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Authenticity in Virtual Reality for assessment and intervention in Autism:

A Conceptual Review

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Abstract

Virtual Reality (VR) technologies have shown potential for learning and assessment for children, adolescents, and adults with autism. Much of the research in this area has taken a conceptual stance of veridicality; that is, that VR offers promise because it can provide authenticity and levels of realism alongside stimulus or environmental control, or both, which may first facilitate learning and the generalization of skills to the real world, and secondly can provide experimental contexts with strong ecological validity for assessment. This conceptual review raises questions about the assumption of veridicality of VR for autism research by examining research literature that has used VR to support learning and to investigate social responding. In so doing, it provides a framework for examining the assumed relationship between virtual and real contexts in order to highlight particular features of design and interaction, as well as background characteristics of participants, that may help or hinder learning and understanding in VEs. The conclusions suggest there is a need for the field to systematically examine the different factors that influence responding in VR in order to understand when, and under what circumstances, the responses of individuals with autism can be considered appropriately authentic. There are also opportunities for thinking more radically about research directions through focusing on the strengths and preferences of people with autism, and promoting more participatory and inclusive approaches to research.

Keywords: Virtual Reality; autism; education; assessment; interactive technologies.

1. Introduction

With the acquisition of the Oculus Rift headset by Facebook in 2014, Virtual Reality (VR) technologies have once again been making news headlines. Facebook Founder and CEO, Mark Zuckerberg, claims that 'Virtual Reality will change our lives' (Blunden, 2016). More specifically, Albert 'Skip' Rizzo, Director for Medical Virtual Reality at the Institute for Creative Technologies at USC Davis, argues that the new, lightweight, and inexpensive headset could be 'transformative' for rehabilitation, educators, and psychologists (Robertson & Zelenko, nd), because VR can provide access to highly realistic, and motivating online contexts and experiences for learning and assessment. Such enthusiasm echoes that of researchers considering the potential of VR well over a decade ago for studying and supporting social interactions (e.g. Blascovich et al., 2002).

Fundamental to understanding human behaviour, such studies usually present the dilemma of trading experimental control in the laboratory setting with real world ecological validity. However, VR technologies have the potential to avoid this trade-off, providing both experimental control and realistic scenarios with good ecological validity. As a consequence, VR technologies have been argued to offer particular promise for supporting learning for children and adults with autism who may find social interactions difficult or may respond differently to 'typical' social overtures. Indeed, the majority of published interventions in autism educational research are targeted at social-communicative difficulties (Parsons et al., 2011), underscoring why VR may have particular application for this group. However, despite nearly twenty years of research, the potential of VR for autism education still remains an aspiration rather than a reality. This paper provides a conceptual review of the field and argues that a rethink may be needed about paradigmatic assumptions regarding the role of VR technologies for assessment and intervention in autism research.

1.2 Potential of VR for Investigating Social Interaction

Blascovich and colleagues (2002) argue that immersive virtual environment technology (IVET) could transform the study of social behaviours through being able to carefully control and simulate different aspects of social interactions. They suggest that IVET would enable researchers to determine 'the critical aspects of successful and unsuccessful social interactions' (p. 121), because the technology provides experimental control in ecologically valid, and replicable contexts. Underpinning these claims of transformation lies the fundamental assumption of veridicality; *viz*. that the experiences within VR technologies are authentic and realistic such that people will behave and respond in a similar way in virtual worlds as they do in the real world, thereby enabling generalization from the former to the latter (Yee, Bailenson, Urbanek, Chang, & Merget, 2007).

People with an Autism Spectrum Disorder (ASD) comprise a large group of users for whom VR has been argued to be of especial interest (e.g. Parsons & Mitchell, 2002). According to the most recent definition (American Psychiatric Association (APA), 2013), ASD is diagnosed on the basis of pervasive difficulties with social communication and interaction, coupled with restrictive, repetitive, and stereotyped behaviours. Approximately one in 100 children in the UK (Baird et al., 2006), and one in 68 (Baio, 2014) in the US receive a diagnosis of ASD, and the personal and familial impacts of an autism diagnosis are significant. For example, despite over thirty years of intervention research, the social, economic, employment, and accommodation-related outcomes for adults on the autism spectrum remain poor (Billstedt, Gillberg, & Gillberg, 2005; Eaves & Ho, 2008; Howlin, Goode, Hutton, & Rutter, 2004). Consequently, finding more effective ways to educate and support individuals with autism to improve outcomes and decrease reliance on specialist provision remains a research priority for individuals and their families (de Bruin, Deppeler, Moore, & Diamond, 2013; Pellicano, Dinsmore, & Charman, 2014).

There are many research reviews of the field (see Table 1 for a summary): some focusing on interactive technologies in general, but not VR (e.g. Boisvert, Lang, Andrianopoulos, & Boscardin, 2010; Ramdoss et al., 2011, 2012; Shane et al., 2012); others including VR alongside a range of interactive technologies (Grynszpan, Weiss, Perez-Diaz, & Gal, 2014; Ploog, Scharf, Nelson, & Brooks, 2013; Reed, Hyman, & Hirst, 2011;Wainer & Ingersoll, 2011; Wass & Porayska-Pomsta, 2014), and others focusing on VR technologies specifically (Bellani, Fornasari, Chittaro, & Brambilla, 2011; Georgescu, Kuzmanovic, Roth, Bente, & Vogeley, 2014; Parsons & Cobb, 2011; Rajendran, 2013). All suggest that technologies have valuable potential for helping to meet this research priority in relation to education and assessment for children and adults with ASD. Indeed, there is some evidence (discussed further below) that VR can provide an effective platform within which social interactions and communication of individuals with ASD can be controlled, explored, examined, and supported. However, existing educational technology reviews (Table 1) have mostly reported on the effectiveness of technologies for supporting learning outcomes, regularly reporting similar limitations in the evidence base as a result of small sample sizes and research design weaknesses. Therefore, another review that considers effectiveness would not contribute much new knowledge to the field. Instead, this paper aims to take a different perspective and argues that the fundamental assumption of veridicality of VR technologies in terms of recreating authentic assessment and learning contexts for people with autism may be open to question. Given the renewed interest in VR technologies, it is timely to revisit this fundamental assumption with a view to shaping the future research directions in this area.

Insert Table 1 about here

1.3 Virtual Reality as a Powerful Methodological Tool

Blascovich and colleagues (2002) propose that immersive VR technologies offer considerable promise to researchers by overcoming longstanding threats to reliability and validity in social research. They define a virtual environment (VE) as 'synthetic sensory information that leads to perceptions of environments and their contents as if they were not synthetic' (p. 105); in other words, the person using the VE has a psychological sense of the representational reality of the experience. In addition, Blascovich et al. (2002) define an immersive VE (IVE) as:

> one that perceptually surrounds the individual. Immersion in such an environment is characterized as a psychological state in which the individual perceives himself or herself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli. (p. 105)

According to Blascovich et al. (2002), these qualities, or affordances, of IVEs mean that the challenge of authentically (re)creating ecologically valid contexts in which human behaviour can be studied can be substantially overcome, *viz*: 3D scenarios and contexts approximating 'real life' can be created; these identical scenes can be experienced by multiple users without necessarily a feeling of pretence or artificiality; collaborative VEs can support the interaction of multiple users (participants, researchers, and confederates) at the same time, and so social interactions can be manipulated and studied; experimental conditions can be replicated for different studies with high fidelity; and participants can be more easily randomly assigned to conditions of the experiment, thereby improving generalizability. The combination of controlled conditions with high ecological validity within VR therefore offers a very powerful tool with which to study human behaviours in real time, dynamic interactions. Although Blascovich et al. (2002) specifically discuss immersive VEs, the affordances noted here could apply equally to non-immersive VEs (such as those presented on desktop or laptop computers). While the degree of immersion may differ between mode of presentation and this may influence the sense of presence that users experience (see below), the fundamental ideas underpinning this review could apply to any hardware configuration that allows users to engage with 3-D VEs.

