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Virtual-Reality-Based Social Interaction Training for Children with High-Functioning Autism

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ABSTRACT. Employing the multiple-baseline across-subjects design, the authors examined the implementation and potential effect of a virtual-reality-based social interaction program on the interaction and communication performance of children with high functioning autism. The data were collected via behavior observation and analysis, questionnaires, and interviewing. The children participants demonstrated increased performance of responding, initiation, greeting, and positive conversation-ending during the intervention, and improved social competence measures after the intervention. The study also contributed salient themes on the adaptive design of a virtual-reality-based learning environment for learners with special needs. The study findings should extend the discussion on the design and usage of technology-supported informal learning environment for children with diverse characteristics and learning needs.

Keywords: autism, multiple-based across-subjects design, social interaction training, virtual reality

In recent years, increasing numbers of children have been identified as having autism spectrum disorders (ASD). Reports indicate that 1 in 88 American children have ASD and 1 in 58 boys has ASD (Autism Speaks, 2009; Centers for Disease Control and Prevention, 2012). The core features of ASD are profound deficits in the acquisition and use of social skills and social competence. These deficits impact children's ability to perform a range of verbal and nonverbal communications and social interactions, such as turn taking in conversation, taking the listener's perspective, and understanding and expressing emotions via speech prosody, gesture, body posture (Goldstein, 2002; Spence, 2003; Weiss & Harris, 2001; White, Keonig, & Scahill, 2007). Social skill deficits also contribute to academic and occupational underachievement (Howlin & Goode, 1998; Webb, Miller, Pierce, Strawser, & Jones, 2004).

Among children with autism, those diagnosed with Asperger syndrome or high-functioning autism (AS/HFA) may be the fastest growing segment (Rao, Beidel, & Murray, 2008; Sansosti & Powell-Smith, 2006). Different from children with other subtypes of autism, children with AS/HFA have intelligence and language within the normal range of functioning (American Psychiatric Association, 2012). Similar to other children with autism, however, they have social skill deficits that include but are not limited to problems initiating and maintaining social interactions, difficulty sharing affective experience or understanding the perspectives of others, and deficiency in cooperation and negotiation (Macintosh & Dissanayake, 2006; Weiss & Harris, 2001).

Therefore, it is important to involve children with AS/HFA in intervention or training programs to improve their social and communicative competence of performing initiation, response, negotiation, and collaboration with peers (Downing, 2005). In this study we aimed to examine the implementation and potential effect of a virtual-reality-based (VR-based) social interaction program on the interaction and communication performance of children with AS/HFA.

Overview of Current Social Interaction Training for Children with Autism

Multiple strategies have been used and found effective in teaching social interaction and communication for children with autism. Frequently reported intervention strategies include but are not limited to didactic instruction (Odom & Strain, 1986), pivotal response training (e.g., Pierce & Schreibman, 1997), incidental teaching (e.g., McGee et al., 1999), peer modeling (Carr & Darcy, 1990), social stories (Sansosti & Powell-Smith, 2006), social scripts (e.g., Barry et al., 2003; Goldstein & Cisar, 1992; Krantz & McClannahan, 1998), and class-wide interventions (e.g., Kamps, Barbetta, Leonard, & Delquadri, 1994).

Adult reinforcement and guidance is important for the social skill learning of children with autism. There is solid

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evidence on the effectiveness of social skills training that emphasize the usage of adult initiation and monitoring, and explicit prompting in a structured learning setting (Delprato, 2001; Schreibman & Ingersoll, 2005). Odom and Strain (1986), for example, deployed a teacher-antecedent intervention in which teachers prompted and reinforced children with autism to initiate socially to peers. However, teacher-led social interaction intervention has been shown to compromise the spontaneous use of the social behavior, prevent generalization to the natural environment, and be not representative of natural adult–child or peer interactions (Schreibman & Ingersoll, 2005).

Recent practices of social interventions for children with autism have seen the fading of direct intervention for in situ intervention, and the transferring control for prompting social interactions from teachers' verbal antecedents to transportable or naturally occurring stimuli (McConnell, 2002). In comparison to more structured techniques, naturalistic training techniques are those that are conducted in loosely controlled contexts, let the child initiate the interaction, and incorporate the target child's preference into the teaching materials and episodes (Delprato, 2001; Pierce & Schreibman, 1997). For example, in the incidental teaching intervention developed by McGee et al. (1992), the adult agent waits for the target child to initiate a request for a desired item or activity, and then prompts an elaborated response. Empirical evidence suggests that naturalistic strategies, in comparison with the more structured techniques, lead to more generalized and spontaneous use of skills and are more enjoyable for trainees (Charlop-Christy & Carpenter, 2000; Delprato, 2001; Schreibman & Ingersoll, 2005).

Despite its promising nature, naturalistic interventions for children with autism are still an understudied, but worthy candidate for further development and testing (Spence, 2003; White et al., 2007). Particularly, the previous naturalistic interventions have been typically conducted in classrooms and target only social interactions in the school setting, with few extending the setting to child's home or involving peers and interactions outside the classrooms.

Technology Integration in Social Interaction Training

Computing technology is a highly effective teaching medium for individuals with autism (Beaumont & Sofronoff, 2008; Moore, McGrath, & Thorpe, 2000). It has intrinsic appeal as an instructional tool for children with autism who are typically visual learners and tend to excel in treatment materials or communication systems that rely on visual stimuli (Schreibman & Ingersoll, 2005). Empirical research has shown that people with autism tend to enjoy computerized intervention programs and have made significant learning gains using various technology-integrated training packages, such as video modeling, computer-assisted instruction, cartoons, and computer games (e.g., Beaumont & Sofronoff, 2008; Bernard-Opitz, Sriram, & Nakhoda-Sapuan, 2001; Charlop-Christy & Daneshvar, 2003; Moore et al., 2000; Silver & Oakes, 2001).

However, generalization of knowledge to real-life contexts appears to be limited in prior computerized learning programs for autism (Beaumont & Sofronoff, 2008). A major reason hypothesized by Parsons and Mitchell (2002) is that most computerized programs for autism have not created a role-play and naturalistic situation in which the transfer of skills between taught and real contexts becomes possible, and hence failed to offer in situ social skills training.

Virtual Reality for Social Interaction Training for Children with Autism

Recently, Internet-based VR, such as Second Life developed by Linden Lab (San Francisco, CA), has been proposed as an emerging and promising learning platform to support a variety of education activities. VR or a virtual world is a computer-generated, three-dimensional representation of real-life environments. A user can autonomously navigate around a VR (in the form of graphical representations of themselves, known as avatars) and interact with simulated objects and other avatars (via both verbal and nonverbal communication) in real time at the same pace one would experience events in the real world (Mitchell, Parsons, & Leonard, 2007; Parsons, Leonard, & Mitchell, 2006). The educational activities supported by VR include role-play, designing and building virtual exhibitions and presentations, and interacting with instructor-built simulations of physical or procedural processes. VR's usefulness as an education tool has been evidenced in the fields of health science, art, and language, but is underutilized as a learning tool for students with special needs (e.g., Boulos, Hetherington, & Wheeler, 2007; Kumar et al., 2008).

VR has been considered as a useful tool for individuals with autism because it could support the generalization of social interaction learning to the real world situations while providing a controlled and safe learning environment (Beaumont & Sofronoff, 2008; Parsons & Cobb, 2011; Parsons & Mitchell, 2002; Schmidt & Schmidt, 2008; Strickland, McAllister, Coles, & Osborne, 2007). In particular, Parsons and Mitchell (2002) argued that VR allows role-play with flexible scenarios and, hence, can increase cognitive flexibility of individuals with autism. Moreover, individuals with autism have opportunities to practice diverse responses to simulated real-world scenarios with reduced anxiety toward the social interaction (Moore et al., 2000). Prior research shows that individuals with autism could transfer newly learned knowledge, such as fire safety skills, tornado safety skills, and road safety skills, from VR-based training programs to real-world situations (e.g., Josman, Milika Ben-Chaim, Friedrich, & Weiss, 2008; Self, Scudder, Weheba, & Crumrine, 2007; Strickland et al., 2007). A recent empirical study also revealed the possibility of VR as a training platform to teach individuals with autism to recognize others' thoughts and feelings (Kandalaft, Didehbani, Krawczyk, Allen, & Champman, 2012).

Given the fact that the practice of VR-based social interaction training for individuals with autism is still new, there are not many published research in this area. Wainer and Ingersoll (2011) reviewed 14 studies that used innovative technologies in social interaction training programs for people with autism. Two VR studies were introduced in the review and were conducted by the same researcher group. Mitchell et al. (2007) examined the effects of virtual environments on social understanding training to young adults with autism. Six adolescents with autism participated in a 6-week training program in which participants learning social understanding via a virtual-environment-based café, with scaffolding from adult facilitators. The study found significant improvement in participants' judgments and explanations about decisions.

