British Journal of Educational Technology Vol 49 No 4 2018 728–741
doi:10.1111/bjet.12626

Virtual collaborative gaming as social skills training for high-functioning autistic children

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Abstract

Using OpenSimulator, we constructed a 3D virtual playground that affords competition-themed social gaming, role-play gaming and design-themed architectural gaming among high-functioning autistic (HFA) children. A mixed-method, multi-case study was conducted to examine the association between the game task and setting features, learners' participation patterns, and their game-based social interaction performance. Eight 10–14-year-old HFA children participated in the study. Data were collected via screen recording and observation of participants' gaming actions and reactions. We conducted a behavioral analysis with the recorded social interaction performance of participants in the virtual gaming sessions. The study found that virtual reality-based gameplay promoted the social interaction performance of HFA children. The study findings also suggested that gameplay should be adapted based on the competencies and in-situ reactions of learners.

Introduction

Social skills are the behaviors "that result in positive social interactions and encompass both verbal and nonverbal behaviors necessary for effective interpersonal communication" (Elliott & Gresham, 1987; Gresham, 1986; Rao, Beidel, & Murray, 2008, p. 353). High-functioning autistic (HFA) children lack specific social skills to navigate the social environment, such as initiating and maintaining social interactions, sharing or understanding the perspectives of others, negotiation, and adaptive behaviors in situations where interpersonal interaction occurs (Macintosh & Dissanayake, 2006). Hence, they can experience substantial social relational problems and difficulty participating in community life, school and work (Church, Alisanski, & Amanullah, 2000). Because the majority of HFA children are included in regular education classrooms, they are more consistently exposed to social pressures and demands than their lower functioning counterparts (Rao *et al.*, 2008). Research demonstrates that effective design and delivery of social skills training interventions or strategies help to improve these children's social and academic well-being (Foster & Bussman, 2007; Stichter, Laffey, Galyen, & Herzog, 2014).

This mixed-method, multi-case study aims to examine the design and implementation of virtual reality (VR)-based games for the social skills development of HFA children. Specifically, the investigation explores the types of game tasks and scenes that facilitate the practice of different social

Practitioner Notes

What is already known about this topic

- Virtual reality (VR) can be a platform for naturalistic social skills training.
- Computer games can be a learning tool for autistic individuals.

What this paper adds

- The feasibility of using VR games for high-functioning autistic (HFA) children.
- Effectiveness and features of VR game tasks and settings in social skills training for HFA children.
- Adaptive VR game design and implementation for individuals with special needs.

Implications for practice and/or policy

- Serious game designers should make purposeful design efforts to create learner-adaptive gameplay.
- Learning process should be a core and active part of gameplay.
- Game task and setting should be adapted to learners' profiles and in-situ reactions.

interaction skills. The research question to be addressed is: *What was the relative effectiveness of varied VR-based game tasks and settings in reinforcing social interaction practice and performance of high-functioning autistic children?*

Naturalistic social skills intervention

Autism spectrum disorders (or autism) are characterized by persistent difficulties in communication and social interaction and by restricted, repetitive patterns of behavior, interests or activities (APA, 2013). Though research on the explanations and presentations of autism is still inconclusive, difficulties in social functioning that requires perspective sharing, negotiation and cognitive flexibility have been used to characterize autism and examined as potential facets and outcomes of the intervention for autism (Leung & Zakzanis, 2014; Rao *et al*., 2008). From the neurodiversity perspective (Lorenz & Heinitz, 2014; Milton, 2014; Robledo, Donnellan, & Strandt-Conroy, 2012), qualitative differences in the way autistic people socialize and their strengths and interests should be recognized and valued. Interactional expertise can and should be gained by both parties in interactions between autistic and non-autistic people. In addition, constructing positive identities, a highly social process that shapes people's ways of presenting the self and interacting with the outside world, is also considered imperative for autistic individuals (Bagatell, 2007; Forber-Pratt, Lyew, Mueller, & Samples, 2017). Yet, existing stereotyping and stigma toward autism have hindered autistic children from constructing positive identities.

Although there are common diagnostic features, there is great heterogeneity associated with autism. It is critical yet challenging to design an intervention that is effective and versatile for diverse autistic learners because their specific needs vary (Ke, Whalon, & Yun, 2017). Recent reviews of social skill interventions with autistic individuals proposed a reduction of direct interventions for *naturalistic* interventions, and the transferring of control for prompting social interactions from teacher verbal antecedents to self-monitoring or naturally occurring stimuli (eg, Rao *et al*., 2008; White, Keonig, & Scahill, 2007). A naturalistic intervention is usually conducted in loosely controlled contexts, lets the child initiate the interaction, and incorporates the target child's preferences into the social skills training. Naturalistic interactions are promising in engaging autistic children and moving them toward more generalized use of social skills and more spontaneous social interactions (Schreibman & Ingersoll, 2005).

