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In the past decade there has been a rapid advance in the use of virtual reality (VR) technologies for leisure, training and education. VR is argued to offer particular benefits for children on the autism spectrum, chiefly because it can offer simulations of authentic real-world situations in a carefully controlled and safe environment. Given the real world social difficulties experienced by children on the spectrum, this technology has therefore been argued to offer distinct advantages and benefits for social and life skills training compared to other approaches. Whilst there has been some progress in testing the relevance and applicability of VR for children on the autism spectrum in educational contexts, there remains a significant challenge in developing robust and usable technologies that can really make a difference in real world classrooms. This article considers the evidence that has been published over the past 10 years to assess how the potential of VR has been explored in practice and reflect on the current state-of-the-art in this field.

Keywords: virtual reality; autism spectrum; social skills; learning

Introduction

Because computers offer a context-free environment in which many people with autism feel comfortable, therapists and teachers [can use] virtual reality tools to teach life skills...and social skills (National Autistic Society [NAS UK] 2001)

This quote from the NAS in 2001 illustrates the sense of optimism with which virtual reality technologies (VR or 'virtual environments' (VEs)) were viewed near the start of the new century. Such hopefulness reflected the potential of VR for education and rehabilitation of people with learning, social, cognitive or physical impairments or difficulties identified in the previous decade (e.g. Brown, Cobb, and Eastgate 1995; Cromby, Standen, and Brown 1996; Trepagnier 1999). Interestingly however, and as recently as 2008, authors were still commenting on the *potential* of this technology for autism (e.g. Goodwin 2008; Schmidt and Schmidt 2008) rather than its demonstrated use or effectiveness; thus, potential rather than *realisation* remains the main focus of discussion and published research. However, there might be good reasons for the endurance of optimism regarding the application of VR for

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children on the autism spectrum. This paper examines why (at least some) authors and researchers remain convinced that VEs have something useful to offer these children and evaluates the existing evidence to understand the current state-of-the-art in this field.

VR and autism

VR is a specific type of computer-based technology offering three-dimensional, real-time virtual environments that can be used to simulate real or imaginary environments. These offer advantages for learning and rehearsal of actions and responses in different settings (see Cobb 2007 for more detailed explanation of VEs and their application in education for children with special educational needs). The level of sophistication for interacting with the VE differs depending on the type of software and hardware used – for example, standard desktop computer and input devices (mouse, joystick and keyboard) or VR head-mounted displays that are used to visually 'immerse' users within the VE. The user primarily experiences the virtual world visually with audio feedback, but other types of sensory feedback, such as touch or motion, may also be included.

Early discussions of the potential of VEs for educational purposes noted the powerful intuitive appeal they have for educators, especially for children with special needs, because teachers can imagine the value of learning environments in which content can be controlled and responses/understanding explored in ways that may not be possible in the real world. For example, by allowing wheelchair users '...to see how the world looks from a standing perspective...[and] to take part in activities or visit places that are inaccessible to them in real life' (Cromby, Standen and Brown 1996, 493). Strickland (1996) emphasised the importance of being able to program and control stimuli and to provide safe learning environments in VEs, arguing that these features made them potentially valuable for children on the autism spectrum in particular. The possibility of being able to offer individualised 'treatments', capitalising on children's preferences for visual material, was also considered beneficial.

Trepagnier (1999) further suggested that VR may be particularly helpful for people with cognitive and perceptual impairments (including autism) because the technology can assist in planning, problem-solving and management of behaviour, and offer powerful communicative facilities for people with limited expressive language. In a review of strengths, weaknesses, opportunities and threats of using VR technology for rehabilitation and therapy, Rizzo and Kim (2005) identify a number of qualities of VR that make it suitable for use as a learning resource. These include the facility for stimulus control and consistency as well as cuing to support 'error-free learning'; self-guided exploration and independent practice in a safe test/training environment; use of gaming factors to enhance user motivation to complete tasks; interface modification for individual user needs; and potential for enhanced ecological validity and naturalistic performance measures with real-time performance feedback. Although these are listed as independent features of VR technology, it is likely that it is the collective value that offers unique potential for learning.