A few other studies explored the use of virtual agents to promote language learning of children with autism, and found an improvement of language skills after interventions and positive attitude of participants toward virtual agents (Bosseler & Massaro, 2003; Ryokai, Vaucelle, & Casell, 2003; Tartaro & Cassell, 2006). For example, Bosseler and Massaro (2003) developed a three-dimensional computer animated tutor called Baldi, who taught vocabulary and functional language use to children with autism. Participants identified significantly more words after intervention, and recalled 85% of new words one month after the program completion. Another research group (Foster et al., 2010) developed a multimodal learning environment (ECHOES) to teach shared gaze and joint attention, by letting children with autism engage in interactive narratives with virtual characters through a "sensory garden" and touchable screen.

A research group in Taiwan (Cheng, Chiang, Ye, & Cheng, 2010; Cheng & Ye, 2010) explored the impact of a three-dimensional, collaborative virtual learning environment on the reciprocal social interaction behaviors and the performance of social empathy of children with autism. Two of three participants showed improved performance of eye contact, listening to others, and social empathy during both verbal and nonverbal communication with the three-dimensional characters. Parents also reported their children's improvement on daily-life social tasks, such as greeting people and having more social interaction with others.

Recently, Kandalaft et al. (2012) developed a Second-Life-based VR environment with simulated daily-life social settings, such as an office building, coffee house, school, and park. The intervention was designed to provide young adults with high functioning autism with opportunities to experience realistic and diverse social scenarios and improve social skills, social cognition, and social functioning. The study reported that the VR intervention had positive effects on emotion recognition and theory of mind.

Summary

Major reviews on the social skill interventions with children with autism (e.g., McConnell, 2002; Rao et al., 2008; Schreibman & Ingersoll, 2005; Spence, 2003; White et al., 2007) unanimously reported that much work remains to be done in order to provide relevant and effective interventions for children with autism. In particular, it is warranted to develop the social skill training programs that can be easily implemented in naturalistic settings to improve the maintenance of skills.

Prior research has suggested that the emerging VR technology enables the creation of an alternative, versatile learning setting in which children with autism can engage in different types of in situ interactions, with an extended agent community (e.g., peers and adults at the school, home, local, or distant places), and over an extended time period. As yet, though, limited research has explored the design and implementation of VR as a tool for teaching individuals with autism. Therefore, in this study, we examined the use of a Second-Life-based social interaction program for children with AS/HFA.

Method

Because the study involved a special learner group—children with autism—a large sample for an experimental comparison was extremely difficult, if not impossible. At the same time, the field of technology-integrated intervention needs much more empirical evidence on what works for whom, under what conditions, and for which tasks (National Center for Technology Innovation, 2012). Therefore, the multiple-baseline across-subjects research design was adopted in this study. The multiple-baseline across-subjects design is sensitive to individual differences. Children with autism, even those with the same diagnosis, often experience unique needs.

The study addressed the following research questions:

Research Question 1: What are the potential impact of the VR-based intervention on the social interaction and communication performance (i.e., responding and maintaining interaction, initiating interaction, and nonverbal communication) of children with autism?

Research Question 2: What specific features and tasks of the VR-based intervention promoted the target children's social interaction performance?

Participants and Setting

For the current study, four children in Grades 4–5 who had a formal medical or educational diagnosis of AS/HFA were recruited from local schools. The participants were verbal as reported by their parents and special education teachers. The four children's information is outlined in Table 1. Seven adult volunteers, who were all education majors and 27–35 years old, including three men and four women, were also recruited. Along with the researchers of this study, they acted as paraprofessional facilitators and communication partners for the target children during the VR-based social interaction activities. The baseline and intervention

TABLE 1. Participants Information

Participants	Profile	Observation Notes
Subject 1—FH	Grade 5, age 10 years, Asperger syndromes, White/Caucasian	FH was shy and passive during conversation during the baseline condition. She had narrow topics of interests (i.e., animals and computer games), and demonstrated short attention span with what she was not interested in. She did not tend to make eye contact or use facial expressions during conversations at the early stage of the program. However, she was competent and elaborative when communicating on the topics that she enjoyed. She also voluntarily greeted people. As a computer gamer, she used computer and Internet every day, and demonstrated excitement and engagement in interacting with the Second-Life-based virtual environment.
Subject 2—K	Grade 5, age 10 years, Asperger syndromes, PDD-NOS, receiving language services, African American	K was shy during the baseline condition, and it was hard to hear his voice. He responded to a conversation initiation with either "Yes" or "No," in a very soft voice and without eye contact. We observed that K lacked skills with sentence completion during conversations. He also typed slowly and was not good at spelling.
Subject 3—MH	Grade 5, age 10 years, Asperger syndromes, receiving language therapy consultation, White/Caucasian	MH was an energetic boy whose after-school fun activities included computer-based story writing (with pictures sought from Internet) and video game playing. He usually stayed in his mom's office after school, and was observed deftly responding to the questions or initiations from her mom's colleague or students. However, he seemed not comfortable interacting with strangers. He did not greet us when we first met, and did not make eye contact during conversation either. He showed obvious excitement toward the three-dimensional virtual reality environment and demonstrated advanced computer skills.
Subject 4—CR	Grade 4, age 9 years, Asperger syndromes, ADHD, White/Caucasian	During the first meeting, she greeted us with smile and eye contact and gave us a 10-min self-introduction about herself (emphasizing that she was "strong," a "tomboy," and a "gamer"). She self-reported preferring color and clothes that were less "girlish." She demonstrated a good understanding of basic etiquettes of greeting and conversation ending. She was also competent in answering questions with full sentences and providing elaborative explanations. It was observed that she blinked her eyes a lot during conversation, but managed to maintain eye contact. She also demonstrated excitement with the Second-Life-based virtual environment and advanced computer skills.

Note. PDD-NOS = pervasive developmental disorder not otherwise specified; ADHD = attention deficit hyperactivity disorder.

sessions, based on the children's preference, took place at their home, parents' offices, or at the schools' computer labs during off-hours to promote their sense of comfort with the performance setting.

Intervention

The VR-based social interaction program involved three social interaction tasks: (a) recognizing body gestures and facial expressions of a virtual communication partner, (b) responding and maintaining interactions at a school cafeteria, and (c) initiating and maintaining interactions at a birthday party. Correspondingly, the Second-Life-based virtual world simulated two social interaction settings, a virtual school (including a playground and a school cafeteria) and house parties (as depicted by Figures 1–3). In Task 1, a target child, when spending his or her first day at the virtual school, got to meet with a peer student in the school lobby. In order to befriend with this peer, the child was requested to identify what this peer likes or dislikes (e.g., about foods, animals, hobbies, academic subjects), based on the peer's facial expressions and body gestures. In Task 2, the target child would need to order lunch in the school cafeteria, take a seat at a café table, respond to

FIGURE 1. Task/Scenario 1: Body gesture and facial expressions recognition (color figure available online).

FIGURE 2. Task/Scenario 2: Cafeteria (color figure available online).

FIGURE 3. Task/Scenario 3: Birthday party (color figure available online).

the interactions initiated by peers sitting around the same table, and maintain interactions with others who came to the table. In Task 3, the target child would attend birthday parties, with alternated roles of a guest and the party host.

Procedure

A preintervention social interaction baseline was established for all four children participants or subjects. Behavior data on participants' daily communication were collected at school, home, and a community library during three 1-hr sessions over 1 week to establish a stable baseline. The intervention was introduced to Subject 1, and at the same time the other subjects' baseline condition was continued. This procedure was repeated with four subjects. When Subject 1 reached the 80% accuracy criterion in Task 1, he or she began Task 2, and Subject 2 began the Task 1 intervention while Subject 3 continued in the baseline condition. When Subject 2 reached the 80% accuracy criterion on Task 1, he or she proceeded to Task 2 and the Task 1 intervention started for Subject 3. The procedure was the same for Subject 4. Each child participant received six to nine intervention sessions (two to three sessions per task for three social interaction tasks), with two to three sessions per week (depending on the child's rate of progress). Each intervention session lasted approximately 60 min. The intervention program commenced with a 1-hr orientation session, in which the VR-based interaction tasks were explained and participants practiced navigation (e.g., how to walk, fly, teleport) and communication (e.g., doing text and voice chat) in the Second Life game.

Adult facilitators were trained based on a semistructured protocol that was developed based on the prior research on initiating, prompting, and reinforcing social interaction for children with autism and refined during the project. They were all technologically competent and went through a 3-hr orientation on Second Life.

During an intervention, the target child and his or her adult facilitators all logged on to and lively interacted with each other in the Second-Life-based virtual world. One facilitator sat along with the target child before the computer. This facilitator provided technical help and guidance on online communication as requested by the child. Other facilitators, via the VR and virtual avatars, role-played scenario-contextualized interaction agents and performed situation-specific, naturalistic social communication with the child.

Data Collection and Analysis

Observation and dependent measures. Each participant was observed and videotaped during baseline and intervention sessions. During the intervention, both virtual and physical communication behaviors of the participants were observed and digitally captured for later analysis. Frequency data were collected on each target social interaction behavior. Rate per hour or session was reported. Baseline and intervention data were collected simultaneously for the targeted social interaction and communication behaviors. Data were coded by two coders. The observation of participants' physical expressions and behaviors focused on their reactions toward the virtual learning environment and the sequential record of the contextual events for their virtual performance.