The purpose of this article is not to review the substantial research in VR that has taken place to explore such interactions. Nevertheless, it is important to emphasize that real world social conventions and behaviours are regularly anticipated, and imported, within interactions in VEs by many different groups of users (Bailenson, Blascovich, Beall, & Loomis, 2003; Parsons, Bowerly, Buckwalter, & Rizzo, 2007; Slater, 2009; Schroeder, 2002; Yee et al., 2007). However, it is also well-established that such expectations and implementation of behaviours are influenced by the individual characteristics of the users, as well as specific features of the technology, and how information is displayed and interacted with. For example, responses in VR are known to be influenced *inter alia* by the personality characteristics of the user (Alsina-Jurnet & Gutiérrez-Maldonado, 2010; Hammick & Lee, 2014; Sacau, Laarni, & Hartmann, 2008); their prior experience of technology (Richardson, Powers, & Bousquet, 2011), their familiarity with the interface (Waller, 2000), and their expectations of the technology (Garau, Slater, Pertaub, & Razzaque, 2005). Indeed, Waller (2000, p. 316) concludes that the scale of individual differences shown in responses within a VE ‘are large enough to be worthy of careful scientific scrutiny’.

1.4 Sense of presence: the importance of ‘being there’

These individual and technological factors contribute to the extent to which users feel a sense of ‘presence’ within the VE, that is, ‘the sense of being caught up in the representations of virtual worlds’ (Jacobson, 2001, p. 653). There is a substantial literature that discusses, explores, and critiques the concept of presence that is beyond the scope of this article, but there is broad agreement that presence is fundamental to how VEs are experienced and, therefore, whether and how behaviours and interactions take place (Riva, Waterworth, & Murray, 2014; Sanchez-Vives & Slater, 2005). For example, Fox, Christy, and Vang (2014) discuss the factors that influence the extent to which individuals experience presence in VEs to the point that they are persuaded by their content, providing examples from health, education, advertising, and work collaboration. The extent to which someone is persuaded by their experiences in VEs depends on the degree of involvement or engagement that they feel with the content (Boucenna et al., 2014; Witmer, Jerome, & Singer, 2005). Consequently, levels of engagement are ‘inextricably linked with instructional power’ (Mineo, Ziegler, Gill, & Salkin 2009; p. 185) and, therefore, the likely success of a VE for supporting learning and intervention (Mikropoulos & Natsis, 2011).

In addition to the characteristics of the users, features of the technology contribute to the sense of presence and are known to influence how participants respond and behave within VEs (Bente, Rüggenberg, Krämer, & Eschenburg, 2008). These features include the virtual characters (avatars) within the VE: how anthropomorphic they are; their behavioural realism; the interaction between these two features (Nowak & Biocca, 2003; Georgescu et al., 2014; Vinayagamoorthy, Steed, & Slater, 2005); and whether the other characters encountered in a VE are controlled by humans (human-avatars) or by computers (agent-avatars) (Blascovich et al., 2002; Nowak, 2004). Other features are: how the user interacts with the VE, for example through a joystick, head-mounted device, or desktop computer (Mikropoulos & Natsis, 2011; Santos et al., 2009); and the sense of agency that is experienced by participants as a product of these technology features (Riva, Banos, Botella, Wiederhold, & Gaggioli, 2012). Indeed, Riva and Mantovani (2014) emphasize that presence and agency are directly related within experiences of using VEs such that: 'presence is a core neuropsychological phenomenon whose goal is to produce a sense of agency and control: I am present in a real or virtual space if I manage to put my intentions into action (enacting them)' (p. 10). Consequently, judgements about, or behavioural indicators of, presence are vital for understanding whether a particular form of media has the potential for supporting realistic actions and influencing future behaviours, i.e. can be useful as a basis for promoting memorable experiences (Sylaiou et al., 2013) and encouraging learning (e.g. Mikropoulos & Natsis, 2011; So & Brush, 2008).

The assumed veridical nature of the relationship between real and virtual behaviours and experiences, as well as strong stimulus control within VEs, has prompted researchers to use VR technologies for physical and psychological educational intervention and rehabilitation, with success: for example, for people with motor disabilities to practise physical movements (Holden, 2005); in psychotherapy for phobias and social anxiety (Gega, White, Clarke, Turner, & Fowler, 2013; Riva, 2005); for treatment of symptoms of psychosis (Freeman, 2008); for patients following a stroke (Weiss, Naveh, & Katz, 2003); and for daily living, cognitive, and social skills of people with intellectual disabilities (Standen & Brown, 2005). Consequently, there is evidence that VEs can, and do, represent authentic, realistic, and plausible scenarios and social encounters that both reflect and support real world conventions, understanding and behaviours for a range of different user groups (cf. Blascovich et al., 2002).

1.5 Virtual Reality Technologies and ASD

It is perhaps not surprising that the promise of veridicality of VEs has proved alluring for research in the field of ASD. Given the core diagnostic impairments of social communication and interaction (APA, 2013), and the substantial impacts of the disorder, authors have suggested that VR technologies have significant potential for assessment, training and education for individuals with autism (Goodwin, 2008; Parsons & Mitchell, 2002; Trepagnier, 1999), precisely because social scenarios and encounters can be carefully designed and controlled. Indeed, in reviewing research that has explored the use of VR for individuals with autism, Bellani et al. (2011) use a definition of VR that assumes veridicality, while also emphasizing stimulus control (emphasis added): 'VR is *a simulation of the real world* based on computer graphics [which] can be useful as it allows instructors and therapists to offer a safe, repeatable and diversifiable environment during learning' (p. 235). Similarly, Parsons and Mitchell (2002) suggest that VEs might be particularly useful for the field of autism research because of the capacity for role play: 'responses can be practised in realistic settings in the absence of potentially threatening and frightening real-world consequences' (p. 438).

However, Parsons and Cobb's (2011) review of the field raised two important questions that relate to the assumption of veridicality: (1) '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?' and (2) '…what are the special and unique affordances of these [VR]…technologies for supporting learning for children on the autism spectrum?' (p. 363). They concluded that there is a need to consider these aspects more directly, and in more detail, if we are '…to understand how to use the features of VR to best support learning' (Parsons & Cobb, 2011; p.362). This review offers a framework below for making more explicit the assumed relationship between virtual and real contexts in order to highlight particular features of design and interaction, as well as background characteristics of participants, that may help or hinder learning and understanding in VEs.

2. Approach to the inclusion of literature in the review

The approach to this review is conceptual rather than systematic. While the former does not preclude the latter there are different ways of synthesising research literature according to the aims and objectives of the review. Here, the claim, and indeed the aim, is not for this to be an exhaustive review of literature relating to VR and autism; as noted above, other reviews of the field exist, all based on different approaches to the inclusion of literature including systematic methodologies, and mostly focused on outcomes, effectiveness, or quality of the research (Table 1). While these reviews provide particular insights, not every review needs to be systematic to be useful (Petticrew & Roberts, 2008). Instead, this review contributes new knowledge by following similar approaches to others (e.g. Boucenna et al., 2014; Georgescu et al., 2014; Parsons & Cobb, 2002; Parsons & Cobb, 2011; Rajendran, 2013) in raising specific issues for this field of enquiry, using a range of evidence to make conceptual links between autism- and non-autism-focused research to illustrate the question of veridicality. Inevitably, there are limitations to this approach, not least the critique of bias and favourable selection of articles. However, my bias is explicit and critical, and can be judged accordingly by peers *viz.* I think there is an issue of importance that needs to be considered and addressed by the field and I present evidence below to illustrate why.

Of course, the inclusion of papers is not random. Parsons and Cobb (2011) included a range of international literature in their state-of-the-art review, focusing on psycho-educational approaches to investigating the application of VR technologies within the social communication domain for people with ASD. The evidence base discussed below uses Parsons and Cobb (2011) as its starting point, and extends their enquiry with a view to provide evidence specifically relating to their questions noted above. Major bibliographic databases were searched for papers published since the Parsons and Cobb (2011) review using 'autism AND virtual reality' and 'autism AND virtual environments' as the main search terms. Included papers focus on social responses, communication and interpretation, rather than non-social skills or processes (where ecological validity has been directly investigated e.g. neuropsychological assessment of attention and memory; Parsons, 2015). They are intended to be illustrative (rather than exhaustive) of key issues, are peer-reviewed, and published in English.

3. Main themes and discussion

The affordances of veridicality offered by VEs have been pursued in two main ways in the autism field: first, as a way of creating synthetic but realistic social scenarios in order to provide supportive contexts for learning and intervention that may support participants in transferring knowledge and skills to the real world; and secondly, as a way of providing authentic and well-controlled contexts in which social responding can be assessed and monitored, with a view to understanding the nature of core perceptual, neurological, and cognitive differences in autism. In both cases, VEs are assumed to be veridical in that they can be used either as a bridge to the real world or as a truthful stimulus to prompt and reproduce real world responding, respectively. Each of these categories is examined in turn below.