Parsons and Mitchell (2002) suggested that VEs could be particularly helpful for people on the autism spectrum because:

(1) the user has active control over their participation;

(2) interaction can take many forms and does not necessitate face-to-face communication (users may communicate via their avatars) which many people with autism might find particularly threatening;

(3) the level and number of non-verbal and verbal features of communication can be directly controlled and manipulated;

(4) behaviours and responses can be practised and built upon in a context that shares some similarities with the real world, thereby offering greater potential for generalisation; and

(5) a more realistic representation of a situation on a computer-screen could, in theory at least, assist with the mental simulation of events, thereby improving social problem-solving.

In more recent reviews, Goodwin (2008) suggests that VR could form the basis of 'sophisticated training packages that are engaging and easy to administer [and which] could promote learning across contexts' (126). Similarly, Schmidt and Schmidt (2008) note the importance of VR in supporting the generalisation of skills and knowledge between contexts, although also note that there is limited research in this area. Thus, overall, there is a convergence of views – at least from these authors – that features of VR may make it especially well suited for supporting the learning of children on the autism spectrum, particularly in the realms of life and social skills, which may be difficult to practise in the real world.

We evaluate below the extent to which the field has made progress in testing the suggested potential and whether there is any evidence that children on the autism spectrum find virtual worlds difficult to use, understand and interpret. We explore the current available evidence regarding where and how the technology has been applied. The findings are grouped into three sections focusing on experiences of using the technologies and outcomes for learning.

Use and understanding of VEs

Early single-user case study applications of VR for children on the autism spectrum (involving one or two participants) demonstrate the use and tolerance of simple interactions and scenes using a range of different displays and input devices (Kijima et al. 1994; Strickland 1996; 1998; Strickland et al. 1996; Brown, Kerr and Eynon 1997; Eynon 1997; Charitos et al. 2000). In all cases, children on the autism spectrum were able to focus on, and interact meaningfully with, the scenes and respond appropriately through the technology. Conclusions from these studies are limited overall due to the small number of children involved, lack of direct evaluation of children's responses and the immersive headsets being experienced as large and heavy by the children (Strickland 1998: 'The available VR helmet weighed approximately 8 pounds', 322). Nevertheless, it is important to note that small-scale, case study approaches are appropriate for exploring the potential of emerging technologies in the early stages, especially for hitherto untested populations. Overall, therefore, these early studies were useful for demonstrating some acceptance and tolerance of the technology by children on the autism spectrum.

The next demonstration of the use of VR for children with autism came from the *AS Interactive* project in the UK. This was a three-year multidisciplinary research project (Parsons et al. 2000) exploring the use of VEs for facilitating social

understanding for higher-functioning children and young people on the autism spectrum. The VEs and learning objectives were designed with the input of teachers working with the participants and so were based on clearly identified needs (Cobb et al. 2002). 'Single-user' VEs (allowing only one person to navigate the scene at any time) of a café and a bus were developed; children viewed the scenes on a standard laptop and used a joystick and mouse as input devices. Participants completed 'training' trials to familiarise them with the set-up before undertaking tasks in a virtual cafe such as finding somewhere to sit and buying a drink. They were also asked a series of questions about the similarities and differences between real and virtual environments. Findings from the first study showed that most of the 12 participants on the autism spectrum (aged 13–18 years) used and interpreted the VE appropriately: they found navigation and interaction with the scene straightforward and correctly identified the VE as something that represented, but was not identical to, reality (Parsons, Mitchell and Leonard 2004).