In spite of their promise, naturalistic and adaptive interventions for children with high-functioning autism are still understudied but worthy candidates for development and testing (White *et al.*, 2007). Prior naturalistic interventions were typically conducted in classrooms and targeted mainly social interactions in the school setting, with fewer extending the setting to the child's home or involving interactions outside of classrooms. A recent review on social skill interventions (Ke *et al.*, 2017) reported that prior research typically lacked a purposeful investigation of learning activities in the intervention, and it is difficult to determine the factors which affect the impact of an intervention, or to extract findings that may contribute to the design heuristics and theoretical insights that will guide future intervention development.

VR as learning platform for naturalistic social skills training

Research showed that autistic children tend to enjoy computerized intervention programs (Beaumont & Sofronoff, 2008). Recently, VR was proposed as a promising platform for naturalistic social skills training. VR is a computer-generated three-dimensional (3D) representation of real-life environments where a user, in the form of avatar, can interact with simulated objects and other avatars in real time at the same pace he or she would experience events in the real world (Mitchell, Parsons, & Leonard, 2007). In comparison with other computerized programs, VR supports high-fidelity role-playing to facilitate the transfer of skills between taught and real contexts, and provides a multi-user, open-ended design space for real-time collaboration. A VR-based learning environment will allow users to practise social skills in a non-threatening, completely controllable sandbox setting before testing them out in the real world (Schmidt & Schmidt, 2008). The embedded construction kit of a virtual-reality platform then makes it a good primer for active learning through design (Barry *et al.*, 2003). VR has intrinsic appeal as an instructional tool for autistic children who are typically visual learners (Mitchell *et al.*, 2007). Supporting multisensory interactions for multiple users across a distance is another promising feature of VR-based environments because the learning can be extended to multiple settings.

Empirical research examining the design and instructional characteristics of VR-based social skill training is emerging and still limited. Kandalaft *et al.* (2013) constructed and used a set of VR-based simulation of real-world social situations as a social cognition training intervention for young autistic adults. The study reported significant increases in social cognitive measures and emotion recognition, as well as in real life social and occupational functioning post 10-session training. Stichter *et al.* (2014) examined the delivery of an existing curriculum for social competence through VR for autistic youth. They found that a social competence curriculum can be delivered with fidelity in the 3D VR and the 3D virtual learning shows promise for social competence benefits for youth. Bekele *et al.* (2014) and Lahiri *et al.* (2015) studied the usability of VR-based, gaze-sensitive facial expression stimuli and social interaction tasks in a group of autistic adolescents and a group of age-matched typically developing participants. Their studies reported improved task performance of both groups, suggesting the potential of VR as an intervention paradigm to enhance and generalize social interaction skills. Smith *et al.* (2014) investigated the feasibility and efficacy of VR-based job interview training for autistic adults. The investigation indicated the advantage of VR-based training in enhancing participants' observed and self-reported job interview role-play performances. These early efforts have shown potential for the use of VR as a naturalistic and interactive learning platform for autistic individuals.

Virtual games for social skills training

There is emerging research on the design and implementation of computer games as interventions for autistic people. A recent review of serious games for autistic children (Noor, Shahbodin,

& Pee, 2012) reported 13 studies that examined the usage of computer and mobile games for the training of social and communication skills, visual motor coordination and real-life functioning for autistic learners. These studies demonstrated that well-designed serious games can act as cost-effective teaching tools at home, in classrooms or other settings to supplement traditional teaching methods. Battocchi *et al*. (2010) designed and evaluated a collaborative, tabletop jigsaw puzzle game for autistic children. They reported that the puzzle game was effective in facilitating collaborative interaction and triggering behaviors of co-ordination of the task and negotiation. Bernardini, Porayska-Pomsta, and Smith (2014) examined the effects of a serious game called ECHOES in which children interacted with a 3D, intelligent virtual agent (or social partner) through a multitouch LCD display. The game, by having the children interact with the agent and touch interactive objects in a two-dimensional sensory garden, was found to promote children's responding to and initiation of the interactions with the virtual agent partner. Craig, Brown, Upright, and DeRosier (2016) evaluated the efficacy of an online single-player game, called *Zoo U*, for social skills learning by children with behavioral and emotional problems. The online game presented a variety of social problem-solving scenes along with an in-game pedagogical agent. The study found a significant and positive effect of the game-based learning program in enhancing the participants' parent- and self-reported social skills, functioning and self-confidence.