In this project we focused on the following social interaction and communication skills of the target child (based on the definitions by Pierce & Schreibman, 1997; Selman, Beardslee, Schultz, Krupa, & Podorefsky, 1986; Webb et al., 2004):

1. *Responding and maintaining interaction*: Continued engagement in the same verbal or nonverbal activity with peers. During intervals of peer initiations, verbal or nonverbal positive responses (e.g., complying with request), turn taking, and appreciation expression were scored as maintaining interaction.
2. *Leading or initiating interaction*: Initiation comprising verbalizations that are not in direct response to a preceding question or that occur at least 5 s after a preceding verbalization. Greeting and ending a conversation positively, in both verbal and nonverbal expressions (e.g., wave to greet a peer's avatar or wave goodbye), were also scored as part of interaction initiation.
3. *Nonverbal communication*: Interpreting and recognizing facial expressions and body postures correctly.

Pre- and postintervention measures. The Social Skills Questionnaire: Parent and Pupil Forms (SSQ; Spence, 1995) were used to evaluate children's social competence. The 30-item questionnaire requires the respondent to indicate how accurately each of 30 statements describes a child's social behavior over the past 4 weeks. Parents and children completed the SSQ parent and pupil versions both before and after the intervention. Assessment of Perception of Emotion from Facial Expression and Posture Cues (Spence, 1995) was used to examine children's ability to identity facial expressions and body postures displayed in photographs. All of the aforementioned measures have good internal consistency and have been used in prior studies of social interaction skills programs for autistic populations (e.g., Beaumont & Sofronoff, 2008; Wetherby, Watt, Morgan, & Shumway, 2007).

Subject satisfaction interviewing. A satisfaction interviewing was conducted after the intervention to measure participants' and parents' satisfaction with the VR-based learning program and their perceptions on VR-based interaction and learning experiences.

Analysis. The researchers conducted graphical or visual analysis (Alberto & Troutman, 2006) to examine the potential impact of the VR-based intervention on the targeted social interaction performance within and across participants. Comparisons were made between the pre- and postintervention measures to examine the potential communication competence improvement. Qualitative thematic analysis was conducted with the video recordings of the social interaction activities and the interviewing results to explore the salient themes on the interaction between the target children and the intervention tasks.

Results

Acquisition of Targeted Social Interaction Skills

All four children met criterion (80% correct for performance trials during each task) for each Second-Life-based social interaction task. Different tasks were associated with different numbers of successful trials to criterion, but progress was generally more obvious and the trials were more frequent during Tasks 2 and 3.

Responding and Maintaining Interactions

Responding. The data for the baseline and intervention sessions across subjects are shown in Figure 4. In general, participants performed an average of 32–43 successful trials of responding per session during the baseline condition, indicating a degree of competence in their responding performance. Still, they demonstrated an increase in the performance of responding during the intervention sessions, especially those of Task 2 (the Cafeteria scenario). A cross-subject comparison (Figure 4) indicated that Subjects 2–4 had generally equivalent responding performance during the baseline condition. When the intervention started, Subject 2 demonstrated more responding performance than Subjects 3 and 4 who were still on the baseline situation, and the same trend was observed with Subject 3 when compared with Subject 4 on the baseline situation.

For Subject 1 (FH), the responding performance varied among alternative tasks during intervention sessions. Overall, she performed an average of 50.4 successful trials of responding during the intervention sessions, in comparison with an average of 43.5 successful trials during the baseline condition. During the intervention sessions of Task 2, FH's responding performance was obviously increased to an average of 87 trials per session, but it was not maintained during the Task 3 sessions (the Birthday Party scenario).

For Subject 2 (K), there was generally a trend of increase in the performance of responding during the intervention sessions, from an average of 32 successful trials per session in the baseline condition to an average of 63 per session in the treatment condition. His responding performance was increased particularly during the second or third

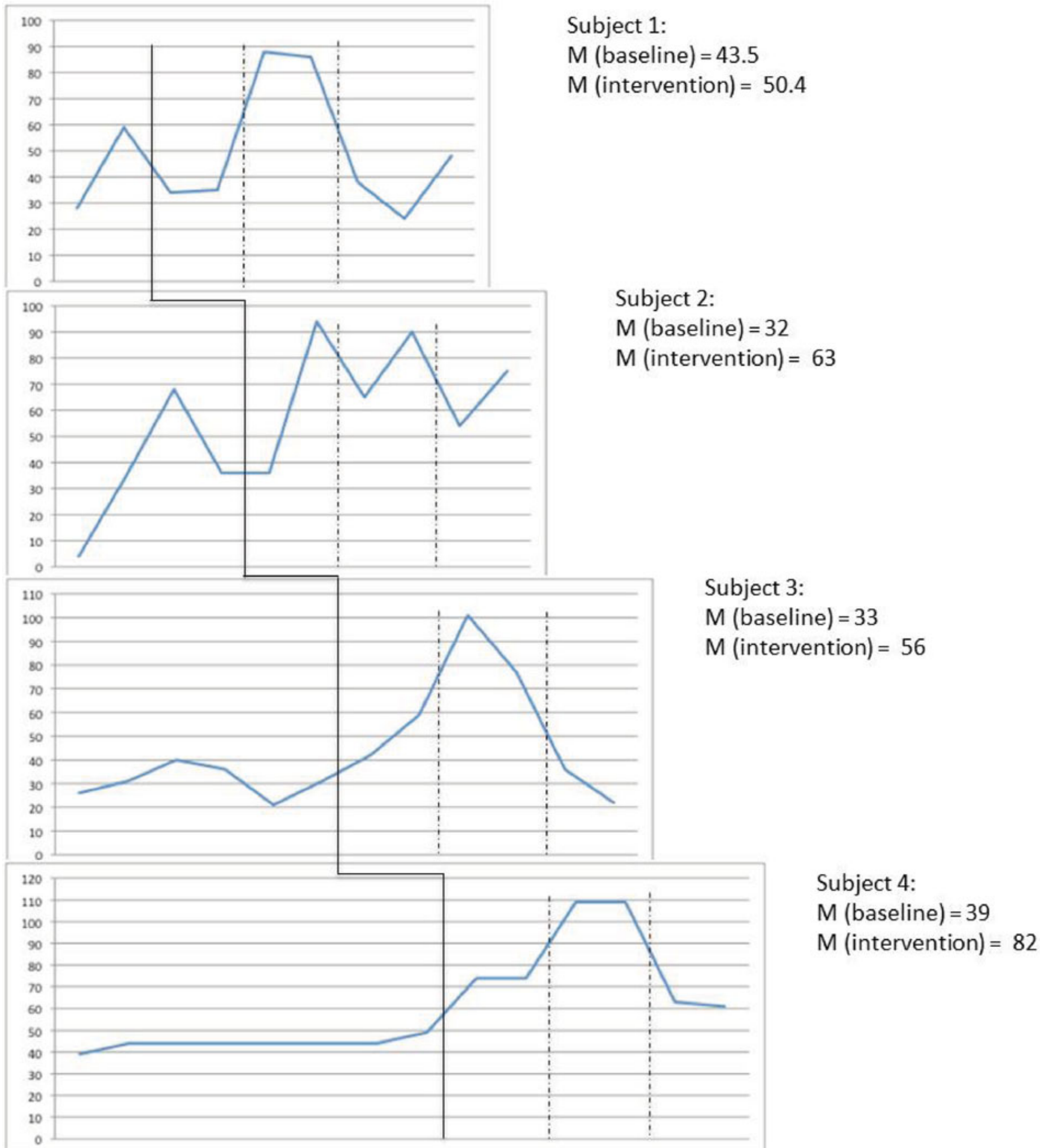

FIGURE 4. Responding (successful trials per session). The solid line represents the start of the intervention condition; the two dotted lines represent the start of Task 2 and Task 3 phase of the intervention (color figure available online).

intervention session during each intervention task, suggesting that he performed better with more time or practice on each scenario.

For Subject 3 (MH), there is an increase in his responding performance during Task 1 and 2 sessions of the intervention condition. In comparison with an average of 33 successful trials per session in the baseline condition, there was an average of 51 successful trials of responding per session during the sessions of Task 1, and an average of 89 trials per session during the sessions of Task 2. His performance of responding declined during the intervention sessions of Task 3, especially when he acted as the host of the virtual birthday party.

Similarly, Subject 4 (CR) demonstrated an obvious increase in responding performance during the intervention sessions (with an average of 82 successful trials per session) from the baseline condition (with an average of 39 successful trials per session). In particular, her responding performance was increased most during Task 2 intervention sessions (with an average of 109 successful trials per session).