3.1 VEs as a bridge to the real world: for learning and intervention

By focusing on the ability to recreate authentic scenarios in which skills can be learned and practised, researchers have designed VEs for rehearsing specific interactions and responses that may be difficult to practise in other ways. For example, researchers have developed: café and bus VEs to explore and support social behaviours and understanding (Mitchell, Parsons & Leonard, 2007; Parsons, Mitchell, & Leonard, 2004, 2005); a street-crossing VE to develop road safety skills and knowledge (Josman, Ben-Chaim, Friedrich, & Weiss, 2008); VEs for fire and tornado safety drills (Self, Scudder, Weheba & Crumrine, 2007); a range of social VE scenarios (e.g. job interview, celebrating with a friends, meeting strangers or friends) to assess and support social cognition (Kandalaft, Didehbani, Krawczyk, Allen, & Chapman, 2013); a virtual classroom for practising public speaking (Jarrold et al., 2013); a virtual school (playground and classroom) and house party to practise social interaction and conversation (Ke & Im, 2013); and bespoke scenarios (e.g. shopping, buses, and trains) to reduce anxiety (Maskey, Lowry, Rodgers, McConachie, & Parr, 2014). There are some promising results from these studies with regard to showing changes or improvements in participants' responses after a period of use, and some evidence of learning new skills and knowledge that is then applied to real world contexts (see Table 2 for a summary).

Insert Table 2 about here

However, state-of-the-art reviews of the field (see Table 1) suggest that the evidence base regarding the application of VR to support learning and understanding for children and young adults with ASD remains limited and small-scale overall (Boucenna et al., 2014; Parsons & Cobb, 2011). Indeed, in their meta-analysis of interactive technologies for autism (including VR) Grynszpan et al. (2014, p. 358) conclude that 'there is still little evidence supporting the efficacy of this [VR] technology'. Given the strong rationale for why VR might be especially valuable for people with ASD, coupled with the evidence that VR can be highly effective in learning and rehabilitation for other groups, as noted earlier, this position seems somewhat surprising (Parsons & Cobb, 2011). However, the heterogeneity of responding by participants may be one of the reasons why, as yet, there is a lack of convincing evidence about actual, rather than potential, effectiveness and this is explored in the following section.

3.1.1 Influence of background characteristics on responding. The studies cited above and summarised in Table 2 report substantial variability in the responding of their participants, as well as different influences from background characteristics. For example, Parsons et al. (2004) report that their participants with lower verbal abilities were much more likely than participants with higher verbal IQs to take a navigational path between two agent-avatars in a virtual café, suggesting a lack of consideration or understanding of the social convention of personal space. Mitchell et al. (2007) report that three of their six participants showed demonstrable gains in understanding social conventions following periods of VE experience and instruction, while three participants did not. Two of the three participants who showed the strongest development in understanding had the lowest verbal IQs, suggesting that failure to demonstrate learning was not simply a function of general ability. Ke and Im (2013) also report highly individualized responding by their four participants to VE scenarios, despite all being high-functioning and of similar age (9–10 years), concluding that: 'The same social interaction tasks, scenarios, or scaffolding strategies can retrieve different communication performance from individual target children' (p. 459).

Josman et al. (2008), in their VE street-crossing study, report that the ability to use a VE is not related to age or severity of autism characteristics. Nevertheless, only three of the six participants showed a transfer of learning from the VE to a real world simulation and the authors note that: ‘There was considerable variation… in the level of intervention needed by the different participants’ (p. 53). In Kandalaft et al.’s (2013) study, while there was an overall improvement on various measures from pre- to post-intervention for their eight young adult participants, this was not the case for all participants or for all measures. Crucially, in Jarrold et al.’s (2013) study exploring a public speaking task in a classroom VE, findings showed that responses to agent-avatars in the VE were moderated by individual characteristics relating to ADHD symptoms, IQ, and measures of social anxiety. Specifically, participants (all with high-functioning ASD, HFASD) with higher social anxiety and higher scores on ADHD symptoms were the most likely to show atypical patterns in social attention. That is, compared to (typically developing) TD participants, those with ASD were much less likely to look towards the virtual characters in the classroom that were in their direct line of sight when undertaking the public speaking task. These findings highlight the heterogeneity of responding in samples of participants with ASD, as well as the potentially influential factors of background characteristics that impact on the responses observed when using VEs and interacting with characters in the scenes. Indeed, Jarrold et al. (2013, p. 13) conclude that there is a:

> need to anticipate heterogeneity, and examine its correlates in studies of children with ASD, especially children with HFASD. The data in this study stress the need to resist the temptation to design and interpret research as though children with HFASD children can be described as one homogeneous group with respect to some putative strength or impairment.

Similarly, Parsons et al. (2005) showed that ‘off-task’ behaviour in the VE activities by some adolescents with ASD was linked to a combination of lower verbal ability and weaker executive function, as measured by standardized tasks. Related evidence from Hopkins et al. (2011) also found that lower-functioning children with autism (with lower verbal abilities) respond differently from higher-functioning children. This difference was in terms of outcome measures assessing whether a VE intervention that was focused on facial expressions supported improved understanding and recognition of facial stimuli, based on photographs and drawings. The lower-functioning children showed improvement in response to photographs of faces, but not to drawings of faces, while the more able children showed improved understanding of both types of stimuli. It could be that the less able children interpreted the VE scenes in a different way, or were less able to make the links between the representations in the VE and the more schematic drawn images (with reduced photorealism), or simply that they did not look so long at the drawings. In other words, it is not possible to separate whether the learning through the VE was different and less generalized for the lower-functioning children because of either their experiences of the VE or their learning difficulties, or whether they responded differently on outcome measures due to differences in the nature of the stimuli (see, for example, Riby & Hancock, 2009). The nature of the stimuli is important, because it is used both as an indicator of learning outcomes, in some studies (e.g. Hopkins et al., 2011), and as a measure of social engagement that is used as a basis for assessment and intervention (see below).

3.1.2 Influence of technology-related features on responding. As noted in Section 2, Parsons and Cobb (2011) suggest that there are important aspects of VEs and participants' interaction with them that have remained underexplored and need to be examined systematically in order to gain a better understanding of how best to design VEs to support learning more effectively. Specifically, Parsons and Cobb (2011) argue that the appeal of VR technologies in being able to design them in whatever way we want, and to control specific features, also makes them highly challenging because there are so many degrees of freedom over which the presentation and experience of VEs can vary. They suggest that two of the main areas that need to be explored are the realism (behavioural, representational) of the VEs, and how or with whom interactions are supported, i.e. the technological features relating to how collaboration with others (human-avatars) can be achieved in a VE.

These suggestions align strongly with the two core factors of IVEs that Blascovich et al. (2002) argue are central to how social influence in VEs could be studied and experimentally manipulated *viz*: behavioural realism and social presence. Blascovich et al. (2002) describe behavioural realism as the ‘degree to which virtual humans and other objects within IVEs behave as they would in the physical world’ (p. 111). This includes photographic realism (representational fidelity) but, more crucially, the extent to which believable and authentic verbal and non-verbal responses can be exchanged between users of the technology. Social presence refers to the extent to which a participant using the technology ‘believes that he or she is in the presence of and interacting with another veritable human being and that the behaviors of virtual humans within IVEs represent the actions of real individuals in the physical world in real time’ (pp. 111-112).

The extent to which these features influence social responding in VEs are argued also to be moderated by the extent to which the scenario or response is perceived as relevant to the individual, and the level of behavioural responding required (Blascovich et al., 2002); that is, individual characteristics of users. As noted earlier, there is good evidence that individual as well as technology-specific factors relating to behavioural realism and social presence influence the responses of participants without autism in VEs. Thus, the nature of the stimuli, tasks, and hardware (such as input devices) involved in VR studies for autism are also likely to influence the responding of participants with ASD.

Some evidence for this comes from Mineo et al. (2009), who reports very variable responses in her study examining the engagement of participants with ASD with different forms of electronic screen media. Specifically, she compared gaze duration and vocalization of participants to animated videos, videos of the self, a video of a familiar person using a VR game, and immersion of the self in a VR game. Participants were aged 6–18 years and varied in terms of their expressive and receptive communication capabilities. Although there was a general trend for participants in the self-VR condition to gaze longer at the screen and for those in the other-VR condition to make more vocalizations, overall the responses highlighted the heterogeneity of responding across the groups; there was no straightforward mapping between the different electronic media and the responses or backgrounds of participants. This emphasizes that the heterogeneity of people with ASD extends to different preferences for forms of media. Therefore, it is evident that the specific form of media being used as a stimulus in studies with participants with ASD should always be taken into account when interpreting responses. It is surprising, then, that such considerations do not seem to feature in most VR studies involving participants with ASD.

