autistic spectrum. This intervention offered participants training on six vocational skills (cleaning, loading the back of a truck, money management, shelving, environmental awareness and social skills), which were identified as transferrable to and useful in many common jobs. The autistic participants were accompanied to the sessions by job trainers who were supporting them with finding employment. Follow-up surveys indicated improvement for the autistic individuals in the six trained skills and high immersion scores for all six skills were recorded. However, the autistic participants regarded this as immersing themselves in using the VR experience, as opposed to feeling present in the VEs. Despite this, the researcher felt that the intervention could be an effective assistive tool to assess, train and prepare the participant for follow-up on-site vocational training.

The use of VR-HMD technology to develop the social skills of autistic individuals was looked at in more depth by Cheng *et al.* (2015) who conducted a preliminary study on its use to improve the social understanding and skills of three autistic children in the USA. All three children attended a local special school (two on a part-time basis) and each was involved in baseline, intervention and maintenance phases of the intervention (three sessions for each phase). The sessions were delivered by one of the children's teachers over a six-week period and performance of the target behaviours was recorded. Results indicated that there was an improvement in the behaviours for each child, namely, non-verbal communication, social initiations and social cognition. There were no recorded adverse effects of using the HMD technology. Furthermore, the strategies adopted by the researchers for this intervention, i.e., modelling, promoting, reinforcing and guiding, were cited as helping the participants develop these target behaviours and maintain them over a period of time. The study offered evidence for the use of immersive VE and HMD as an approach to support the development of social skills and understanding in autistic children.

The final study in the review by Mundy *et al.* (2016) focussed on the use of VR-HMD as a methodological tool to assess the information processing abilities of autistic children when engaging in joint attention activities. They concluded that the atypical pattern of information processing response to joint attention in the autistic children may be a clinically feature of autism. This contrasted with the typically developing cohort, and those with ADHD, who displayed evidence of enhanced stimulus information processing and recognition memory during the sessions.

Discussion

The studies using HMD virtual technologies, identified in this review, have shown potential for the learning and assessment of children, adolescents and adults on the autistic spectrum. Furthermore, the barriers to using VR-HMD in research, i.e., a costlier and less comfortable solution with respect to ordinary computer monitors, have largely been overcome in recent years.

It is therefore surprising that so little research has emerged in this field since the first study by Strickland *et al.* (1996).

The limited number of studies and participants means that drawing conclusions about the results more widely is problematic, notwithstanding the relevance of small-scale, case study approaches for exploring the potential of emerging technologies. Furthermore, the lack of a typically developing control group in four of the studies limits the understanding of the extent to which the findings relate to the VR technologies used, the type of intervention or diagnostic features of the participants. Many of the limitations of the studies identified in the literature are consistent with those found autism education research more generally (Charman *et al.*, 2011).

One of the main criticisms in this field has been the lack of involvement from practitioners in research on educational approaches for autistic populations (Parsons *et al.*, 2011) and the gap between research and practice in real-life settings (Reichow *et al.*, 2008). This is consistent with the present review, where the work by Cheng *et al.* (2015) and Adjorlu *et al.* (2017) were the only studies in the literature that took place in "real life" settings, namely, the children's school and a local supermarket. Furthermore, the research by Adjorlu and colleagues was the only study to assess whether the participants went on to demonstrate target behaviours learnt in the intervention in daily life.

Though several studies had an element of participatory research methodologies, only two explicitly sought feedback from practitioners about the intervention (see Adjorlu *et al.*, 2017; Bozgeyikli *et al.*, 2017). This type of information is valuable and would enable more robust recommendations to be made on the sustainability of educational interventions and approaches using VR-HMD technologies within educational, health or community settings. Furthermore, the inclusion of autistic individuals in the research was predominantly in the role of passive participants whose experiences of the interventions were primarily gained through quantitative data. It can be argued that the lack of qualitative data, i.e., interviews with participants, limits our understanding of how they perceive VR technology and the use of HMD. It is therefore important to evaluate both outcomes and the process of implementation of VR technology through the involvement and experience of autistic individuals and the practitioners who work with them. Several researchers had made use of existing good autism education practice in their studies (see Strickland *et al.*, 1996; Cheng *et al.*, 2015) or made recommendations based on their findings (see Bozgeyikli *et al.*, 2017), but this was not consistent across the studies.