Turn taking. The data for the baseline and intervention sessions across subjects are shown in Figure 5. Subjects' turn-taking performance varied during the intervention tasks. Subject 1 (FH) performed an average of 6.5 successful trials of turn taking during the baseline condition. Her performance of turn taking was similar during Task 1. A potential reason may be that this social interaction task focused on reactive performance. Her turn-taking performance was improved obviously during the later phase of Task 2 (to 33 successful trials per session). As observed, she became more involved in interactive dialogues in this session, appeared to get acquainted with the virtual social setting and her virtual communication partners. Her turn-taking performance during Task 3 sessions declined when she acted as a guest in the Birthday Party scenario, but still achieved an average of 14.3 successful trials per session during Task 3.

For Subject 2 (K), there was an obvious increase in turn-taking performance during Task 1, from an average of 2.5 successful trials per session in the baseline condition to an average of 32 trials per session during Task 1 sessions. As observed, K reacted actively to the topics on food, hobby, and animals during Task 1, which involved only one-to-one communication with a single partner. His turn-taking performance was not maintained during the later intervention sessions. As observed and reported, K was not as competent as the other participants in sentence completion and public speaking. His turn-taking performance declined on Tasks 2 and 3 when the social interaction involved multiple communication partners. As observed, in many cases he would respond to a peer initiation with a simple "yes" or "no" without elaboration, thus making the conversation less interactive or necessary for turn taking.

Subject 3 (MH) did not demonstrate increase in the turn-taking performance during most intervention sessions. But he demonstrated a strong turn-taking performance during the later phase of Task 3, from an average of 16.3 successful trials per session in the baseline condition to 33 successful trials per session. During this session, he acted as the host of the virtual birthday party. As observed, he had taken a leader role during the social event and was actively involved in interaction initiation and maintenance with multiple communication partners.

Similar to Subject 3 (MH), Subject 4 (CR) demonstrated a strong turn-taking performance during the baseline condition (with an average of 12.5 successful trials per session). Her turn-taking performance declined to zero during the intervention sessions of Task 1. A notable observation was that she demonstrated a clearly different communication style in the virtual social setting. She appeared to be an active and energetic communicator in the face-to-face setting. For example, the first time when she met with the researchers, she delivered a 5-min speech about herself, and responded to every question or initiation with an elaborative explanation. Yet in the virtual world, she became a reserved, reactive communicator. In Task 3 she performed more question answering with a short straight response, which made it hard to promote turn taking between her and the communication partners.

Appreciation expression. The data for the baseline and intervention sessions across subjects are shown in Figure 6. Overall, there was a trend of increase in the performance of appreciation expression from the baseline condition to the intervention condition. For Subject 1 (FH), the increase occurred during Task 2 and Task 3 sessions of the intervention, from zero in the baseline condition to a range of 2–16 successful trials per session during sessions for Tasks 2 and 3. In particular, the increase was strong when she acted as the host of the virtual birthday party (up to 16 successful trials per session). A similar trend was observed with Subject 2 (K). He performed 0 successful trial during baseline condition, but contributed an average of 8 (a range of 5–11) trials per session during Task 3 sessions. For Subject 3 (MH), there was a steady and increased performance of appreciation expression during Task 3 sessions, with a range of 2–3 successful trials per session (versus 0 trial in the baseline condition). For Subject 4 (CR), the increase of appreciation-expression performance also started in Task 3 condition (with an average of four and a range of 2–6 successful trials per session). In general, the task of birthday party hosting appeared to promote appreciation-expression performance for all participants.

Initiating or Leading Interactions

Initiation. The data for the baseline and intervention sessions across subjects are shown in Figure 7. Overall, the initiation performance was increased during the intervention sessions for most participants, particularly in the Task 3 phase. For Subject 1 (FH), the trend of increase started from Task 1, continued steadily during Task 2 (with an average of six successful trials per session) and reached the highest point during Task 3 (with an average of 10 successful trials per session). For Subject 2 (K), the performance of interaction initiation increased from an average of two trials per session in the baseline condition to an average of 21.5 trials per session in the Task 1 condition, and then an average of 34 trials per session in the Task 3 condition. The birthday party hosting task for K was associated with the most initiation trials.

For Subject 3 (MH), there was an obvious and steady trend of increase during the Task 2 and 3 sessions. Starting from Task 2, MH's initiation performance was increased from an average of 8 trials per session in the baseline condition to an average of 13.5 trials per session in Task 2, and an average of 52.5 trials per session in Task 3. Notably, he demonstrated

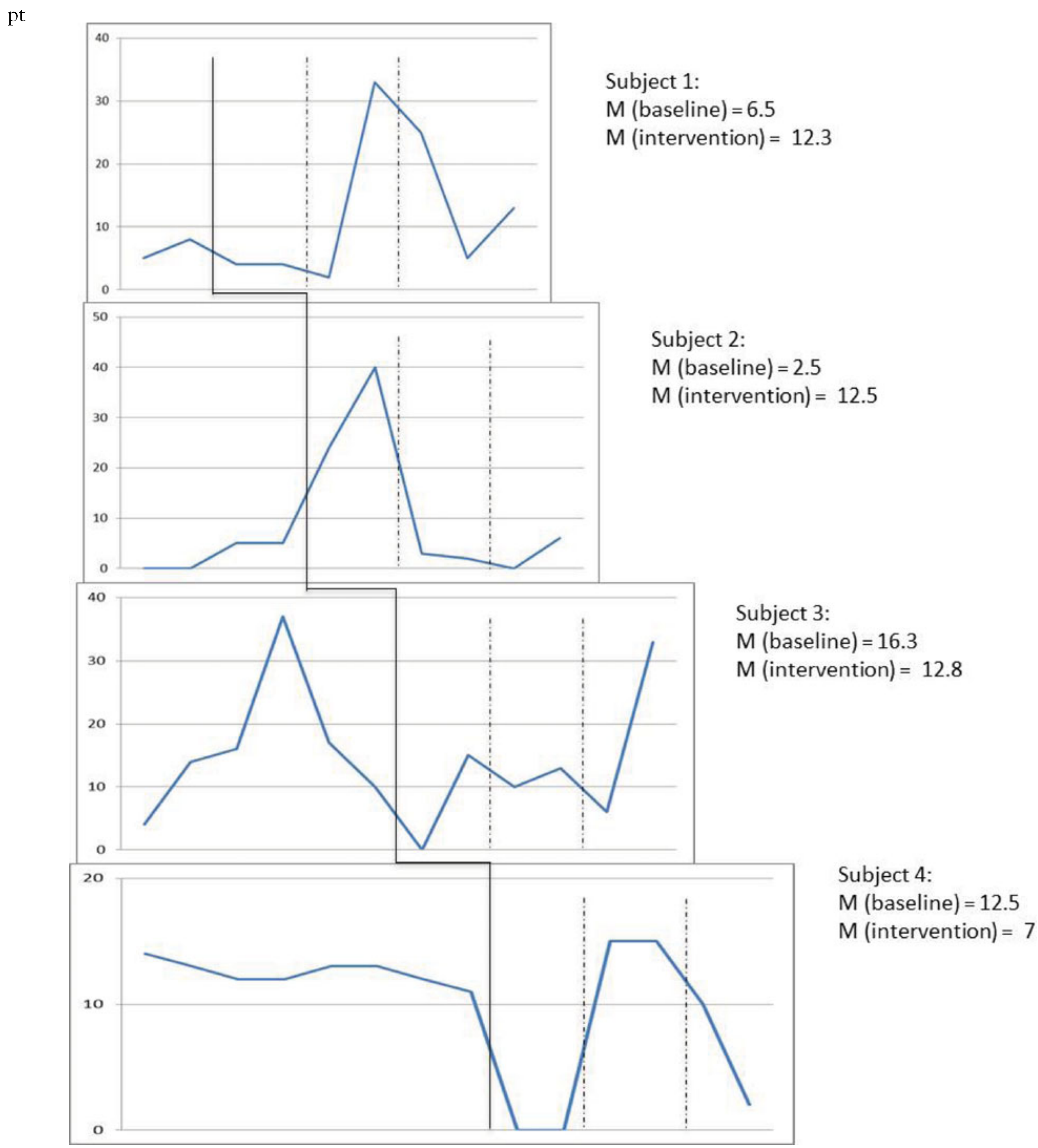

FIGURE 5. Turn taking (successful trials per session). The solid line represents the start of the intervention condition; the two dotted lines represent the start of Task 2 and Task 3 phase of the intervention (color figure available online).

the capability of finding appropriate, new conversation topics to initiate an interaction in Task 3 when he role-played as a party host. For example, he innovatively suggested playing the rock-scissor-paper and hide-and-seek social games at the virtual birthday party (by taking the advantage of the body gesture feature and the landscape of the virtual world), and explained rules patiently to all communication partners. He demonstrated an active and sincere manner as a party host who led conversations on a variety of topics, such as weather, favorite party food, and birthday songs.