In a follow-up study (Parsons, Mitchell and Leonard 2005), participants on the autism spectrum (aged 13–18 years; some, but not all, of whom were involved in the previous study) navigated a VE that explored their adherence to social conventions such as avoiding walking across a neighbour's garden and respecting the personal space of people ostensibly engaged in conversation. The majority of participants behaved in a similar way to non-autistic comparison groups by treating the VE like a game in most situations, although were less likely to remark verbally that they would behave differently in real life because it was not socially appropriate to walk through people's gardens, or between people having a conversation. A third of the group of adolescents on the autism spectrum (4 out of 12) showed substantial 'off-task' behaviour, which involved them walking around the café, sometimes even behind the counter, and navigating up to other people in the scene. This behaviour was linked to low verbal IQ and weak executive abilities, suggesting that a minority of students on the autism spectrum may need extra support to complete tasks successfully in VEs.

In a third study, four out of six students on the autism spectrum (aged 14–15 years) improved in their awareness of social conventions following their use of the VE (Mitchell, Parsons and Leonard 2007). Case studies with two adolescents on the autism spectrum also demonstrated that they were able to comment on the social situations in which they would most like a VE in order to practise and understand social intentions and behaviour (Parsons, Leonard and Mitchell 2006). Taken together, the findings from the project suggested that participants on the autism spectrum found the VEs straightforward to use and understood how they could be helpful in facilitating understanding of real-world social situations.

Use of VR for any form of social interaction and/or skill development requires interaction with virtual characters or avatars (virtual representations of a person). One of the challenges for successful design of VR therefore is how these avatars and their role in the environment can be interpreted by children on the autism spectrum. For example, avatars can be used to represent the user, provide feedback or other information to the user, or to populate the environment. David Moore and colleagues in the UK implemented simple VEs for children with autism by testing whether they could understand basic emotions (happy, sad, angry, frightened) as represented by a humanoid avatar (Moore et al. 2005; Fabri and Moore 2005; Fabri, Elzouki and Moore 2007). Results showed that the basic emotions portrayed by the avatars were appropriately understood by children with autism at levels significantly

better than chance, although this finding should be interpreted with some caution given that the study relied on a software questionnaire sent by mail to a sample of participants and the responses of participants were not supervised by a researcher.

More recent work has incorporated highly sophisticated and realistic images of facial expressions into VR systems in order to explore the gaze behaviour of children on the autism spectrum in relation to stimuli of faces (Trepagnier, Sebrechts and Peterson 2002). In addition, 3-D VR stimuli are now being used as the basis for interventions to help children on the autism spectrum attend to meaningful information in the face generally (Trepagnier et al. 2005) and more specifically, to use facial expressions as informative for disambiguating speaker meaning (Grynszpan et al. 2009). These studies have yet to report their findings and it will be very interesting to see whether such approaches can facilitate understanding. It is noteworthy though that the facility for creating photo-realistic and controllable stimuli in VEs is being used to target one of the core impairments of autism, i.e. difficulties in social and emotional understanding. It could be that this area of study holds future promise for educational applications.

A specific feature of VR that may be particularly beneficial for children on the autism spectrum is that it can be used collaboratively. Collaborative virtual environments (CVEs) enable several different users to share and interact with the VE at the same time. Each user is represented in the VE by a virtual character (avatar). They move around the VE independently and, when they are close enough to another user's avatar, they can communicate directly (i.e. talk to each other using a microphone and speaker system). It is therefore possible to use VR for remote peer interaction (i.e. peers are actively working together on a shared task or activity, but are physically separated). This has obvious intuitive appeal for social interaction between children on the autism spectrum who may not necessarily feel comfortable being in physical proximity with others. The question for effective use of CVEs concerns user interpretation and interaction with peers in the virtual environment. Early exploration of CVE usability for young adults with Asperger syndrome as part of the *AS Interactive* project, identified problems relating to technical robustness and lack of willingness of participants to interact with each other (Rutten et al. 2003).