The challenge, as Parsons and Cobb (2011) imply, is that little attention has so far been paid to whether such factors actually make a difference to responses of participants with ASD. For example, the majority of the VR studies focusing on participants with autism (see Tables 2 and 3) have involved agent-avatars rather than human-avatars. According to Blascovich et al. (2002), the type of avatar can impact on whether a user feels social presence within the VE and, therefore, the extent to which any social influence on behavioural responding may occur.

Although limited, there is evidence to suggest that knowledge about whether a virtual character is an agent or a human does indeed influence the responses of participants with ASD. For example, Parsons and colleagues (2005, 2006) examined whether adolescents with ASD adhered to social conventions in VEs by observing and then questioning the behaviours shown while using the (single-user) VE involving agent-avatars. On some occasions participants made a strong link between the VE and real world social conventions, but at other times rejected a link because the scene was not real. For example, one student said he did not walk across the grass of a neighbours' garden in the virtual scene because he might get his shoes muddy; but he walked between two people having a conversation in the café because they 'weren't real' and 'it didn't matter' (Parsons et al., 2005). Another student chose to sit on the front seat of a virtual bus because there was plenty of legroom, but said the people in the scene in the VE were 'blocky' and 'had no personalities', so it did not really matter how you behaved (Parsons, Leonard, & Mitchell, 2006).

In contrast to the studies involving agent-avatars, Kandalaft et al. (2013) and Ke and Im (2013) included human-avatars in their VEs. Both studies used collaborative VEs (CVEs), built in Second Life, where other researchers or teachers acted as confederates in the virtual interactions via human-avatars. Inferences from behavioural observations suggest that participants responded socially to the human-avatars, taking part in role plays (Ke & Im, 2013) and reported that the intervention gave them greater confidence in social situations (Kandalaft et al., 2013). Kandalaft et al. (2013) also report anecdotally that some of the demonstrated real life social difficulties of their young adult participants were imported into encounters in the CVE, suggesting in that sense that the CVE scenarios were veridical (though this was not investigated or observed directly).

However, not revealed in the literature are details concerning features of the avatars that can influence behavioural realism and social presence, such as the contingency of gaze and non-verbal features (e.g. head nodding) of the avatar in response to the participant, and the different types of non-verbal body gestures shown by the avatars (cf. Georgescu et al., 2014; Vinayagamoorthy et al., 2005). In addition, participants were not asked direct questions about the extent to which they felt their interactions were ‘real’ or not, and so it is not possible to know whether different scenes or characters were experienced or interpreted differently on the basis of different features of the tasks, scenarios, or characteristics of the avatars.

Other studies investigating the application of CVEs for autism are few in number, not least because some of those claiming to investigate CVEs had looked at single-user VEs using animated, pre-programmed characters rather than human-avatars (e.g. Moore, Cheng, McGrath, & Powell, 2005). One of the exceptions is a pilot study by Cheng and Ye (2010) involving three participants with ASD (aged 7–8 years) using a CVE with a teacher role playing one of the avatars. The children were asked to watch pre-programmed animated scenes relating to a classroom or an outdoor scene and to answer questions about them using text-communication, speech, or non-verbal facial expressions via their ‘expressive avatars’ (p. 1069). Although the technology was collaborative, given that a teacher could play another character in the scenario, there was very limited interaction in the sense that the teacher’s role involved reading and asking questions from a script to which the child could respond (as above). The participants appeared to gain some benefit from being supported to use the CVE over a period of weeks, but the scripts and the nature of the scenarios or tasks are not described in the paper, and the teacher’s avatar did not seem to be able to vary in its non-verbal gestures and communication. Consequently, the extent to which this study provides an insight into the interactions between a child with an ASD and a human-avatar is limited.

By contrast, Schmidt, Laffey, Schmidt, Wang, & Stichter's study (2012) resulted in one of the few published papers in the field that specifically aimed to investigate the detailed interaction between users in a CVE, as well as between the behaviour of users and particular features of the technology. Four participants with ASD, aged 11–14 and in the average ability range, took part in a pilot study where their interactions with the technology, as well as their verbal responses, were carefully analysed and mapped with a focus on reciprocal social interaction. The CVE was built in a virtual lighthouse in which the four participants could interact with each other to discuss social competence and negotiate group norms. Each participant sat in a different room at a laptop computer, alongside a facilitator, and communicated with the others with microphone headsets. Interaction with the CVE, and each other, could be achieved via speech, text chat, or the gestures and movements of the avatars. The findings showed that different activities produced different responses from participants, sometimes only verbal and at other times verbal + movement + gesture. In addition, there was considerable variability in responding between participants.

The findings highlight the complexity and variability in how and when different behaviours occur in CVEs in the context of specific tasks. As the authors themselves note, this was a pilot study and so there are many further questions to be explored, including how structure and different features could be designed into the CVE scenarios potentially to influence behaviours and, therefore, learning outcomes. In a formal evaluation of the system used for distance learning, Stichter, Laffey, Galyen, and Herzog (2014) report good acceptability of the CVE by parents and students, but few instances of successful learning outcomes relating to social judgements of others' perspectives, and facial features and expressions in the group of 11 participants with ASD. However, the group-based analyses coupled with the sample size and variability in responding mean that effect sizes would need to be large in order to be detected. Nevertheless, it is feasible that how participants interacted with the content of the CVEs, the extent to which they felt present within the interactions, and the specific nature of the stimuli used to assess learning outcomes may have influenced their responding in important but, as yet, unexplored ways.

3.1.3 Conclusions about using VEs for learning and intervention. Overall, this section highlights that the development and application of VEs to support practise, learning, and understanding of 'real world' behaviours for children and adolescents or young adults with ASD, is influenced or mediated by various factors. These include technology-related factors such as the nature of the stimuli used (e.g. whether they are more cartoon-like or more photorealistic); the tasks being undertaken and how they relate to personal motivation or interests and different ways of interacting (e.g. text and speech); whether the virtual characters are known to be agent- or human-avatars; and the particular type of electronic media being used (e.g. whether this involves the self or others interacting with a virtual scene). Moreover, individual characteristics of the users influence responses in VEs including verbal ability, executive functioning, severity of autism characteristics, a comorbid diagnosis of ADHD, and level of social anxiety. Although the total number of studies seeking to apply VEs for learning and intervention is small overall, they all show variability in responding among participants, suggesting that there are individual preferences and characteristics that influence behaviours shown in VEs. In addition, most studies involve participants who are described as high-functioning, and so the variability in responding is likely to be under-represented by the current literature because participants with ASD and intellectual impairments tend to be excluded. In short, there is no easily identifiable association between types of features (of the technology and the individuals taking part) and the extent to which responses may or may not support real world behaviours or understanding. Consequently, there remain many questions about how VE technologies could or should be designed and developed in order for them to act as a reliable bridge between virtual and real world experiences.

3.2 VEs as mirrors for reflecting and assessing real world social behaviours.

Notwithstanding these questions about the application of VR for learning and intervention, researchers have used VEs as a way of providing strong experimental control in which the social responses of people with ASD can be assessed and manipulated as a way of trying to understand aetiological and consequential factors of the social difficulties in autism that are central to the diagnosis (APA, 2013), and intervene accordingly. Much of the research in this category has focused specifically on the role of eye gaze, and the interpretation of facial stimuli more broadly (examples are summarised in Table 3). This has been based on the theory that abnormalities in joint attention mechanisms and affective engagement (Hobson, 2004) in infancy may lead to differences in how social information is processed, interpreted, and experienced. In turn, this may result in some of the core difficulties in social behaviour and understanding seen in autism (Mundy & Crowson, 1997). An important corollary for educational intervention, therefore, is that supporting children to look at the faces, and the eye region in particular, of other people during social interactions could improve social responding and understanding of children with ASD.

Differences in how participants with ASD look at the eyes and faces of other people, compared to people without ASD, are well-established in the literature. For example, Klin, Jones, Schultz, Volkmar, and Cohen (2002) used eye-tracking technology to examine the gaze patterns of adolescents and young adults with autism compared to TD controls. Participants viewed short video clips from a movie presenting complex social interactions, and the results showed that the participants with autism spent much less time than the controls looking at the eye region of protagonists on the screen, instead tending to look more at the mouth and also other objects in the scene. Similar findings are well-replicated (e.g. Dalton et al., 2005), suggesting that the face does not hold the same interest or value for people with autism in terms of looking at, and interpreting, social stimuli (Rosset et al., 2008).