In comparison, Subject 4 (CR), the only participant also diagnosed with attention deficit hyperactivity disorder, had

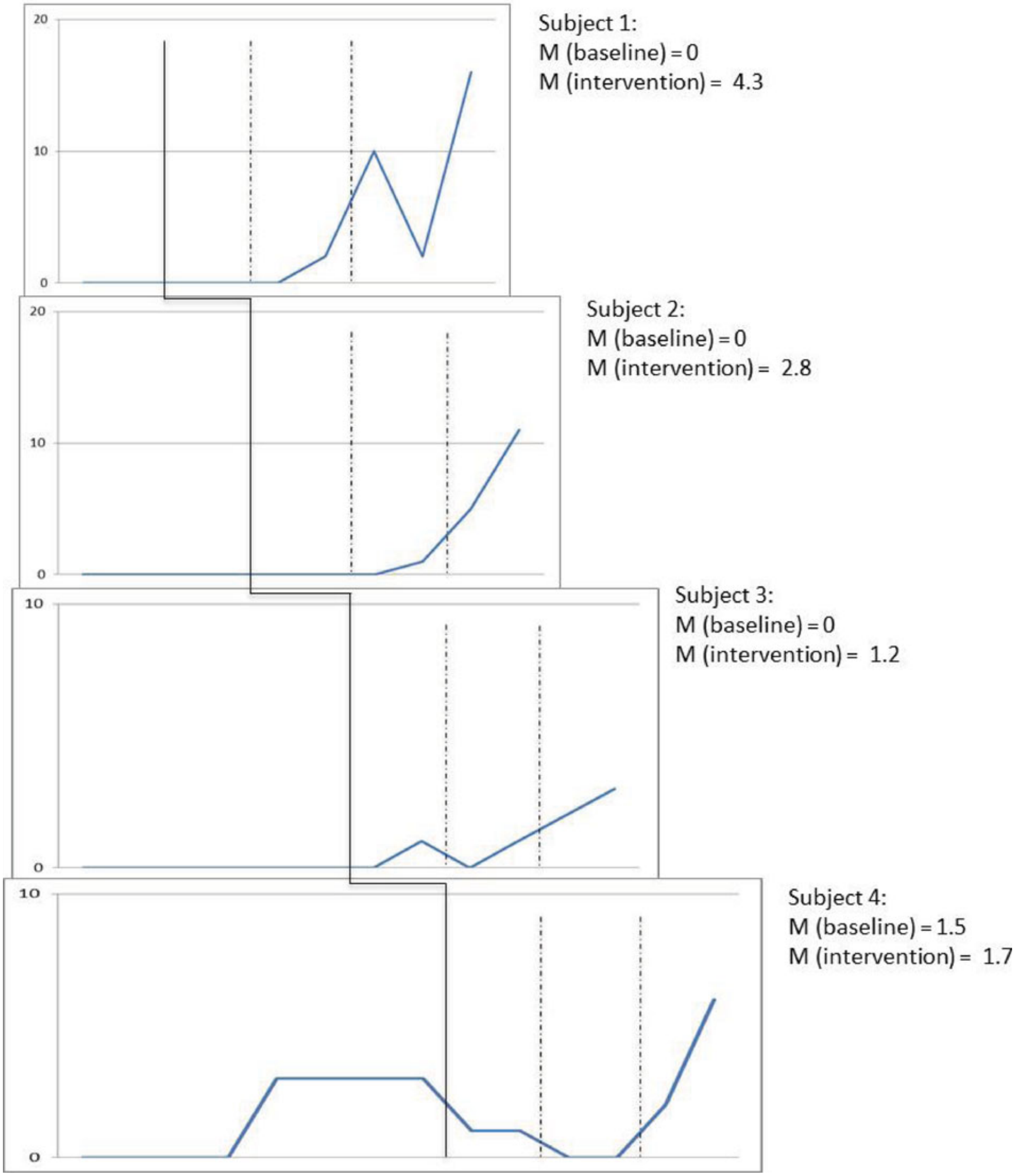

FIGURE 6. Appreciation expression (successful trials per session). The solid line represents the start of the intervention condition; the two dotted lines represent the start of Task 2 and Task 3 phase of the intervention (color figure available online).

demonstrated a significantly more active initiation performance than other participants during the baseline condition (with an average of 21 successful trials). Her initiation performance declined to zero during the Task 1 and 2 intervention sessions, and then resumed in the Task 3 condition. As observed, Subject 4 was an active communicator during face-to-face conversations, but was apparently more reserved and reactive in the virtual setting.

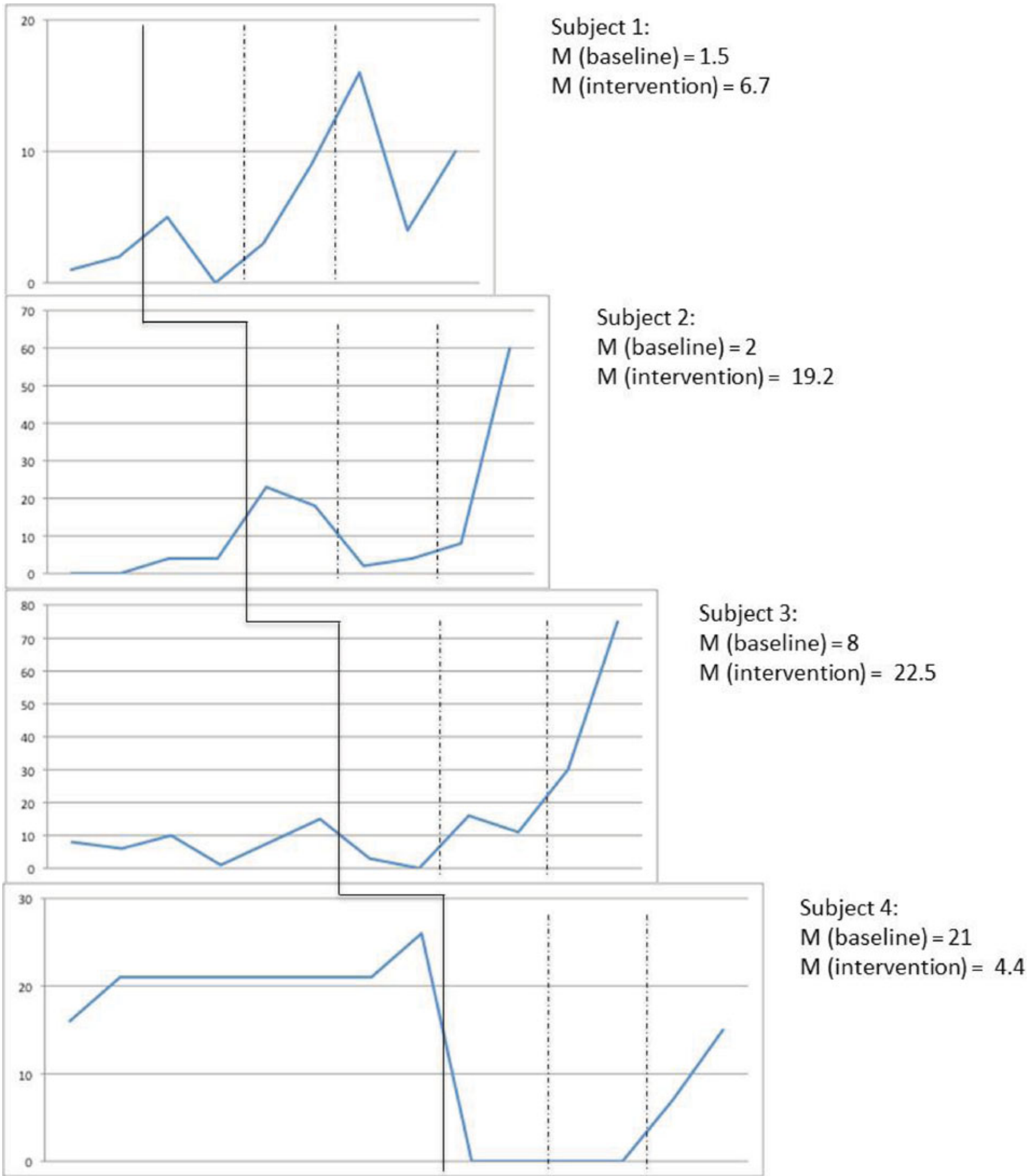

FIGURE 7. Initiation (successful trials per session). The solid line represents the start of the intervention condition; the two dotted lines represent the start of Task 2 and Task 3 phase of the intervention (color figure available online).