Whilst current research is exploring this form of VR in more detail (e.g. through the COSPATIAL project: http://cospatial.fbk.eu/), related literature provides insight into the use of 'virtual agents' for learning. Bosseler and Massaro (2003) developed a three-dimensional computer-animated talking head (called 'Baldi') that provided realistic and visible speech to help children learn vocabulary. Children on the autism spectrum aged 7–12 years learned new words and generalised the new vocabulary to images and to a structured classroom setting not involving the computer task. A follow-up study (Massaro and Bosseler 2006) showed that the inclusion of 'Baldi' enriched children's learning over and above simply hearing the words spoken. 'Baldi' was not used as an avatar per se but these findings nevertheless suggest that the inclusion of virtual characters in computer-based tasks can facilitate learning for children on the autism spectrum, and so including 3-D characters in virtual environments could be a useful mechanism through which social interactions or conversations could be supported.

A different type of virtual character was used in a case study report by Tartaro and Cassell (2006) with an 8-year-old girl with Asperger syndrome who used a virtual tutor for improving linguistic ability through storytelling. Based on Ryokai,

Vaucelle, and Cassell (2003), this study involved a 'virtual peer' called Sam, which was a life-sized three-dimensional conversational agent designed to look like a child aged about six years. The girl was enthusiastic about Sam and moved her gaze back and forth between Sam and the toys available for the story, suggesting some engagement with the storytelling process. Although the evidence for the use of virtual characters for storytelling is currently limited, the approach offers potential through seeking to address the autistic triad of impairments in social communication, social interaction and imagination.

Different VR displays and media types

The use of different display media for presentation of VR facilitates different user experiences with regard to how much they feel part of, or engaged in, the virtual scene. Mineo et al. (2009) compared the responses of 42 children on the autism spectrum (aged 6–18 years and varying in terms of expressive language ability) to three different electronic media conditions: a self video condition in which the participant saw a video clip of themselves engaged in an activity, an other VR condition in which participants watched a video of someone they knew engaged in the VR activity, and a self VR condition in which the children engaged directly in activities within an 'immersive video'. The authors described this condition as immersive in the sense that the person using the equipment was depicted on the screen interacting with the virtual objects. There was variability in responding across the conditions, but despite this there was still a preference (as expressed through increased vocalisations and longer eye gaze) for the VR conditions compared to the video condition, which did not include VR. Notably, the self VR condition prompted longer gaze durations than the other conditions, suggesting that children were more engaged with this technology (spent longer looking at the screen) than video. As the authors rightly point out however, whether this motivational aspect of VR can be translated into effective instruction and learning remains an open question to be explored.

Wallace et al. (2010) explored the responses of high-functioning adolescents on the autism spectrum to a 'blue room' which shows animations projected onto the walls and ceilings of a screened space. The blue room does not require headsets or goggles to feel perceptually surrounded by the virtual scenes. Participants experienced street, playground and school corridor scenes and were asked to rate their feelings of 'presence' measured by the ITC Sense of Presence Inventory (ITC-SoPI; Lessiter et al. 2001). This is a 44-item self-rated questionnaire developed to measure how involved participants feel when experiencing different media and includes questions about how physically located the participant felt in the virtual environment, how involved the participant felt with the content, how natural the environment felt to the participant and any unpleasant physiological effects that a participant experienced in the virtual environment (e.g. dizziness). Participants on the autism spectrum reported similar ratings on the ITC-SoPI as a typically developing group and no negative sensory experiences; as part of the ITC-SoPI measure they also judged the scenes to have a high ecological validity (i.e. represented things or scenes that were 'life like'). This research is at the very early stages but taken together, these studies appear to support evidence noted above (from the *AS Interactive* project) that participants on the autism spectrum accept virtual environments, in different media, as digital representations of the real world; they do not

find them aversive and viewing themselves within the scene can be a motivating experience.