On the other hand, empirical research on the design and efficacy of game-based social skills training, especially VR-based collaborative gaming for autistic individuals, is still limited and sporadic (Whyte, Smyth, & Sherf, 2015). Though individualized and goal-directed game development for autistic individuals is recommended (Noor *et al*., 2012; Whyte *et al*., 2015), research comparing alternative types of gameplay for autistic learners and examining the association between game features and specific social skills to be enhanced is still lacking.

Methods

VR-based collaborative gaming

Using OpenSimulator, we constructed a 3D virtual world that simulates a variety of real-world locales, such as the township, a school, parks and resorts, restaurants, and stores. It also portrays novel, fantasy locales, such as an underwater world and a historical western town. This 3D virtual world offered and simulated three types of social gameplay for autistic learners: (1) competition-themed social gaming via puzzle solving (eg, chess games), inquiry (eg, scavenger hunting) or fast response/action (eg, sports & racing games); (2) role-playing, simulation games (eg, a food serving game) and (3) design-themed architecture games. These games (Figures 1–5) were designed based

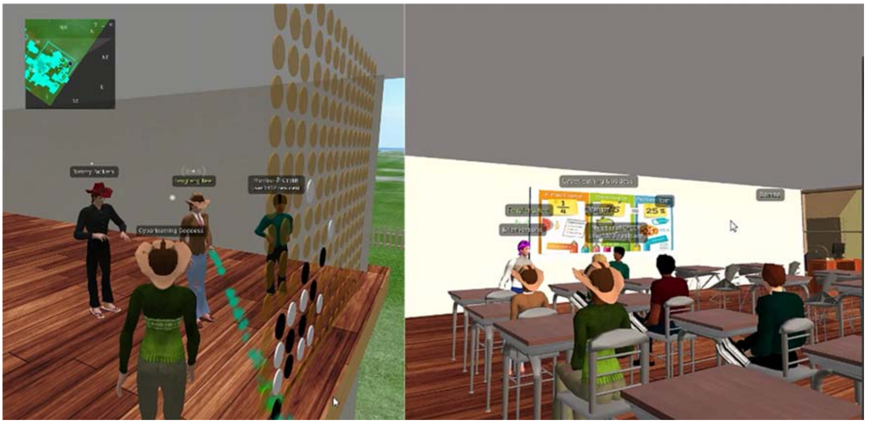

Figure 1: Board chess and mathematical puzzle games [Colour figure can be viewed at wileyonlinelibrary.com]

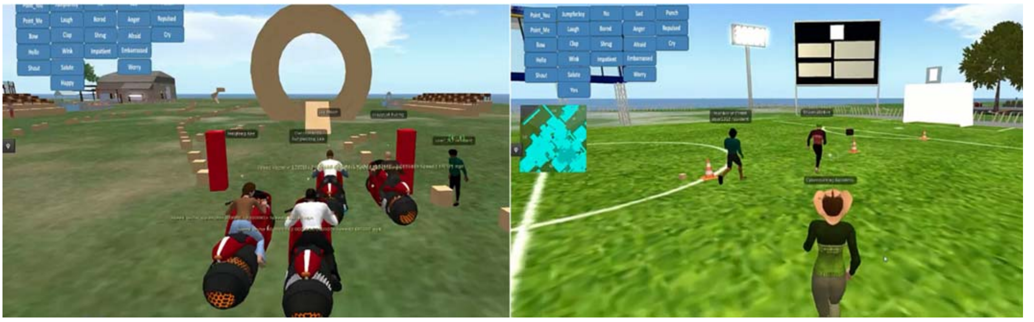

Figure 2: Racing and sports games, such as motorcycle racing and soccer games [Colour figure can be viewed at wileyonlinelibrary.com]

on prior research on game-based learning for autistic individuals. We hypothesized that these games, by involving learners in iterative interactions with play partners in the context of social and design problems, would stimulate their practice of multiple targeted social skills (such as responding, initiation, negotiation, self-identity manifestation and adaptive behaviors). These game tasks and corresponding scenarios were presented in a dynamic pacing and sequence to individual learners based on their learning progresses, needs and preferences. Two trained adult facilitators, puppeteering multiple virtual social characters via a voice-morphing software, provided naturalistic and adaptive scaffolding during participants' gameplay. These puppeteered characters, in the quantity of 3–5 in each activity, were task- and scenario-relevant (eg, partners, clients, supervisors, competitors and consultants). The prompts, following the principle of naturalistic intervention (Rao *et al*., 2008), acted mainly as a supplement to naturalistic prompting presented by the tasks and scenarios. Prompting was both verbal and non-verbal (eg, via animated body postures and movements), and adaptive based on participants' needs: From passive proximity presence (eg, standing before the participant), responding, active initiation or inquiry (eg, repeating a question or request), to modeling or instructive cuing (eg, "Let me show you" or "I think. . .").