Consequently, the paradigm of using VEs to explore gaze patterns of people with ASD when interacting with, or viewing, social stimuli has been used to test different hypotheses. Here, again, the assumption of veridicality underpins the validity of taking such an approach. For example, in reviewing the literature on using virtual characters (or 'VCs') for the assessment and training of non-verbal communication in people with autism, Georgescu et al. (2014) argue that:

> The most important prerequisite for using VCs for non-verbal behavior research is that they are veridical and convincing and that they are able to evoke impressions, attributions, and reactions in an observer that are comparable to those evoked by real human beings. (p. 3)

Indeed, the authors go on to conclude that: 'VCs and IVEs are experienced in a similar manner by individuals with HFA and typically developing individuals, and… they can reliably be used to simulate authentic social situations in experimental settings (Georgescu et al., 2014, p. 7).

Insert Table 3 about here

3.2.1 Using VR to explore patterns of eye gaze towards social stimuli. Grynszpan et al.'s (2009) research is a good example of virtual characters being assumed to represent an authentic, realistic stimulus via which social gaze behaviours can be observed and manipulated. Grynszpan et al. (2009) describe the development of a VR system aimed at helping people with ASD to focus on relevant facial cues during social conversation. Their hypothesis was that people with ASD do not recognize the value of paying attention to facial expressions during conversation and, as a result, miss important non-verbal cues that can aid comprehension of meaning. Looking at, and gleaning information from, a conversational partner's face is something that typically developing individuals do naturally (e.g. Beier & Spelke, 2012). Grynszpan et al. (2009) argue that by using eye-tracking technology to identify where participants look during a social conversation with a virtual character (an agent-avatar), they can encourage participants with ASD to shift their attention to the faces of virtual characters by blurring the field outside of the direction of eye gaze. In other words, participants could see the virtual character clearly only when they looked at the face region, not elsewhere in the virtual scene. By manipulating the direction of gaze in this way, the authors hoped to show that participants with ASD improved their ability to read the emotions of virtual conversational partners and, therefore, interpret their (ambiguous) meaning correctly.

Grynszpan et al. (2012) report on the application of this system with 13 high-functioning participants with ASD and 14 TD individuals, matched for chronological age (13–31 years). The participants with ASD showed an improvement in scores (successfully disambiguating an utterance) in the experimental condition where their direction of gaze was manipulated to look at the face region of an agent-avatar. There was a also a significant correlation in the ASD group between length of time spent looking at the face of the avatar and giving correct answers to questions that asked ‘How does John feel’ and ‘How do you know that?’ This suggests that there could be some benefit in encouraging participants to look at the face region of avatars, although it was noticeable that participants did not maintain this behaviour when the experimental manipulation was switched off to enable free visual exploration of the scene. Indeed, the authors conclude: ‘The eyes’ motor reactions in regard to the gaze-contingent lens [experimental condition] highlight the high inter-individual heterogeneity among participants with HFASD’ (p. 1648). Moreover, the extent to which the responses to the virtual characters could be considered comparable to responses to real people is unknown, because there was no comparison between different stimuli and no information reported on whether typically developing respondents interpret these virtual characters as authentic and life-like.

Lahiri, Warren, and Sarkar (2011) report on the development of a similar system using a real time gaze monitoring mechanism while participants viewed virtual characters (agent-avatars) on a desktop computer. The virtual characters were developed by using 2D photographs to create 3D heads, onto which standard facial expressions were morphed and eye blinks randomly inserted. The characters narrated a story and, unlike Grynszpan et al.’s system (2009, 2012), feedback based on eye gaze was given verbally by the character rather than through on-screen highlighting of the face region. For instance, the character could say, ‘You may try to pay more attention to her… so that you can correctly understand how she is feeling’. A usability study with six participants with ASD (aged 13–17 years) showed that participants increased the time they spent looking at the avatar’s face in response to the feedback provided, however the authors acknowledge that the data were limited and that conclusions about the system’s effectiveness for supporting social interactions could not be drawn (no controlled study using the system has yet been published). In addition, the responses of typically developing participants were not compared in the study, and so the extent to which responses were related to having an ASD diagnosis or related to the specific features of the system, or both, is unknown.

The absence of comparison with other stimuli in these studies (Grynszpan et al., 2009; 2012; Lahiri et al., 2011) raises an important question about the extent to which responses observed when viewing the VR agent-avatars are authentic or not. Although Georgescu et al. (2014) conclude that VR can authentically simulate real life situations and that people with and without ASD interpret VEs in similar ways, they draw upon only two studies to support this assertion. The first is by Wallace et al. (2010), the only study so far to have directly measured the self-reported sense of presence of 10 participants with ASD, within a series of IVE scenarios and compared their responses to a group of 14 TD adolescents. Their findings suggest that the two groups did not differ in reported measures of presence and, crucially, there was no significant difference in the reporting of negative sensory effects. However, there was a notable trend for the TD group to score higher on at least some measures, raising the possibility that with a larger sample significant differences may have been found. While similar findings have recently been reported in a desktop VE (Wallace et al., in press) the results would need to be replicated with different and larger groups to establish whether this is a reliable result. Moreover, Slater (2004) strongly critiques the reliance on self-report measures to assess sense of presence in VR, arguing that the questionnaire forces participants to make a post hoc construction of their experience.

The second study cited by Georgescu et al. (2014) to support an argument about the veridicality of virtual characters in VEs is by Hernandez et al. (2009), who compared the gaze behaviour of 11 adults with ASD with 23 typically developing individuals to a series of stimuli presenting static photographs and avatar faces. Participants were not asked to make any comments about the faces or to respond to any questions about them, only to look at them. The findings showed that there were no differences in the gaze patterns of participants to the photographic versus the avatar facial stimuli, suggesting that the stimuli were interpreted similarly. However, Hernandez et al. (2009) note that the findings are restricted to interpretations based on static stimuli only, thereby limiting the application of the results.

3.2.2 Influence of the nature of stimuli on responding. In agreement with this, other evidence suggests that differences in responding to facial images emerge according to whether the stimuli used are dynamic or static. For example, Speer, Cook, McMahon, and Clark (2007) compared the length of time TD and ASD participants spent looking at the eye region of static (photographic) versus dynamic (video-based) images. Their findings show that the only difference between the two groups was in the condition that used video clips showing interaction between people in the scenes; here, participants with ASD spent much less time looking at the eye region than those in the TD group. The authors conclude that ‘the face processing deficit associated with autism appears to be at least partially dependent on stimuli being both realistic (i.e. dynamic or moving) and social in nature’ (p. 274). This aligns with other research that shows that people with autism often correctly interpret emotional states in static, posed images in contrast to their difficulties reported in interpreting emotions in everyday life (Cassidy et al., 2015).

Nevertheless, Forgeot d’Arc et al. (2014) demonstrate that even social judgements about static stimuli can differ, depending on whether the images are ‘real’ or synthetic. They examined the social judgements of children and adults with autism to photographs of real faces compared to the ‘synthetic’ images of faces rendered in 3D computer-generated graphics. Results showed that participants with autism made atypical judgements about photographic faces, but were as accurate as those in a typically developing control group in making social judgements about the synthetic faces. The authors suggest that the differences might arise because of a 'diminished tolerance to variability' in natural compared to synthetic stimuli. In other words, that people with autism do not necessarily interpret synthetic and natural stimuli in the same way, perhaps because the synthetic stimuli are easier to judge since they are more uniform in appearance. This is an important finding, because it suggests that differential responding to virtual compared to natural stimuli in experimental contexts may be as much a function of the stimulus as it is about underlying difficulties in social cognition. This also suggests, in contrast to the assertions of Georgescu et al. (2014), that the veridicality of synthetic stimuli as a basis for providing authentic contexts in which to study behaviours of individuals with autism may be open to question.

Indeed, Cassidy et al. (2015) suggest that it could be that static stimuli are not sufficiently realistic to recreate conditions experienced in real life authentically, and people with autism need greater 'signal clarity' (from dynamic stimuli) in order to make successful judgements about others' emotions. Cassidy et al. (2015) found that adults with autism were not impaired in looking at the eye region of people in video clips, and made more or less successful interpretations of emotional responding depending on the nature of the stimuli (dynamic versus static) in conjunction with the nature of the social response presented (judging whether the response was related to a gift of chocolate, a homemade card, or Monopoly money). This suggests that the social motivation and relevance (i.e. features of the task) may also impact on responses.