Greeting. The data for the baseline and intervention sessions across subjects are shown in Figure 8. Overall, there is a steady increase of successful trials of greetings during intervention sessions for every subject, especially during Tasks 2 and 3 of the intervention. The average number of successful trials of greeting per session by Subject 1 (FH) was 4.3 during the invention sessions, in comparison with the average of one trial in the baseline condition. The increase of her greeting performance was obvious during the phases of Task 2 and 3. FH was shy and quiet when meeting a stranger, either

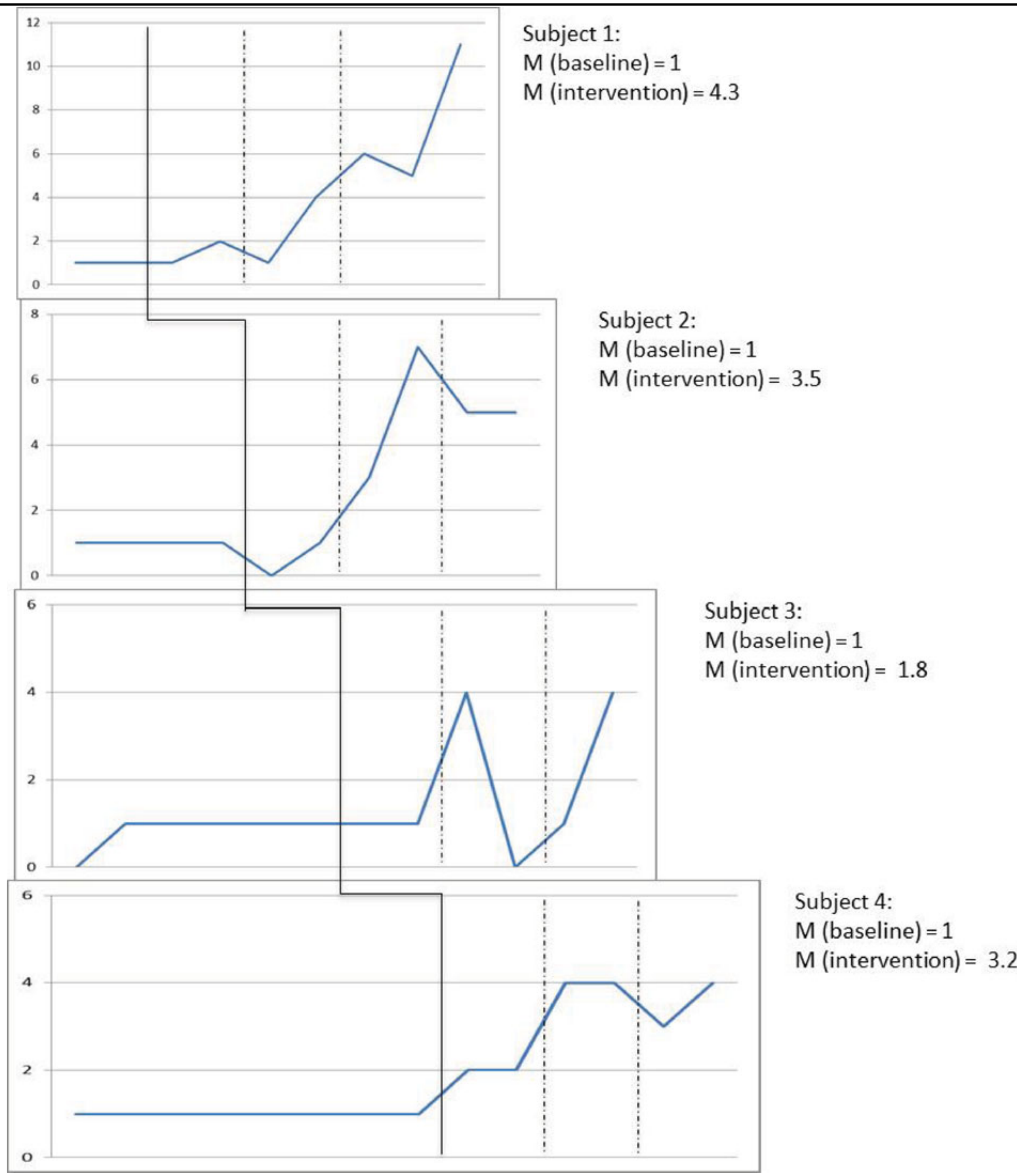

FIGURE 8. Greeting (successful trials per session). The solid line represents the start of the intervention condition; the two dotted lines represent the start of Task 2 and Task 3 phase of the intervention (color figure available online).

online or offline. During Task 1, she appeared to be involved in exploring the novel three-dimensional virtual world, and somehow was not concentrated on the social interaction task. During the later phase of the intervention, she became acquainted with her virtual communication partners and was found engaged in the social interaction task when the novel effect of three-dimensional virtual world faded. During Task 3 of the intervention, FH demonstrated an average of 7.3 successful trials of greeting per session.

Similar to FH, Subject 2 (K) also demonstrated an obvious and steady increase in his greeting performance during the intervention sessions, from an average of one successful trial per session during the baseline condition to an average of 3.5 successful trials per session. Moreover, the increase of greeting performance occurred generally during the later phase of the intervention (i.e., Task 2 and 3). He did not voluntarily greet people or greeted in an almost inaudible voice (with a simple "hi" without addressing the others) during the baseline sessions. It was also observed that he preferred to use text chat more than voice chat during virtual social interactions. But during the Task 2 or 3 sessions, K greeted his virtual communication partners in clear voice and tried to call every partner's virtual name, including those that were hard to pronounce.

The improvement of greeting performance of Subject 3 (MH) was observed only in the earlier phase of Task 2 (Cafeteria scenario) and the later phase of Task 3 (in which he hosted a birthday party), contributing four successful trials per session. He was observed smiling a lot when communicating with his partners during the Task 2 or 3 sessions. During the baseline sessions, MH usually needed cuing to greet others. During the aforementioned intervention sessions, he voluntarily and instantly greeted his virtual communication partners when they joined in the virtual world, via verbalization (e.g., "hello!") or body gesture in the Second Life simulation (e.g., waving or bowing).

Subject 4 (CR) had also demonstrated an obvious and steady increase in greeting performance during the intervention sessions, to an average of 3.2 successful trials per session from an average of one trial per baseline session.

Ending a conversation. The data for the baseline and intervention sessions across subjects are shown in Figure 9. There was an obvious increase of positive conversation-ending performance during the intervention situation for all participants. For Subject 1 (FH), there was an increase in positive conversation ending from one successful trial per session during the baseline condition to an average of three successful trials per session during Task 3 of the intervention. For Subject 2 (K), the performance of positive-conversation-ending was improved to an average of 4.5 successful trials per session during Task 2 and an average of six successful trials per session during Task 3 of the intervention condition. Similarly, Subject 3 (MH) showed an increase in the performance of positive conversation ending during the intervention sessions, from an average of one successful trial per session during the baseline condition to an average of 2.5 successful trials per session during Tasks 1 and 2 and an average of 6.5 successful trials per session during Task 3. Subject 4's (CR) performance of positive conversation ending also demonstrated an obvious increase during the Task 2 and 3 sessions of the intervention condition, with an average of 2.7 successful trials per session.

Nonverbal communications. Overall, all participants had achieved an accuracy of 95% in the body gesture and facial expression recognition tasks during Second-Life-based Task 1 sessions. There was also a consistent and obvious increase between all participants' pre- and postintervention performance in the Spence's (1995) facial expression and posture cues assessment. The assessment scores for the four participants are listed in Table 2.

TABLE 2. Assessment of Perception of Emotion from Facial Expression and Posture Cues

	Facial expression (pre)	Facial expression (post)	Posture cues (pre)	Posture cues (post)
Subject 1 (FH)	13	17	19	24
Subject 2 (K)	16	21	14	20
Subject 3 (MH)	17	19	18	20
Subject 4 (CR)	18	21	23	24

Note. The full score for the pre- and postintervention was 24.

The pre- and postintervention SSQ scores of both parents and pupils forms are listed in Table 3. There was generally an increase between pre- and postintervention SSQ results for participants, except for FH.

TABLE 3. Social Skills Questionnaire

	Parents form (pre)	Parents form (post)	Pupils form (pre)	Pupils form (post)
Subject 1 (FH)	47	45	56	53
Subject 2 (K)	36	47	38	43
Subject 3 (MH)	20	30	28	32
Subject 4 (CR)	24	39	26	37

Note. The full score for the pre- and postintervention was 60.

Interactions Between Participants and the VR-Based Learning Environment

There was commonality observed across participants in how they interacted with the VR-based social interaction environment. At the same time, the four study participants differed in their task-specific social interaction performance and learning needs. In this section, we describe the salient themes on the commonness and distinction among participants when they interacted with the VR-based learning environment.