Generalisation of learning from the virtual to the real world

One of the main arguments proposed for the educational use of VR is its potential for supporting learning between a virtual and the real world, and a few studies have attempted to help children on the autism spectrum learn about and understand real world situations. Strickland et al. (2007) developed desktop VEs to teach fire safety skills to young (three- to six-year-old) children on the autism spectrum. These included recognising the fire danger and responding appropriately i.e. leaving the house swiftly and waiting outside in a predetermined place. Eleven out of the 14 children who took part completed the fire safety VE without error.

Similarly, Self et al. (2007) developed a fire safety and tornado safety VR train-ing program and tested it with eight children on the autism spectrum aged 6–12 years. Although they were able to use the programs reasonably successfully, the responses of the children varied widely and there was limited evidence of unprompted generalisation of understanding to real-world fire and tornado drills. Josman et al. (2008) tested whether VR could be used to teach children on the aut-ism spectrum to cross the road safely. Six children aged 8–16 years were compared to typically developing children matched for age and gender. Findings showed that the children on the autism spectrum could use the VE and improved in their ability to cross a virtual street during the study; three also showed some transfer of this learned knowledge to a real street (carefully supervised).

These studies suggest that children can learn information from VR and some can transfer this knowledge to the real world. However, it should be emphasised that the skills being taught in these studies were procedural and strongly rule-based and did not focus on more inherently unpredictable social skills and situations. There was also variability in responding suggesting that programmes need to be carefully targeted according to the individual abilities of children.

Discussion

For at least some children on the autism spectrum, there appears to be a positive picture overall with regard to their use and understanding of VR technology across varied ability groups and ages. They appear to like using it, can learn new informa-tion (about the real world) from it, and appear to respond to it in a manner that sug-gests that they have an appropriate representational understanding of VEs. They also seem not to find virtual scenes perceptually aversive and indeed show greater engagement with an 'immersive video' display than one without this feature. Of course, these findings are also mediated by the age and ability levels of the partici-pants included, which vary greatly between studies: some focus on higher-function-ing adolescents while others focus on younger less able children. Notwithstanding such variability, there do not seem to be any strong indications from the literature so far that VR is generally unsuitable for children on the autism spectrum.

Nevertheless, the overall scale of the research identified, at least in terms of VR's actual application for educational purposes generally (and supporting social skills specifically), is undeniably limited. Most of the studies tend to be fairly small-scale in nature, with limited extension beyond one or two preliminary

investigations, which can present equivocal results. Although these do offer some positive support for the earlier arguments regarding potential of VR, there is still a considerable challenge in translating this into workable, useful tools that offer realistic applications for everyday classrooms. Part of the reason for this is that VR is an inherently flexible technology; the attractive features of the technology (for example, you can create and control VE content), become design questions (i.e. what should the VE look like? How realistic should it be? How much can you interact with in the virtual world?). Consideration for effective design is further exacerbated by the facility to integrate VR with other digital media and display technology (such as video, photographs and cartoon-like images and animations). The challenge, then, is to design learning applications that provide the most effective combination of the features of VR technology to support the required learning. If successful, Rizzo and Kim (2005) suggest that there is opportunity for VR to become a viable rehabilitation tool that has 'widespread intuitive appeal to the public' as well as 'academic and professional acceptance' (136–7).

Establishing the most effective ways of integrating such features, in ways that are educationally appropriate and useful, are key challenges for the field, not least because scaffolding responses via software may also result in more constrained response options which may, in turn, impact negatively on the role(s) VEs could play in supporting learning of real-world skills. In addition, the skills of any facilitator or teacher will vary and so there needs to be sufficient guidance given about how a program could be used whilst also allowing some scope for greater exploration and innovative application to suit the needs of individuals. We have noted above that VEs appear to be engaging and motivating for some children on the autism spectrum, but translating this into effective platforms for learning is a complex process which is, as yet, significantly underexplored in research terms.