3.3.3 Possible role of agency in influencing responding. It is noteworthy that much of the research cited in Table 3 involves participants in predominantly passive situations, viewing images on a computer screen without needing to interact with the images, videos, or virtual characters presented. However, as noted earlier, the extent to which participants are able to interact with a virtual scene – to put their intentions into action –– impacts on their sense of agency and, therefore, the extent to which the experience within VR is considered realistic and believable (Riva & Mantovani, 2014). There is evidence from non-VR-based research that individuals with autism experience difficulties with agency in relation to action monitoring (Russell & Jarrold, 1999) and making error corrections (Russell & Jarrold, 1998), although this varies with the nature of the task and judgement (Hill & Russell, 2002; Russell & Hill, 2001).

It is interesting that in a study of emotion- and action-based responses of 20 adults with high-functioning autism (HFA) to dynamic virtual characters, participants with HFA were not different from a TD control group in their reported feelings of emotional involvement with the characters, yet were less likely either to experience contact or to report an urge to make contact with the virtual characters (Schwartz et al., 2010). The authors suggest that a possible reason for this difference could be the passive nature of the tasks, being ‘easier to handle than an interactive situation and has decreased ecological validity’ (p. 108). Moreover, the authors admit that they ‘prioritized experimental control over ecological validity’ (p. 101) in using the stimuli that they did, suggesting that their tasks may not be able to tell us very much about the veridicality of the observed responses. Consequently, the extent to which some of the findings relating to responses in VEs would change if the experimental set-up required participants to interact, or engage, with the scene or characters in a more direct and naturalistic way remains an important open question (cf. Boucenna et al., 2014; Witmer, Jerome, & Singer, 2005).

3.2.4 Conclusions about using VEs as mirrors for reflecting and assessing real world social behaviours. Overall, this section highlights that using virtual scenes and characters in experimental studies may offer good stimulus and experimental control, but may not, at least for participants with ASD, offer a context as yet with sufficient veridicality in which confidently to interpret and assess individual responses. That is, the studies reported provide interesting insights about how participants with ASD respond to specific tasks and different stimuli in VEs, but the extent to which these responses may be generalizable to real world responding and interpretation is debatable. Studies show that the nature of the stimuli presented (static versus dynamic; real vs. synthetic 3D) influences the success demonstrated by participants with ASD in making appropriate emotion-based interpretations or judgements. This means, at the very least, that any conclusions drawn about wider applicability of the findings to social cognition should be approached with some caution. Some studies lack any TD comparison data and this makes it difficult to disentangle the extent to which findings are diagnostic group- or technology-specific. Moreover, the reported studies are mostly based on passive viewing of stimuli rather than more naturalistic, interactive encounters with virtual characters, and so the extent to which agency might influence responding has not yet been taken into account sufficiently (Herrera, Jordan, & Vera, 2006; Riva & Mantovani, 2014). Consequently, many questions remain about which specific features and combinations of VE stimuli and interaction modes show the most promise in providing a context within which real world understanding and skills can be authentically assessed, and subsequently designed appropriately for educational intervention.

4. General conclusions

This conceptual review has illustrated the challenges of pursuing veridicality in VR-based educational intervention and psychological assessment research for autism. Specifically, the background characteristics of users as well as features of VEs (including how realistic the characters are, who controls them, and how tasks are carried out) can all influence the responses of participants. 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. Research tends to focus on more able participants and so one of the main ways to move the field forward is to undertake a systematic investigation of the responses of participants across the autism spectrum to different stimuli and modes of interaction within VEs, to compare these with each other (e.g. low- vs. high-functioning) and with typically developing participants. In this way, we might arrive at a better understanding of the extent to which findings relate to the diagnostic features of ASD, and the specific tasks undertaken or particular technology-related factors, or both. Blascovich et al.'s (2002) aspirations for VR as a powerful social-psychological methodological tool, therefore, remain applicable in the autism field, but the many layers of features that influence responding need to be much better understood if the potential of VR is to be translated into wider use and applicability for people with ASD. The scale of such a task is substantial and complex, but remains important to tackle.

There are important questions that remain for practice contexts too, not least in terms of the cost of investment in technologies and the tendency for practice to outpace the evidence base (Grynszpan et al., 2014). Given the rapid adoption of interactive technologies by the general public, especially children (Rideout, Foehr, & Roberts, 2010), questions are regularly asked about which technologies work best for autism? The question is understandable but misplaced: the focus needs to be instead on which technologies work for whom, in which contexts, with what kinds of support, and for what kinds of tasks or objectives? In other words, it is the interaction between the learner and their learning environment that matter for assessing the value of any learning tool and whether it 'works' (Higgins, Xiao, & Katsipataki, 2012). As the preceding analysis illustrates, how the pedagogical tool is designed is likely to be crucial and we need to understand much more about how we can do this appropriately and effectively.

The appropriateness of innovative technology design in the autism field leads to a final question and perhaps the one of greatest importance in this context: who is involved in making decisions about the design and development of technologies, and with what objectives? Increasingly, there is recognition in the autism research field generally (e.g. Pellicano et al., 2014), and in technology development for autism more specifically (e.g. Parsons & Cobb, 2014), that there should be greater participation of 'end-users' and other stakeholders, in making decisions about what is researched and developed, and in what ways. Although not without challenges (Parsons & Cobb, 2014), such 'user-centred' approaches to design at least aspire to recognize the views and experiences of people with autism as making a valid, and different, contribution to design decisions. Such approaches align with a position that it is ethically more appropriate, socially empowering, and better for designers as well as end-products if representatives of the user population can be involved in designing technological solutions from the start of the process, rather than simply be testers or evaluators of products (Abascal & Nicolle, 2005; Bleumers et al., 2012; Lally, Sharples, Tracy, Bertram, & Masters, 2012). Such a position also recognises the value and importance of inclusive or participatory methodologies in research for involving, empowering, and enabling individuals who might otherwise be excluded; in other words, there are important ethical and practical outcomes for individuals too (Seale, Nind, & Parsons, 2014).

By contrast, the pursuit of veridicality in VR research for autism is one that has been premised on the difficulties experienced by people with ASD. This focus reflects the dominance of the medical model of educational intervention research in autism, which prioritizes the difficulties and impairments of the individual that need to be addressed and ameliorated. This compares with the social model conceptualization of disability that places the emphasis for accommodation and change on environmental and attitudinal factors that promote inclusion, rather than expecting the individual to change (e.g. Shakespeare, 2006). In the autism field, the social model position is becoming more recognized and supported (MacLeod, Lewis, & Robertson, 2013; Molloy & Vasil, 2002), not least through the neurodiversity movement (Kapp, Gillespie-Lynch, Sherman, & Hutman, 2013) that emphasizes the cognitive, sensory, and perceptual differences in autism as strengths, rather than as disordered and deficient.

Consequently, given the complexity that arises in the pursuit of veridicality in VR research for autism, an alternative way of moving the field forward is to develop lines of enquiry that diverge from veridicality and do not aim to recreate authentic environments in which to bridge to, or mirror, real world weaknesses or difficulties. A more radical re-imagining of the field is one that explores how positive flourishing (Sander, 2011), through the participatory and inclusive design, development, and application of technologies, can be promoted instead. This means taking a different starting point that recognises the strengths of people with autism, and the value of online communication as a safe space, precisely because it is decoupled from at least some of the usual social norms and expectations (Brosnan & Gavin, 2015; Benford & Standen, 2009). For example, if research started from the perspectives of people with autism and asked them to design online spaces or scenarios in which they feel more comfortable, what would those spaces look like? How would they be used and by whom? In what ways would communication and learning be supported and enhanced? What does authenticity mean in this context?

Overall, the field of VR and autism has thus far looked mainly in one direction: towards a closer fit with the real world in order to assess cognition and support the generalization of learning. It is important to keep an eye on this direction, because there is still much to learn about how VEs can be designed to maximize learning, especially within the context of ever-increasing use of technologies by children in their everyday lives. However, it is equally important to look in another direction, grounded in the perspectives, individual needs, and preferences of people with ASD and their families, in order really to understand and explore how VR technologies can positively impact on well-being, learning and, therefore, quality of life.