Observational learning and leadership. In this study, Task 3 was designed to provide the target children an opportunity to observe how an adult agent hosted a birthday party. It was observed that all participants, with observational learning, managed to simulate and perform the modeled party hosting interactions—greeting and welcoming guests outside the

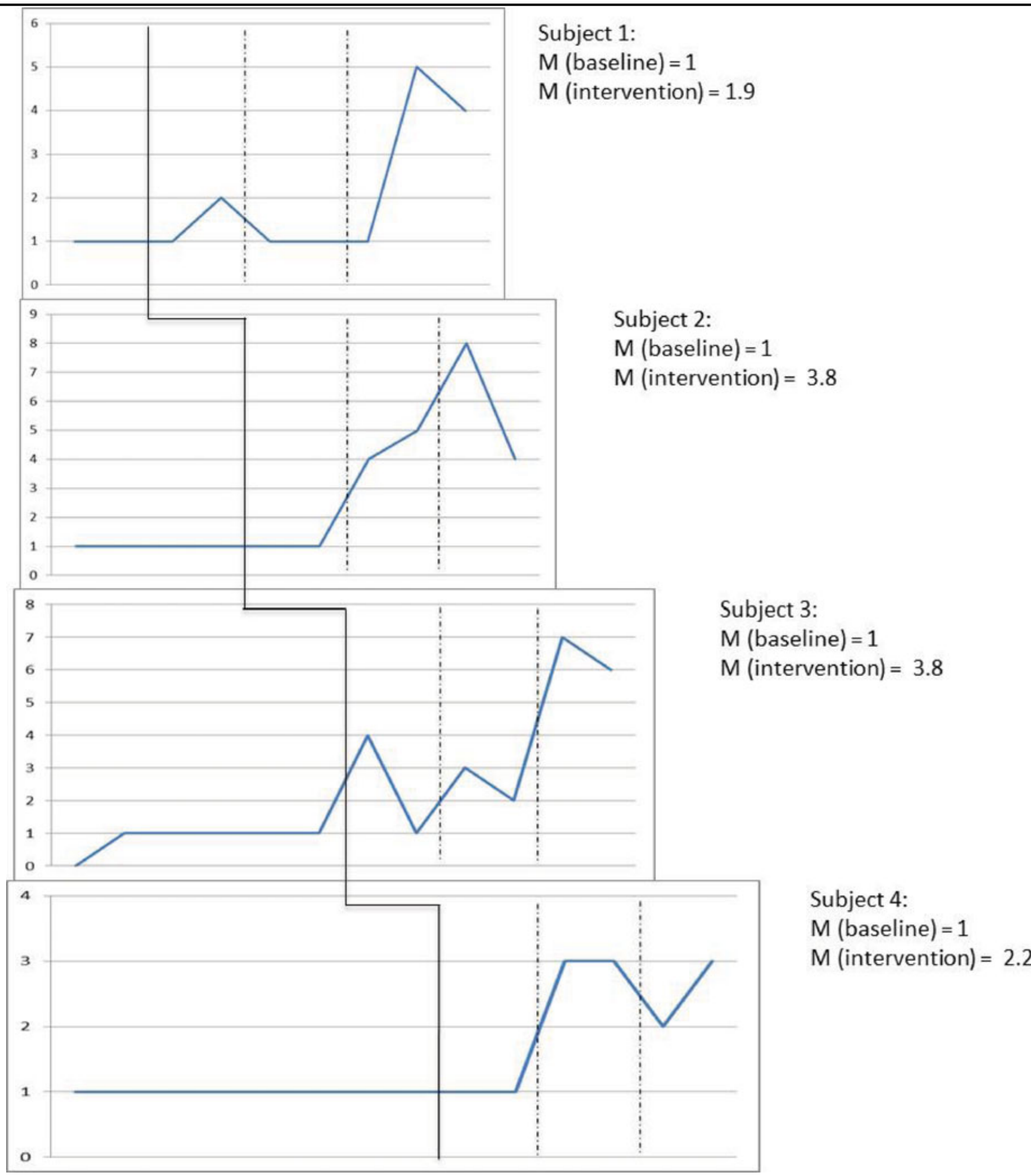

FIGURE 9. Conversation ending (successful trials per session). The solid line represents the start of the intervention condition; the two dotted lines represent the start of Task 2 and Task 3 phase of the intervention (color figure available online).

house, touring the guests around the house, initiating conversations with different guests, opening gifts and expressing appreciations, serving food, and coordinating after-dinner entertainment activities. The effect of role modeling was especially obvious for Subject 1 (FH). When FH hosted her birthday party for the first time, she was passive and barely initiated any conversations. Here is part of the observation notes when FH was a host for the first time:

> FH was probed by a communication partner to check on the person who was silent during the party and make a small talk with him. FH ignored this probe. Instead, she was engaged in flying around the birthday house and giggling.

Changes were observed when FH rehosted another party after being a party guest and observing how others performed party hosting, as shown by the following observation note:

> FH was probed to initiate a conversation with a quiet party guest. FH pondered a little bit. Then she walked toward this guest and initiated, "How are you Jamie? What type of food do you like?" FH and Jamie then continued a small talk about food and their plans for holiday travel.

As observed, FH demonstrated more comfort and willingness with initiating and maintaining conversations with different party guests. She also invited all party guests to fly together around the virtual playground, instead of flying away alone.

On the other hand, all participants were obviously more active and voluntary in leading and maintaining a conversation when they role-played as a party host (vs. as a party guest). This observation was especially true with Subject 3 (MH) and 4 (CR). MH, for example, demonstrated unanticipated imagination when hosting his virtual birthday party. He discovered and collected a selection of virtual body gestures to play the rock-paper-scissors game, and encouraged all to play the hide-and-seek game in the virtual world. He was found patiently explaining play rules to all party guests, inviting all to play the games, arranging their play sequence, and volunteering to play the seeker when everyone else wanted to play hiders.

A communication style of MH was that he could talk so fast or switch topics so quickly that his communication partners had little time to absorb what he tried to say before he moved to the next topic. CR, based on the baseline data and the parent's descriptions, tended to compete and argue with her peers in daily life. Both of them, notably, demonstrated a mature and self-controlled manner during social interactions when they role-played as a party host. It was observed that they were understanding, calm, and supportive in taking care of party guests, as the following observation notes indicated:

> MH initiated a small talk with the first-coming guest about weather. When all guests arrived, he turned to them and said, "Come on in everybody!" He then showed the guests around the house, "You can sit any place where you like except the table. Would you like to have some food?" He then introduced all foods placed on the side table and reminded his guests, "There were some napkins behind the food."

> MH was found tutoring a party guest (Joe) on a social etiquette question posted on the virtual poster. MH asked, "Which one do you think is right? 'Thank you so much?' 'I am so sorry,' 'You are welcome,' or 'How are you?' If you say one, I will click on the card to see if it is right or wrong. Okay?" Joe hesitated, "Ah hah . . . " MH waited patiently and probed again, "What do you think? I will give you a few minutes. You don't know the answer?" Joe answered, "I don't know. What is the answer?" MH persisted with an encouraging tone, "Please read the question twice. This is easy. You can guess it. Try the best." MH was unusually patient. Even when Joe purposefully postponed answering MH's questions, he did not rush Joe or give up the conversation. He repeated and rephrased the question, and then explained the answer.

> CR invited all guests to go outside and have some water fun in the pool. One guest did not come out. CR went back into the house and showed her way out. She also coordinated and led the social game-play (the rock-paper-scissors and hide-and-seek games). One guest lost game several times and hence put on body and facial expressions of frustration and embarrassment. CR recognized them and comforted him, "Next time, I will try to let you win."

Adjustments during VR-based social interaction. It appears that children participants had made their individual adjustments during VR-based social interactions. MH, for example, quickly realized that the Second-Life-based interaction environment, restricted by the distance and the lack of rich nonverbal cues (in comparison with the face-to-face setting), was not lenient to his fast-speaking and quick-shifting communication style. His virtual communication partners frequently requested, "I am sorry, but what did you say?" MH, as observed, gradually slowed down the rate of speech during VR-based conversations, and rephrased himself intermittently. He appeared to be a better listener and would ask his partners for a repetition to double-check if his understanding was correct. He also paid more attention to ending an interaction positively, as the following observation demonstrated:

> It was the end of the social interaction session. MH said "I need to go because I am done today." When a communication partner responded, "Nice seeing you," MH displayed a "bow" body gesture via his avatar and said, "Good bye." Yet in the earlier sessions, he simply said "good bye" and then abruptly logged out at the end of the session.

CR, in the baseline condition, appeared to be self-oriented during social interactions. She tended to dominate a conversation and elaborate on her own feelings and opinions. Somehow she adopted a reactive communication style in the Second-Life-based social interaction environment, especially in a group interaction event (e.g., in Tasks 2 and 3). The average length of her sentences was obviously shorter and the frequency of utterances or initiations was fewer. She resumed her active communication style only when she role-played as a party host.

In comparison with MH and CR, FH and K (Subjects 1 and 2) were obviously more passive and shy. Yet when they were engaged in Second-Life-based social interaction, their facial expressions and communications were filled with exuberance. FH, for example, was found smiling and giggling a lot during Second-Life-based virtual interaction. Yet in the baseline condition, FH had rarely demonstrated an emotional expression, such as excitement. K, similarly, rarely changed his facial expressions in the baseline condition. He demonstrated his first smile when he discovered that he could text and voice chat with others in the virtual world. He instantly sent a "hi" to his virtual communication partners via the text chat, and put on a bright smile when the others greeted him back. On the other hand, K tended to voluntarily use text chat more than voice chat. He demonstrated more comfort with typing his messages, even though he was not fluent with spelling.

Engagement and distraction. Unanimously, all four participants demonstrated and self-reported engagement and excitement during VR-based social interaction. Almost all parents told us that their children were looking forward to the next intervention session. CR, for example, would ask us at the end of every session, "Are we done already? Can we do it 10 more minutes?"