Participants and procedure

Eight 10–14-year-old high-functioning autistic children (ie, individuals with a medical or an educational diagnosis of autism, an IQ of 70 or above, and the ability to speak, read, and write)

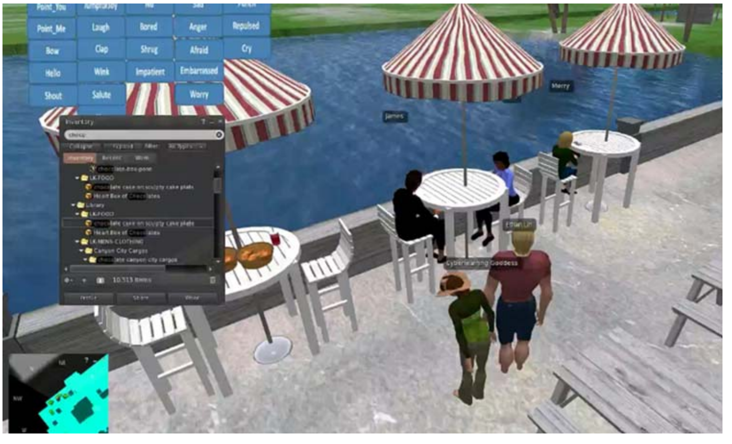

Figure 3: Roleplay games: assuming the roles of foodservice dietitians, waiting staff, amusement-park workers, or interviewers in a simulation setting [Colour figure can be viewed at wileyonlinelibrary.com]

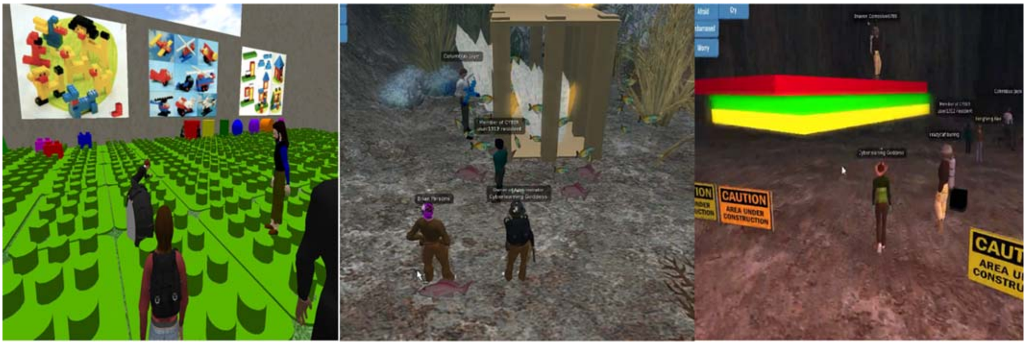

Figure 4: Architecture games: building objects or structures as per the client's request or creatively [Colour figure can be viewed at wileyonlinelibrary.com]

participated in the VR-based learning program at home. The participants included one girl and seven boys, one African-American, one Latino, one Asian, and five Caucasian. Among the participants, one was homeschooled, one attended a public e-learning school and the others attended public schools.

Participants' social interaction performance was measured at 3–5 non-gaming (baseline) observation points (ie, 15-minute intervals). During baseline, participants' social interaction behaviors were observed and coded both infield in a community setting (a public library, at home or a university activity room), and virtually via video conferences and a VR orientation session in which participants explored a plain virtual land without gameplay and in the same natural way as they interacted with a digital tool in everyday life. When the level and trend of the baseline data were stable, the VR-based gaming intervention was introduced to child 1. When the measures of child 1 gained stability over consecutive sessions during the intervention, child 2 began the intervention. This process repeated for each child until the last one. The participation sequence was random and the participation frequency was customized based on each participant's progress and schedule. Each child had to complete each game task to advance to next, which is in line with the mastery model recommended by prior research of social skills training (Craig *et al.*,