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Table 1: Review papers cited focusing on technology and autism

	Authors	Focus	Review methodology / type	Number of studies included (where explicitly stated)	Virtual reality studies included?
General reviews cited on technology and autism	Boisvert, Lang, Andrianopoulos, & Boscardin, 2010	Participant characteristics, technologies, services, research methodology and outcomes of telepractice for assessment and treatment of children with ASD	Systematic	8	No
	Boucenna et al., 2014	Overview of ICT applications in autism treatment, with a focus on joint attention and imitation	Thematic	N /A*	Yes
	Grynszpan, Weiss, Perez-Diaz, & Gal, 2014	Effectiveness and effect sizes of outcomes in.pre-post intervention designs using computer hardware or software, involving participants (children and /or adults) with ASD	Systematic (meta-analysis)	21	Yes
	Ploog, Scharf, Nelson, & Brooks, 2013	Efficacy of computer-assisted technology interventions for social, communication, and language difficulties in children with ASD	'Exhaustive' (p.304)	45	Yes
	Ramdoss et al., 2011	Effectiveness of computer-based interventions to teach communication skills to children with ASD	Systematic	10	No
	Ramdoss et al., 2012	Characteristics of participants and technologies, and outcomes of computer-based interventions for	Systematic	11	No [VR excluded from search

		social and emotional skills of children and adults with ASD			but one of the included studies involved some use of VR]
	Reed, Hyman, & Hirst, 2011	Targeted skills and reliability of technology-based social skills interventions for children with ASD	Systematic	29	Included in search terms but no articles identified in the search
	Shane et al., 2012	Description of the technology-based Augmentative and Alternative Communication (AAC) field in terms of technologies and clinical applications	‘Organizational framework’ (p.1228)	N/A	No
	Wainer & Ingersoll, 2011	Innovative computer technology interventions for social and communication skills for children and adults with ASD	‘Comprehensive review’ (p.97)	14	Yes
	Wass & Porayska-Pomsta, 2014	Effectiveness and generalisation of outcomes in technology-based cognitive training interventions for children and adults with ASD	Not specified, though inclusion criteria stated	30	Yes
VR-specific reviews cited on technology and autism	Bellani, Fornasari, Chittaro, & Brambilla, 2011	Behavioural studies investigating the application of VR technologies for children and adolescents with ASD	State-of-the-art review	8	Yes
	Georgescu, Kuzmanovic, Roth,	Behavioural studies investigating the application and interpretation of virtual characters in non-verbal	Thematic review	N/A	Yes

	Bente, & Vogeley, 2014	communication of children and adults with high-functioning autism			
	Parsons & Cobb, 2011	Use, understanding and interpretation of VR technologies by children with ASD	State-of-the-art review	N/A	Yes
	Parsons & Mitchell, 2002	The potential of VR technologies for social skills training for children and adults with ASD	Conceptual review	N/A	Yes
	Rajendran, 2013	Application of psychological theories to VR applications and development for children and adults with ASD.	Conceptual review	N/A	Yes
	Trepagnier, 1999	The potential of VR for assessment and intervention of cognitive and perceptual impairments in ASD.	State-of-the-art review	N/A	Yes

*N/A means that the number of articles in the review is not demarcated cf. a systematic approach.

Table 2: Empirical papers cited relating to *VEs as a bridge to the real world: for learning and intervention in autism*

Authors	**Focus of the study**	**Number and autism characteristics / diagnosis of participants**	**Human or agent avatars or stimuli?**	**Study design**	**Main findings**
Cheng and Ye, 2010	A pilot study using collaborative VEs (CVEs) for improving social competence in children with ASD	3 children with ASD (IQs in the normal range) Aged 7-8 years ASD diagnosis inferred from school records	Human	Multiple-probe across participants; measures of social understanding and responding.	The three children showed some positive learning outcomes regarding understanding and interpretation of expressive avatars.
Hopkins et al, 2011	Evaluation of a computer-based social skills intervention, focused on emotion and facial recognition, involving photographic ‘avatar assistants’	49 children with ASD (in two groups, described as high and low functioning) Aged 6-15 years ASD screening questionnaire (CARS) used to confirm autism characteristics	Agent	Random assignment to control or training group; intervention used over a number of weeks. Facial recognition tests and social observations of behaviours were taken.	Both the lower and higher functioning children showed some improvements on facial recognition and social interactions. Only the more able children also showed progress in emotion recognition.
Jarrold et al., 2013	A virtual classroom used for investigating social attention and practising of public speaking	37 children with HFASD (IQs in the normal range) 54 typically developing controls Aged 8-16 years ASD screening questionnaires [ASSQ; SCQ; SRS] completed by parents.	Agent	Single 2.5 hour individual session involving completion of a number of tasks; group-based comparisons of performance on eye-gaze and vocalisations presented.	Students with HFASD looked less at virtual peers in a speaking task compared to control group. Patterns of social attention moderated by IQ, social anxiety, and ADHD symptoms.

Josman, Ben-Chaim, Friedrich, & Weiss, 2008	Pilot study examining the effectiveness of a street-crossing VE for developing road safety skills and knowledge	6 children with ASD (moderate to severe) 6 typically developing controls Aged 8-16 years ASD screening questionnaire (CARS) used to confirm diagnosis	Agent	Group-based comparisons, and single-subject design (A-B-A); behaviours within the VE, and in a protected real street reported.	Children with ASD learned to use the VE and improved in crossing a virtual street; 3 children with ASD also showed some ability to generalise to a real street.
Kandalaft, Didehbani, Krawczyk, Allen, & Chapman, 2013	Assessing and supporting social cognition via a range of CVE social scenarios (e.g. job interview, celebrating with a friends, meeting strangers or friends)	8 participants with HFASD (IQs in the normal range) Aged 18-26 years ASD diagnosis confirmed with the ADOS	Human	Pre-post group-based design of various assessments; 10 hours of VE use in total (2 x 1 hour sessions per week) involving a range of scenarios with two adults taking different roles (coach, confederate); verbal and non-verbal measures, and participant feedback.	Some improvements in some skills / domains for some participants. Positive subjective responses to the intervention.
Ke & Im, 2013	Application of a CVE school (playground and classroom), and house party, to practise social interaction and conversation	4 children with Asperger or HFASD diagnosis Aged 9-10 years ASD diagnosis based on existing medical or educational records	Human	Single-subject staggered baseline; 6-9 hours (in 1 hour sessions) over a few weeks; children interacted with adult facilitators within the CVE and social behaviours observed.	Some improvements in some skills for all participants in the intervention phase; but very variable responses, requiring varied levels of support and scaffolding from adult facilitators.
Maskey, Lowry, Rodgers,	Applying bespoke scenarios (e.g.	9 children with ASD, with a specific fear / phobia	Agent	Pre-post design for individual children,	8 out of 9 children responded positively to the treatment; 4

McConachie, & Parr, 2014	shopping, buses, and trains) in an immersive VE to reduce anxiety and phobias, alongside Cognitive Behavioural Therapy (CBT) sessions	Aged 7-13 years Diagnosis confirmed by community clinical team		combining CBT with gradual exposure to feared stimuli in the VE. Anxiety measures, as well as parent and child feedback reported.	overcame their phobia completely. 7 out of 9 children self-reported improvements in confidence.
Mineo et al., 2009	Investigated the relative potential of four different digital media for supporting engagement, including two different forms of VR and two different forms of video	42 children and adolescents A diverse group in terms of the autism spectrum, representing those with higher and lower levels of expressive language (relative to chronological age) Aged 6-18 years Diagnosis assumed based on school records and eligibility for autism-specific programs	Agent & human (self)	Between-groups design, with random assignment to group. All participants viewed the animated video as a baseline, and then one of the three other media forms. Vocal and visual engagement with media measured.	Both forms of VR were more engaging than video-based media for many participants, though all four forms of media supported short-term engagement. There was considerable individual variability in preferences within the groups.
Moore, Cheng, McGrath, & Powell, 2005	Exploratory study to determine whether children with autism could interpret basic emotions from humanoid avatars.	34 children Aged 7-16 years No diagnostic information supplied or checked	Agent	Parents sent a disk containing the stimuli and instructions on using it; completed disks and a questionnaire returned in the post.	Most participants labelled the emotions correctly and provided correct responses to prediction and inference tasks based on facial expressions. However, it is not possible to know whether the participants had an autism diagnosis or the extent to which participants received help from parents.