Flying was definitely the most appealing and engaging part of the VR experience for all participants. On the other hand, it also distracted them from focusing on the social interaction task. Adult agents, occasionally, had to fly around to seek the target child in order to maintain a conversation. The embedded sound effect in the Second Life was another engaging while potentially distracting feature of the VR learning environment. CR, for example, accidentally discovered a sound effect that she interpreted as flatulence. She then repetitively played it, kept laughing loud while ignoring her confused virtual communication partners.

Nonverbal communication. The embedded body postures and facial expressions plug-in in Second Life had enabled the expression and interpretation of nonverbal cues in the virtual world. However, there was still lack of a rich and intuitive interface for nonverbal communication in Second Life. First, Second Life did not enable avatar's facial expressions by default. Rather, a third-party plug-in had to be installed on each computer and could be tricky for child use. Also, it was necessary to shift to a zoom-in view to check an avatar's facial expressions and then shift back to the normal view during a group conversation, which added on cognitive load during communication. Second, unstable Internet speed could create a delay in displaying body posture and facial expression alteration. Third, it was necessary to click a drop-down menu and go through the list to select a specific body posture for the avatar. Although we had customized the drop-down menu to present a shortened list of essential body gestures, selecting body gestures in Second Life was still cumbersome and nonnaturalistic for the target children.

Individual learner needs. Although all diagnosed with Asperger syndrome, our four children participants demonstrated different learning needs during VR-based social interaction. K, in comparison with other children, needed more direct instruction and guidance, especially when facing a multiple-person, group interaction task and when environmental distractions were present (e.g., a well-decorated party house). He had to seek help from the facilitator who sat beside, as the following observation notes indicated.

> K appeared to be passive, distracted, and seemed confused. Lily (the facilitator) reminded K on the general process of party hosting. She also let K read the power cards posted on the party-house's wall. He then followed the cues to initiate a chat with his guests, "How's your day?" Sometimes Lily had to phrase an expression for K or provide K with a sentence opener.

In comparison, MH appeared to thrive in a task or setting that encompassed a rich role-playing context to afford creative story telling—a hobby and gift of MH. As observed, he was fluent in leading the party hosting interaction in Task 3, and even extended the creation of the virtual event setting with his imagination. MH, for example, told his guests that "there were some napkins behind the food," but there were actually no napkins on the food table. MH's communication in Task 2 was a lot less exuberant. It should be noted that he never had lunch at his own school's cafeteria, which made the café interaction task less relevant to him. Moreover, MH was keen on seeing his communication partner's face during a conversation. He would relentlessly walk his avatar toward a communication partner and shift to a zoom-in view to get a close-up of the partner's face before responding or initiating a conversation. In a Task 2 session, he had to jump onto a café table in order to capture the close-up of a communication partner, "It's the only way I can see your face." As observed, the lack of intuitive interface for nonverbal communication in the virtual world adversely affected MH's interaction performance.

CR showed excitement about creating and customizing her own avatar. She intended to reflect her ideal identity onto her SL avatar (i.e., a tomboy girl with wings). The default choices of avatar creation in SL were not to her satisfaction. FH, similarly, expressed a desire for identity expression or personalization in the virtual world, but her desire was more associated with the environment customization. For example, she suggested that we should add sushi, her favorite daily food, to the café lunch menu. She also requested us to design and add her favored wild lives to the virtual space.

Parents' satisfaction. Participants' parents had reported positive changes of their children during and after the VR-based social interaction intervention. FH's mother, after 3 weeks since FH started the intervention, told us that FH, who used to only talk about animals and caterpillars, started to demonstrate more interests on girlish items and girl talk that can help her relate to other similar-aged girls. K's mother told us K kept asking her whether he could chat with more people in Second Life regularly. CR's father told us that CR showed a more positive disposition toward friendship or companionship since she started the program. CR, as described by her father, used to believe that there were only two kinds of people in her school—friends or enemies. To befriend peers was challenging for CR. But a remarkable change reported was that she started to chat with random peers in the school bus. CR also shared with us an interesting incident on the school bus back home: A boy made fun on a peer girl who was wearing an Angry Bird–game themed top. CR stood up to defend this girl, even though she was not her friend. "But she was my friend now," CR proudly claimed.

Discussion

The study findings indicated that participants demonstrated improved performance of responding and interaction maintaining during intervention sessions, especially during the sessions of Task 2. Most participants also demonstrated improved performance of interaction leading, including initiation, greeting, and conversation ending, particularly in the sessions of Task 3. This finding supports our design proposition that Task 2 will focus on interaction responding whereas Task 3 should promote interaction initiation. The study also finds increased facial expression and body gesture recognition by study participants after the intervention. The informal feedback by parents and participants has showed the potential of the VR-based social interaction intervention in expanding children's communication topics of interest, and in promoting a positive disposition toward peer friendship development and social interaction participation. In general, this study supports the hypothesis and report of the prior research that three-dimensional VR can be employed as a promising learning platform to enhance social interaction performance for children with autism (e.g., Beaumont & Sofronoff, 2008; Cheng & Ye, 2010; Kandalaft et al., 2012; Mitchell et al., 2007; Parsons & Cobb, 2011; Parsons, Mitchell, & Leonard, 2004). It is also consistent with the previous study finding on the positive effect of a naturalistic intervention on the enjoyment and active usage of skills of children with autism (Charlop-Christy & Carpenter, 2000; Delprato, 2001; Schreibman & Ingersoll, 2005).

At the same time, the study indicated the necessity of performing purposeful and adaptive design of the VR-based learning activities and environment to address the diverse needs of individual learners. In the following section, we describe specific design considerations implied by the study findings.

Individualized Activity, Scaffolding, and Environment Design

In this study, individual participants appear to interact differently with the VR-based social interaction setting and tasks, and hence are in need of more dynamic and individualized design with the learning activities, scaffolds, and scenarios. The same social interaction tasks, scenarios, or scaffolding strategies can retrieve different communication performance from individual target children. Besides, the engaging and supportive features of the VR-based learning environment may turn into digital distractions in certain cases. These study findings have highlighted a proposition of the prior research on social interaction training that providing relevant and individualized intervention is essential for learner success (Schreibman & Ingersoll, 2005; Spence, 2003; White et al., 2007).

Leadership and Participatory Design in the VR-Based Learning Environment

In this study, it is observed that children with high functioning autism are more active in leading interactions when they role-play as an event host and hence have a leadership role in the virtual interaction and activity. Notably, individual child, such as MH and CR, has demonstrated creative thinking in codesigning the interaction components (e.g., inventing virtual social game play and pool fun). Other participants have also indicated their desire to customize the VR-based social interaction setting and character (e.g., FH suggested adding the wild lives to the virtual space). It appears that the three-dimensional VR environment has provided the target children with an open space that they could explore and interact with in diverse unique ways and as a reflection of their preferences or identities. Such an observation supports an argument on using VR as a learning platform to enable learners to explore actions and appearances that they may not have access to in real life, thus providing opportunities for them to explore various aspects of their personal psychology (Lindsey-Glenn & Gentry, 2008). A design implication is that in a future program, children with autism can be provided with more opportunities to lead and even codesign the VR-based social interaction event and setting.

Observational Learning

In this study, participants have demonstrated a better performance of party hosting after observing an adult communication partner role-modeled the interaction practice. Observational learning could be considered as a type of naturalistic training technique with the benefits of generalization for trainees (e.g., Delprato, 2001; Schreibman & Ingersoll, 2005). Previously, the naturalistic interventions targeted specifically social interaction in the school setting with limited extensions. In this study, the immersive three-dimensional virtual space in Second Life has made the naturalistic training encompass real-life interactions across contexts, making it possible for paraprofessionals (e.g., adult volunteers) and parents to coparticipate in the program as role models.

Limitations on Nonverbal Communication Training in Second Life

The study has used Second Life as a VR platform for both verbal and nonverbal communication. Although subjects' nonverbal communication performance was improved throughout the training, the lack of a rich and user-friendly interface for nonverbal communication in Second Life has been observed in the study. Since VR is a promising learning environment for social interaction training, careful consideration on technical requirements, preparedness, and the customization plan needs to be accompanied with the design process to increase the training effects.

Learning Transfer to Daily Life

Transfer of knowledge and skills to real life context has been regarded as a limitation in computer-assisted trainings for children with autism (e.g., Beaumont & Sofronoff, 2008). VR has been proposed as an engaging learning platform to overcome this limitation (Parsons & Mitchell, 2002). Such a position has been supported by the study finding. The informal feedback by parents and participants suggested that the VR-based social interaction intervention can potentially expand children's communication topics of interest and promote a positive disposition toward peer friendship development and social interaction participation.

Implication and Future Research

The findings of this exploratory study should extend and enrich the discussion and research on using emerging technologies to design adaptive and informal learning environments for learners with diverse characteristics and unique needs. A future study on using VR-based social interaction training for children with special needs should examine its design and impact on enhancing the learning transfer to daily-life dispositions and behaviors. In addition, further efforts should be contributed to the design and development of a VR-based learning environment that integrates other innovative technologies (e.g., a motion-sensing input device such as Kinect) to enable more intuitive, embodied learning and practice of nonverbal communications.

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