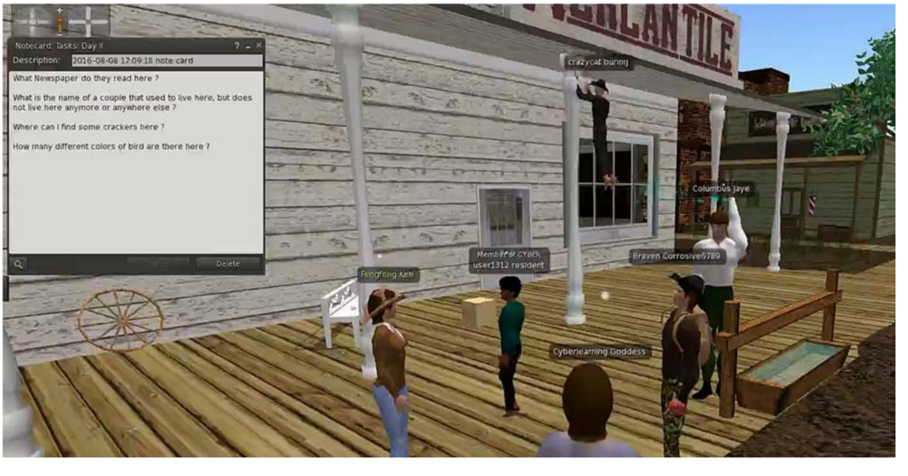

Figure 5: Scavenger-hunting game: seeking/gathering a list of specific items in a fictional setting [Colour figure can be viewed at wileyonlinelibrary.com]

2016; Foster & Bussman, 2007). Participants went through the program in an average of 20.22 hours ($SD = 1.67$), over 16–31 sessions and 0.75–1.25 hour per session.

Data collection and analysis

Behavioral data were collected from the participants via screen recording and on-site observation of their participation actions and reactions. We conducted a behavioral analysis with the recorded social interaction performance in all baseline and intervention sessions (approximately 162 hours in total), using time sampling (per 30 seconds) as the primary unit of coding. The coding focused on the manifestation and frequency of successful enactments of the targeted social skills. The operational definitions of the targeted social skills for the coding were provided below:

- Responding: During intervals of peer initiations, frequency of verbal or nonverbal positive responses (eg, complying with a request) and turn-taking.
- Initiation: Frequency of verbalizations that are not in direct response to a preceding question or that occur at least 5 seconds after a preceding verbalization, and nonverbal initiation of an interaction (eg, wave to greet a peer's avatar).
- Interpersonal negotiation: An indication of recognition of a conflict between one's and another's perspective, a reciprocal exchange (including opinion exchanges and reciprocal communication with a balance of perspective), and verbal collaboration with others and the development of shared goals (Selman, Beardslee, Schultz, & Krupa, 1986).
- Positive self-identity expression: Demonstration of confidence or feelings of worth (Stainback, Stainback, East, & Sapon-Shevin, 1994) by explaining one's own perspectives and preferences, describing individual differences, and identifying with others.
- Cognitive flexibility: Switching between solutions (eg, evaluating alternative moves in a chess game or ideas in a design game), tasks, or perspectives based on the changing contexts or emergent plan or rule changes (Geurts, Corbett, & Solomon, 2009).

The coding followed a structured protocol outlining typical examples of each performance measure. Three trained coders independently coded a randomly selected 20% of the recordings. The interrater reliability was .86. After more formal discussion and reaching 100% agreement on the frequency and occurrence contexts for every core performance measure and their exemplified events, two trained coders then coded the remained recordings.

Based on the social interaction behavioral coding results, we then calculated the average frequency of successful enactments of each targeted social competency (ie, average counts of successful enactments of each competency in a selected 3-minute interval) in each baseline and intervention session. The type of game task and simulated social problem scenario (setting) of each intervention session were also coded. To better examine participants' longitudinal social interaction performance during the progression of game tasks and scenarios, we adopted the time series analysis (Jebb, Tay, Wang, & Huang, 2015) to integrate temporal dynamics in salient pattern detection. We calculated a seasonal index (S-index) using the following formula for each participant with each VR game-based learning task and setting in order to examine the association between the type of VR game tasks/scenarios and a participant's social interaction performance.

$$\text{S}-\text{index} = \frac{\textit{The average frequency of each social competency enactment within each task (or setting)}}{\textit{The average frequency of each social competency across all tasks (or settings)}}$$

If a simulated social scenario (setting) or a game-based learning task's S-index is higher than 1, this specific setting or task has a higher intervention effect in comparison with others, whereas a smaller-than-1 S-index represents a lower intervention effect.

Table 1: Average S-indices (intervention effects) of VR-based game tasks

Game task	Responding	Initiation	Negotiation	Self-identity	Cognitive flexibility
Math game	1.05	0.94	1.00	1.16	1.09
Chess game	0.96	0.93	1.69	0.30	2.12
Sports game	1.04	0.70	0.24	1.06	0.67
Racing game	1.19	1.22	1.50	1.05	0.56
Scavenger hunting	0.99	1.14	1.10	0.83	0.98
Dietitian roleplay	1.15	0.87	0.90	0.88	1.15
Interviewer roleplay	1.13	1.08	1.03	0.97	0.98
Park worker Roleplay	1.00	1.04	1.05	1.06	1.14
Waiter roleplay	1.32	1.64	0.98	1.00	1.04
Client-solicited building	0.97	1.02	1.05	0.66	1.06
Creative building	1.23	0.97	0.98	1.03	0.98

We also conducted a qualitative within and cross-case analysis (Yin, 2009) with the recorded learner behavioral data to further examine the potential differences among varied VR game tasks and settings within and across participants. The qualitative findings helped to illustrate the functional association between VR game task/setting features and learners' participation patterns.