The variance in both technology used (including how realistic the VE are, type of HMD and how tasks were carried out) and the diagnostic features of the autistic participants supported the finding that: "The state-of-the-art in the literature is that there is no single study, or series of studies, that has systematically unpicked and interrogated the ways in which these features may combine to influence responding and understanding" (Parsons, 2016, p. 153). As with other research in this field, there has been a focus on autistic children, young people and adults who have average or above average IQs (Didehbani *et al.*, 2016), which means the findings of these studies may not be applicable to a wider range of autistic individuals. The heterogeneity of response to VR-HMD applications and experiences indicates a need for further research that should take account of both the characteristics of this population and the specific features, characteristics and affordances of this technology, to consider how these features might best support and motivate them. The issue of veridicality is of importance in this context and the results from the six studies were mixed. Promising results were reported by Newbutt *et al.* (2016), with participants showing high levels of engagement, spatial presence and ecological validity within VE. In contrast, participants gave a more nuanced response in the study by Bozgeyikli *et al.* (2017), and indicated that whilst they were immersed in the VR activity they were aware it was not real. As such, more work is needed on how VR-HMD technologies can be designed and developed to act as an authentic real-world experience for this population.

A final and important aspect of our review is that of negative effects (cybersickness). Here we refer to the finding that 50 per cent ($n = 3$) of the studies included in this review considered capturing/measuring reported negative effects users may have felt. This fell to only 17 per cent

($n = 1$) with reference to asking about the HMDs being comfortable to wear. We feel that this, along with developing ethical approaches/frameworks for using HMDs with autistic populations, should be a feature of future work; both because people with autism may have heightened sensory concerns and/or feelings related to VE stimuli that they are being presented with (Newbutt *et al.*, 2016).

Conclusion

While there has been a significant increase in the number of studies over the past decade into autism (Pellicano *et al.*, 2014) there is still much work to be done on developing better methodological frameworks to examine the effectiveness of various approaches within "real life" settings, such as schools. An irony exits where research in VR-HMD proposes to immerse users in computer-generated environments that represent and reflect real-world settings and activities (and retain the key affordances of presence, immersion and ecological validity), but often do not conduct these in real-world settings or test the generalisability of these activities to real life or the real world.

Further research would ideally focus on addressing these issues and the longitudinal effects of involvement in VR-HMD engagements for different populations, to see if this was effective for them or not. This includes addressing the issue of the impact of VR-HMD on the health and well-being of users (Mon-Williams, 2017). Furthermore, the potential of this technology to support the learning of children, young people and adults on the autistic spectrum needs to be considered within the range of existing educational approaches and support for this population. VR-HMD are just one approach, amongst a range of others, that may be used by practitioners, teachers and therapists and its use should not simply replicate existing practice or be a substitute for human interaction, knowledge and skills.

We argue that the potential for VR-HMDs is worthy of continued investigation, despite the limited evidence, as it is gaining traction as both a viable and affordable technology within education. However, further analysis of the mediators and moderators for educational approaches using VR-HMD are needed and the investigation into factors supporting or challenging implementation and sustainability. For example, the cost of the VR-HMD technology or the role of adult facilitators in the delivery of VR-based programmes to autistic children and young people in school settings (Ke *et al.*, 2015). Research methodologies should ensure that the experiences and outcomes of VR-HMD exposure for all stakeholders, such as autistic children, their peers and school staff, are effectively captured.

Note

1. In line with current research (Kenny *et al.*, 2016), we refer to both "people with autism" and "autistic people" throughout, without placing a preference on either; reflecting the views of autistic groups and stakeholders when using terms and language within this field.

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Appendix 1

Table AI Definitions of terms for literature review

Key term	*Working definition*
Literature and evidence	Peer-reviewed empirical studies published in academic journals and drawn from electronic databases: ERIC, British Education Index (BREI), Research Autism Database, Google Scholar and the ISI Web of Knowledge
Autism	From the American Psychological Association (2013), autism or autistic spectrum disorder (ASD) is a neurodevelopmental condition characterised by core differences in social communication, interaction and repetitive behaviours across a variety of contexts The review will include all subgroups identified within the spectrum and include children, young people and adults at all levels of intellectual ability and severity
Virtual reality	Virtual reality refers to computer-generated environments or realities that allow a person to experience and manipulate the environment as if it were the real world
Time and place	To include all international studies, while recognising that most relevant publications were likely to come from the USA and UK only reports written in the English language and produced or published after 1990

Appendix 2

Table AII Search terms for empirical studies

Subject area	*Specific terms*	
Terms for autism	Autistic spectrum condition or disorder (ASC/Ds)	Atypical autism
	(Classic) Autism	Asperger(s) syndrome (AS)
	Autistic	High functioning autism (HFA)
Terms for children, young people and adults	Pupils	Girl(s)
	Students	Boy(s)
	Youth	Individuals
	Adolescents	Men
	Teenagers	Women
	Young people	People
	Young adults	
Terms for education	Pedagogy	Knowledge
	Teaching	Instruction
	Learning	Curriculum
	Approaches	Intervention
	Assessment	
Terms for head-mounted display	Head-mounted display	Headset
	HMD	Glasses
	HMDs	Goggles
	Helmet	
Terms for virtual reality	Virtual reality (VR)	Virtual environment (VE)

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