The challenge for successful application of VR is that we should understand how best to use the technology and develop our understanding about how to construct VEs that are meaningful and applicable to the learning needs of users. Multi-disciplinary research teams are therefore likely to be essential if VEs are to make the transition from the realms of niche academia into real-world classrooms (e.g. Beardon, Parsons, and Neale 2001). Such teams need to include close involvement of teachers and students throughout the development and testing of the technologies. Notably, two large projects currently underway (2009–12) are employing this strategy (COSPATIAL: http://cospatial.fbk.eu/; and ECHOES II: http://echoes2.org/). It is too early for these projects to report on implementation and outcomes of the technologies being used (both including VR) and so we await with interest their findings in due course. Nevertheless, the fact that both teams incorporate expertise in computer science, design, education, and psychology as well as strong user involvement in prototype development and testing highlights the recognised importance of such an approach.

Conclusions and future directions

Despite limited research and wide variability in participant samples, technology used, study design and reporting of the results, the evidence does suggest that VR is an applicable technology with unique potential for children on the autism spectrum. However, we still need to understand how to use the features of VR to best support learning. Future projects could pursue many avenues of enquiry and here we note two main ones that arise through consideration of the published literature

to date. Firstly, there are questions about the nature of the representation itself i.e. to what extent do 3-D images, and the capability of moving around 3-D space, matter for helping children to learn, and in supporting transfer of learning between virtual and real contexts? The assumption is that the more realistic a virtual environment the greater chance of promoting generalisation because the scene is more 'believable' (cf. Wages, Grunvogel and Grutzmacher 2004) and therefore, skills and understanding are more likely to be transferred from the virtual to the real world.

Given the known cognitive, sensory and perceptual differences and difficulties experienced by many people on the autism spectrum it could be that the realistic nature of 3-D scenes is less important because they may not be perceived in the same way as by typically developing children. For example, children on the autism spectrum tend to look at different aspects of a visual array compared to typically developing participants (e.g. Klin et al. 2002), often focusing on visual detail or 'parts' rather than the 'whole' (e.g. Happe 1996). This could mean that representational 'fidelity' is less important or valuable for children on the autism spectrum in helping them to learn the links between virtual and real-world contexts. These are open questions however; it could be that 3-D representational fidelity is important for children on the autism spectrum, perhaps because it can fill in some of the details that imaginative abilities may be unable to.

Second are questions regarding the special and unique affordances of these (and other) technologies for supporting learning for children on the autism spectrum. Specifically, it is important to test and understand the features of the technology that allow experiences and interactions that would not be possible through other means. Representational fidelity and the 3-D qualities of VR are included in these affordances (Dalgarno and Lee 2010), but so too are levels and types of interaction as well as the possibility for collaboration with others in the same virtual space. As argued by Parsons, Leonard and Mitchell (2006) CVEs are an 'aspirational goal' for the development of VEs (203) because they offer more flexible and dynamic interaction opportunities for users as well as the opportunity to collaborate on tasks which can '...foster positive interdependence within a learning group' (Dalgarno and Lee 2010, 22).

Moreover, they offer the possibility for perspective taking (Parsons, Leonard and Mitchell 2006), which is known to be a core cognitive difficulty for people on the autism spectrum (i.e. understanding that others have their own perspectives on the world and these may be at odds with your own) – that is, CVEs can allow enacted responses to be recorded and replayed in 'real time' from the perspectives of different users in the environment, thereby allowing scenes and interactions to be (re)viewed and reflected upon from different user perspectives. This is a unique affordance of CVEs that has yet to be tested out but, in theory at least, could have an interesting role in supporting children to understand concepts underpinning 'theory of mind' abilities.

Overall, then, we remain convinced that there is much potential in the use of VR technologies for autism, but this potential – despite much positive rhetoric and discussion – remains substantially under-explored in research terms. In searching the evidence we have been surprised by the limited empirical research in this area in recent years (although note that there are more projects currently away and possibly many others that have not yet made it into the published research literature). Ultimately, children benefit if there is well-researched evidence-based practice to

implement at home, in school and beyond with a range of interesting, flexible and accessible tools and approaches. VR could still offer one such tool given suitable investment in time and expertise.

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