Results

Overall, participants demonstrated an increased performance of the targeted social skills during the intervention phase. A pair-wise *t*-test was conducted to examine the difference between the baseline and the intervention situations in the observed social interaction performance (the total of averaged frequencies of each social skill performance) of participants. The result showed a clear tendency to significance with a large effect size, $t_{(7)} = -2.28$, $p = .057$, Cohen's $d = -.81$. There is a significant improvement of the observed social interaction performance from the baseline ($M = 3.56$, $SD = 2.43$) to the intervention phase ($M = 5.06$, $SD = 1.34$). The table of descriptive statistics was attached in the appendix.

Differential effects of varied game tasks and settings

Average seasonal indices of the VR-based game tasks, as Table 1 outlines, indicated that the intervention effects of most game tasks on the social interaction performance were satisfactory. Yet, the chess game differed from sports game in the intervention effect on three higher order social skills (ie, negotiation, self-identity and cognitive flexibility). The chess game promoted negotiation and cognitive flexibility more than self-identity expression, whereas the sports game lacked effects on negotiation and cognitive flexibility. Role-playing simulation games demonstrated a generally equivalent intervention effect on the five social skills. In comparison with creative artifact building, client-solicited artifact building in architecture games had a lower intervention effect on self-identity expression.

Table 2 summarized the average S-indices of VR-based game settings. In the game settings where the landscape is extensive (eg, a village, a park, a Lego kingdom or an underwater resort), maneuverable and animated objects abounded and participants were involved in exploring the game world. Thus, the intervention effect on the performance of negotiation, initiation or cognitive flexibility was reduced. In the settings where participants' agency was lessened (eg, school locales), the intervention effect was equivalent across social skills but relatively insufficient. When the space for exploration was restricted (eg, a store) or the construction was centralized in a locale (eg, a snow resort), the intervention effect on the targeted social skills was generally enhanced.

Table 2: Average S-indices (intervention effects) of VR-based game settings

Game scenario/setting	*Responding*	*Initiation*	*Negotiation*	*Self-identity*	*Cognitive flexibility*
Sandbox (open world)	1.14	0.81	0.82	0.71	0.73
School classroom	0.98	0.91	0.91	0.79	0.92
School cafeteria	0.94	0.82	0.89	0.86	0.73
Village	1.28	0.95	0.42	0.86	0.54
Amusement park	1.04	0.47	0.34	1.04	0.75
Fish and chip store	1.54	1.65	1.05	0.81	1.08
Lego Kingdom	1.09	0.82	0.58	1.05	0.84
Western Town Resort	0.96	1.04	1.11	0.84	1.24
Underwater Resort	0.87	0.94	0.61	0.82	0.85
Snow Resort	1.01	1.01	1.14	1.42	1.05

Learner variation in game-based social interaction performance

The finding on the differential effectiveness of the VR-based game tasks and settings on each social skill suggested that participants with different social learning needs could benefit from them differently. This inference was further examined via a variation analysis of the S-indices across participants, and a qualitative within- and cross-case comparative analysis of individual learners' engagement and participation patterns during VR gaming.

The coefficient of variation (CV) is a measure for the relative variation of S-indices across study participants. A CV bigger than 1 signifies a relatively high learner variation. The analysis indicated that for most game tasks, CVs of the S-indices were lower than 1, suggesting a relatively low game-task-related learner variation (Supplementary Tables S2 and S3). Yet, VR game tasks tended to create a higher learner variation in the performance of higher order social skills (average $CV = .50$) than in responding and initiation (average $CV = .33$). Specifically, games that require fast action/response in gameplay (eg, sports and racing games) observed a higher learner variation in the negotiation performance ($CVs = 2.24, 1.45$).

The *CV* analysis with the S-indices of game settings across study participants indicated a low learner variation, though the setting-related learner variation was higher in the performance of the higher order social skills ($CV = .58$) than that in responding and initiation ($CV = .37$). In the game settings that simulated real-world community settings (eg, village, park, or restaurant), learner variation (CV) tended to be higher (>1).

Learners' participation in VR-based gameplay

As observed and self-reported, study participants enjoyed VR-based gameplay. All participants had completed every gameplay session as planned. Diversity in the game tasks and settings appeared to support learners' variation in gameplay preferences, their existing social skills, and skills to be supported.