Mitchell, Parsons & Leonard, 2007	Investigating the potential of a café and bus VE for teaching social understanding and skills	6 adolescents with ASD (all but one with IQs in the normal range) Aged 4-16 years ASD diagnosis inferred from school records	Agent	Same set of tasks completed but in a counterbalanced order. Individual results and comparisons made when using the VE, and in making social judgements about video-based stimuli.	All participants learned to use the VE, and 3 out of 6 showed improved social understanding and reasoning directly following VE use. 2 out of the 3 who showed improvements also had the lowest verbal IQ scores.
Parsons, Mitchell, & Leonard, 2004	Investigating social verbal and behavioural responses within single-user café and bus VEs	12 adolescents with ASD (full-scale IQs in the normal range for all except one) 12 verbal IQ matched controls with intellectual impairment 12 typically developing non-verbal matched controls Aged 13-18 years ASD diagnosis inferred from school records	Agent	Same set of tasks in fixed order during one session. Usability, understanding and responses examined through observations and questions.	Participants with ASD used and understood the VE as a representation of reality. Some participants with the lowest verbal abilities were less likely to adhere to typical social conventions in the VE regarding personal space.
Parsons, Mitchell, & Leonard, 2005	Exploring personal accounts and interpretations of single-user café and bus VEs	2 adolescents with ASD (IQs in the normal range) Aged 14 & 17 years ASD diagnosis inferred from school records	Agent	A number of individual sessions with a facilitator, in a fixed order. In-depth qualitative analysis based on observations and comments.	Responses indicated the potential of VEs for supporting learning and understanding. Variability in interpretations regarding links made between virtual and real world experiences.
Schmidt, Laffey,	A case study for identifying methods to capture and	4 adolescents with ASD (IQs in the normal range) Aged 11-14 years	Human	Four lessons completed together, with the support of	Dominant patterns of responding identified within the group, as well as for each

Schmidt, Wang, & Stichter, 2012	illustrate reciprocal social interactions (conversational turn-taking) in a CVE	ASD diagnosis confirmed via the ADI-R or the ADOS		an online guide. Detailed coding scheme developed for annotating interactions with each other, and with the features of the CVE.	individual. Highly individual patterns revealed through the detailed analysis.
Self, Scudder, Weheba & Crumrine, 2007	Comparing VR with a 'visual treatment model' for teaching fire and tornado safety drills	8 children with ASD (no background data presented) Aged 6-12 years No diagnostic information supplied or checked	Agent	2 groups, each with 4 children: VR intervention compared to visual teaching. Learning of relevant skills and correct responses to questions measured.	Both models successful in teaching safety skills; some generalisation of skills shown, but also high variability in responding for each participant.
Stichter, Laffey, Galyen, and Herzog, 2014	Evaluating the feasibility of delivering a social competence curriculum for distance learning via a 3-D VE	11 adolescents with ASD (IQs in the normal range) Aged 11-14 years Diagnosis confirmed via the ADOS or ADI-R	Human	Pre-post design using a battery of assessments, based on individual responses as well as parent and teacher reports of social understanding and interpretation.	Some changes in some scores between pre- and post-test but few significant differences, partly due to highly variable responding. Parents and teachers were positive about the intervention and reported improvements. Good feasibility overall.

Table 3: Empirical papers cited relating to *VEs as mirrors for reflecting and assessing real world behaviours in autism*

Authors	Focus of the study	Number and autism characteristics / diagnosis of participants	Human or agent avatars or stimuli?	Study design	Main findings
Cassidy et al. 2015*	Comparison of social inferences made from video-based dynamic stimuli versus static images taken from the same videos.	17 adolescents with ASD (IQs in the normal range) Aged 14-21 years Diagnosis inferred from school records	N/A	Within-subjects design, with counterbalanced order of tasks. Eye-tracking data, plus verbal responses to questions about emotional responses of the characters in the videos and images.	Participants with ASD were better at inferring emotions from static compared to the dynamic stimuli, but some variability depending on the specific task / context of the stimuli.
Forgeot d'Arc et al., 2014	Comparison of photographs, and synthetic (3-D virtual) faces, according to social judgements of 'kindness'	33 children and adults with ASD (IQs in or very close to the normal range) 38 age-matched typically developing control participants Aged 7-54 years Diagnosis clinically confirmed via ADOS or ADI-R	Agent	Group-based comparison study. All stimuli presented in fixed order during one test session per participant; participants asked to judge which of a pair of faces looked 'kinder'.	Participants with ASD provided atypical social judgements to photographs of faces, compared to control group, but not to 3-D virtual faces.
Grynszpan et al., 2012	Explores patterns of eye-gaze to virtual stimuli in free, and guided, conditions using VR.	13 adolescents and adults with ASD (IQs in the normal range) 14 age-matched typically developing control group Aged 13-31 years ASD diagnosis confirmed with CARS or ADI	Agent	Group-based comparisons in an A-B- A design of free exploration, guided exploration, and then free exploration of the virtual scenes. Individual session	Participants with ASD were better able to correctly identify facial expressions when they were guided to look at the eye-region of the face.

				with random counterbalancing of scenes. Asked to make judgements about how a virtual character was feeling, and explain why. Eye-tracking data also collected.	Positive correlations between time spent looking at the face and correct emotional inferences.
Hernandez et al., 2009	Comparison of photographic and 3-D virtual faces according to time spent looking at different regions of the face	11 adolescents and adults with autism (in the normal range on ‘developmental quotient’ though measure not specified) 23 typically developing controls Aged 15-35 DSM-IV criteria stated but not checked or confirmed; no source for diagnostic information provided	Agent	Group-based comparison study. Computer-based presentation of stimuli in a random order. Participants asked to ‘pay attention’ to the stimuli; eye movements tracked and recorded.	Participants with ASD tended to look less at the eye region of static facial stimuli compared to the control group; no differences found between responses to photographic and 3-D virtual images.
Lahiri, Warren, & Sarkar, 2011	Usability study of a VR system designed to provide dynamic and individualised feedback about direction of eye gaze to social stimuli	6 adolescents with ASD (described as high functioning) Aged 13-17 years SCQ and SRS used as ASD screening measures based on parental report	Agent	Single, individual session with a series of short tasks, with random presentation of stimuli narrating short stories, and showing different facial expressions. Eye-tracking data and verbal responses to questions recorded.	Participants used the dynamic feedback to increase the time they spent looking at the face of the virtual character.
Schwartz et al., 2010	Comparing feelings of	20 adults with ASD (high-functioning autism or	Agent	Group-based comparison study.	Participants with ASD less likely

	involvement with dynamic virtual characters between an ASD and typically developing group	Asperger Syndrome; IQs in the normal range) 20 typically developing controls Aged 20-53 years Diagnostic traits confirmed via clinical interview, and AQ screening questionnaire		Individual sessions in which gaze direction and facial expression of virtual characters varied systematically in short animated sequences. Participants asked to rate on a likert scale their feelings towards the character, and urge to establish contact.	than controls to express an urge to make contact with the virtual characters. Gaze direction and facial expression had less impact on ratings of involvement for the ASD compared to the control group.
Speer, Cook, McMahon, & Clark, 2007*	Comparison of responses to dynamic and static stimuli depicting social or individual scenes from a film between an ASD and typically developing group	12 children and adolescents with ASD 12 typically developing age- and IQ-matched controls Aged 9-18 years Clinical records used to confirm diagnosis	N/A	Group-based comparison study. Individual session presenting computer-based stimuli and eye-tracking data collected. Participants were asked to view the images and then answer some questions about what they saw.	Participants with ASD showed different patterns of eye-gaze depending on the stimuli; they were only different from the control group when the stimuli were social or dynamic.
Wallace et al, in press	Investigating self-reported sense of presence, and verbal responses, in social scenes in a desktop CVE.	10 adolescents with ASD (IQs in the normal range) 10 age-matched typically developing controls Aged 12-16 Clinical records used for initial recruitment and diagnosis confirmed with the ADI-R	Human	Group-based comparison study. Individual session with a fixed sequence of tasks; types of stimuli viewed were counterbalanced or randomised for each participant. Sense of	Participants with ASD felt as immersed in the desktop CVE as the control group, and made similar judgements on a social interpretation task. They also

				Presence questionnaire completed plus verbal responses to questions about a social scenario, and interpretations of facial stimuli.	showed some difficulties in correctly identifying facial expressions in a virtual gallery.
Wallace et al., 2010	Investigating self-reported sense of presence, and verbal responses, in social scenes in an immersive VE.	10 participants with ASD (IQs in the normal range) 14 typically developing controls Aged 12-16 years Diagnosis confirmed via ADI-R	Agent	Group-based comparison study. Individual sessions in which main tasks were completed in fixed order but stimuli within tasks counterbalanced. Sense of Presence questionnaire completed plus verbal responses recorded to questions about a social scenario.	Participants with ASD felt as immersed in the VE as the controls. They were less sensitive than controls to the differences between a friendly and an unfriendly virtual character.

* These studies are included in the table because although they did not include 3-D virtual stimuli, their comparisons of photographic and video-based images are relevant for understanding whether and how social judgements or interpretations in digital social scenes differ based on the presentation of static or dynamic stimuli.