Adaptive arrangement and design of game tasks

Though the variance analysis with the S-indices of the game task types did not indicate an obvious learner variation, qualitative analysis indicated three variant game-based learning patterns by the participants: (1) practicing less desirable social interactions when interacting with the games that are competition-themed or simulate complex real-world social situations (eg, Participants 1, 3 and 6), (2) engaging in play more than social interactions, especially when gameplay requires cognitive flexibility (eg, Participants 4 and 5), and (c) interacting and learning more actively with game tasks that match their interests (eg, Participants 2, 7 and 8).

In the first learner cluster, Participant 1 demonstrated higher level of self-identity expression than others during the baseline, while Participants 3 and 6 demonstrated relatively higher level of performance in responding but less performance of initiating social interactions or negotiation (Supplementary Table S1). When playing competition-themed social games (racing, sports and chess games), they appeared to be overwhelmed by the competition and peer pressure, demonstrated reduced task engagement and higher level of unexpected social behaviors. Participant 1, for example, was found intermittently and abruptly "teleporting" to another virtual region during gameplay and complaining overtly if one tried to track him down at that moment. When asked why, he explained he was in a bad mood and in need of a 2–3 minutes escaping to "calm himself down." Participant 1's teleporting strategy showed a good level of self-awareness, though his task engagement got lessened. He also demonstrated a lack of competency in negotiation and impulse control in virtual collaborative gaming. For example, in a scavenger-hunting game he was supposed to cooperate with others to find treasures hidden in a wild land. He reacted angrily and destructively when his teammates managed to discover more treasures than he did. The same situation occurred in an architecture game: When one of his peers tried to lead the design process, Participant 1 threatened to destroy the structure co-built. Therefore, we tailored the rules of those games to scaffold a positive disposition toward competition and teamwork, by integrating competition and collaboration (eg, a relay racing game) and emphasizing labor division and inter-reliance among gameplay partners (eg, a sub-contract protocol for the architecture game). We also set-up a virtual meditation space for participants where they could take a break from group activities. As observed, the game rule customization promoted Participant 1's performance of negotiation and cognitive flexibility in handling a complex social situation. His disruptive behaviors were obviously reduced during customized game tasks.

Participants 4 and 5 of the second learner cluster, based on parents' report and the baseline behavioral data, were competent in daily communications but lacked flexibility in switching solutions or behaviors during problem solving. They tried to complete all VR game tasks, but they focused on winning games rather than participating in game-based social interactions with others. For example, Participant 4 were so occupied in solving chess puzzles that he would ignore inquiries from the partner. His intense concentration was beneficial for game-task engagement but reduced game-based social play. Similarly, Participant 5 was found involved in individualistic play rather than game-based peer interactions. To encourage play-based social interactions, we modified the activity structure of the VR game tasks to better integrate peer interaction as a valuable part of gameplay. Specifically, we added a "teaching peer" sector to the chess game in which participants would watch and mentor others, thus motivating their performance of social interactions. We also let them shift in being a referee or a player in sports games, to encourage the practice of social problem solving during play.

The third cluster of learners (Participants 2, 7 and 8), especially Participants 7 and 8, had a lower level of social interaction performance than others during the baseline. Although VR games appeared to engage and benefit these learners in general, the game tasks and settings aligned with their interests retained them more. Specifically, Participant 2 preferred the waiter serving game because he loved fish and chips. Participant 7 was a football fan and most involved in the virtual football/soccer games. Participant 8 liked "moving objects." He managed to self-make a variety of air vehicles (eg, using a rug or a ball) and shared them with others in the racing game. To promote these learners' sense of agency during gaming, we involved them in a participatory modification of those game tasks, by encouraging them to revise the menu of food items, name and incarnate non-player characters using sport stars' profiles and co-build a racing park along with self-designed air vehicles.

Customizing the backdrop setting of VR games

Simulating the social environments of everyday settings such as the school, township, entertainment parks, and restaurants was a salient design element of social games in this study. Yet, it was observed that the simulated everyday settings, in comparison to a novel setting (eg, a snow resort for tropical residents) or a fantasy world (eg, an underwater resort), failed to stimulate participants' enthusiasm. In certain cases (eg, school settings), learners tended to get weary and expressed the intent to shift the scenarios. We then alternated the dose of everyday and fantasy settings within gaming sessions for these participants. We also encouraged our study participants to suggest the design of everyday milieus in the games (eg, building a dream school) and used the landscape design opportunity to encourage positive self-identity expression. We rewarded participants with the opportunity to upload their favorite visuals as decorations in virtual locales.

On the other hand, an open land that offers exploration at liberty (eg, the sandbox or the underwater resort) could distract learners from game-based social interactions. We hence balanced and mixed an open and extensive landscape with a bounded, interior setting (eg, a store in the sandbox and a lab in the underwater world). These adaptive design practices had better engaged the participants in social role-playing.

Discussion and Conclusions

The current study indicated that VR-based collaborative gaming enhanced social interaction practice and performance by high-functioning autistic children. This finding supports prior research on the feasibility and effectiveness of using VR and games as the platforms of naturalistic social skills training (eg, Kandalaft *et al.*, 2013; Noor *et al.*, 2012).

The examination of the relative effectiveness of varied types of gameplay suggested that different gameplay could benefit different social skills while role-playing simulation games promote social interaction performance comprehensively. In the category of competition-themed social games, the chess game appears to better promote negotiation and cognitive flexibility than self-identity expression, while the sports game shows the opposite pattern. A potential reason is that identifying varied patterns of rule application and the necessity to shift thoughts and actions during chess play have stimulated the practice of alternative perspectives review and estimation, thus promoting the performance of negotiation and cognitive flexibility. On the other hand, sports and racing games highlight individuals' sense of achievement along with a procedure execution in gameplay, which assists self-identity manifestation but reduces the practice of either negotiation or cognitive flexibility. Moreover, we found that adding obligated rules in artifact design would confine the performance of self-identity expression in the architecture game. All these findings suggested that the practice of specific social skills is framed by core game actions and rules. This pattern is consistent with prior research on the design of purposeful learning in gameplay (eg, Ke, 2016).

The comparison of alternative settings for VR-based gaming indicated that locales that promoted both agency and concentration were most suitable for developing social skills. As observed, locales enabling learner autonomy engage autistic children; yet an extensive space with overly rich contextual cues could distract them from game-based social interactions. This finding supports the advantage of VR as a primer for active learning, while confirming a concern on the environmental distraction when using VR games for education (Virvou & Katsionis, 2008). A consequential design solution is to integrate open and bounded spaces when designing VR game scenarios for learners with special needs.

The study showed mixed results on learner variation in the game-based social interaction participation and performance. On one hand, learner variation in the intervention effects of VR gaming is generally small. On the other, the intervention effects of VR games on the performance of higher order social skills tend to vary across learners, especially when gameplay requires fast action/response and when the setting simulates a real world, intricate social scene. This finding, as qualitative observations suggested, may imply that autistic learners experience a cognitive, sensory, or psychomotor overload during these game tasks and settings and cannot endorse higher order social skills. This interpretation is aligned with the central coherence theoretical account (Happé, Ronald, & Plomin, 2006) of autism. It could be that the sensory or cognitive overload would interfere with the participants' processing of global and contextual information in a complicated social situation (Happé *et al.*, 2006).

A salient design implication of the study findings is that gameplay and game-based learning activities should be adapted based on the competencies and in-situ reactions of learners. Specifically, the study findings suggested the following adaptive design and implementation strategies of VR-based games for autism and social skills training:

- dynamically aligning the level of competition, cognitive challenges and backdrop themes of a VR game with individual learners' competencies and interests;
- adjusting game-based activity structure to encourage clear labor division, interpersonal reliance, and integrate inter-team competition and interpersonal collaboration;
- integrating and rewarding interpersonal interactions as a core game action; and
- enabling participatory modification and design of virtual gaming by autistic learners to increase their sense of agency and identity manifestation, including their need of a break from sensory overstimulation and external interactions.

Overall, the current study findings support the implementation of virtual-reality-based educational games for autistic children. They extend prior research of serious games by providing information about the design and implementation features of a networked, collaborative gaming environment in which autistic children engage in naturalistic, play-mediated social skills training. This study involves a relatively small sample and mainly in-game performance measures, due to its focus on in-situ, design-based research of VR gaming for autistic learners. Future research should further examine the effectiveness of different types of game tasks and settings on specific social skills development, via an experimental research design and including measures of social skills learning transfer at a follow-up phase. Future research should continue investigating how the adaptive, game-based social skills training will tap into participants' strengths and interests, how gameplay can help to identify participants' strengths in social interactions, and what types of social environment work best for them. It is also warranted to conduct research on whether and how VR-based collaborative gaming will promote the knowledge and awareness of typically developing children in communicating with autistic peers.

Acknowledgement
This work was supported by the Spencer Foundation [grant 2014].

Statements on open data, ethics and conflict of interest

This study was conducted with the university IRB (human subject protection) approval. Being constrained by the human subject protection policies, the qualitative nature of the data, and learners with special needs involved in this study, the original study data are not open. Anonymous quantitative and qualitative analyses results are accessible upon request. There is no conflict of interest in the work that we are reporting here.

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