



Captivating: Avatars as therapeutic agents for children with intellectual and developmental disabilities

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Abstract

Technology is intertwined in our lives. We can be characters preparing to slay dragons in video games or seek help from approachable virtual service representatives to make medical appointments. In this special issue focused on prevention science in the field of research on intellectual and developmental disabilities (IDDs), readers might be surprised to find an article addressing the use of avatars and agents. These virtual characters provide a friendly interface to represent a computer program. The application of avatars

and agents in preventative intervention for children and youth with IDD is in an early stage of development. However, this technology has the potential to innovate the field. Computerized agents can project human-like emotions. These qualities provide unique behavioral and motivational reinforcement for engagement in agent-administered computer programs. Equally important, agents hold the promise of reducing disparities in access to prevention efforts, as they can be delivered (virtually) anywhere. Accordingly, preventative interventions could reach children with IDDs in rural populations or children with low-incidence IDDs who would not commonly have access to a specifically targeted program. In this review, we first define avatars and agents in more detail and provide a brief history of their evolution for context. We then synthesize the extant research that informs our understanding of how children with IDDs respond and engage with agent-based computer programs. We conclude our review with an appraisal of the methodological approaches used and recommendations for future research efforts.



1. Introduction

There is a critical need for the transformative use of technology in intervention for children with intellectual and developmental disabilities (IDDs). Computer technology provides a platform for individualized intervention and educational experiences that can be delivered adaptively as users develop greater competence. Furthermore, computer technology can incorporate numerous modes of feedback and rewards, which is a critical component in reinforcing attention and task engagement. Consequently, computerized interventions have become an area of focus for children with IDDs (e.g., Baragash, Al-Samarraie, Moody, & Zaqout, 2020; Bennett, Holmes, & Buckley, 2013; Federici et al., 2020; Hersh & Leporini, 2018; Lynch, Singal, & Francis, 2021). A significant advance in computerized intervention is the use of avatars, also commonly referred to as embodied conversational agents, embodied agents, virtual peers, pedagogical agents, educational agents, tutors, or just agents. Confusingly, the term avatar can also be used to describe an image such as a character or cartoon one can choose for self-representation in video games or social media platforms.

In the context of computer programs aimed at assisting individuals in some capacity, avatars and agents are virtual characters. To better understand these terms, it may be helpful to begin with an example from popular media. In the classic science fiction movie *The Matrix*, humans live in a world that, unbeknownst to them, is a simulated reality controlled by a computer program using humans as an energy source. When computer programmer Neo learns this, he decides to rebel. However, the computer creates Mr. Smith,

an agent who, despite wearing a suit, tie, and sunglasses, can summon superpowers to fight Neo, squelching a human rebellion. In this storyline, Mr. Smith was an “agent” representing the computer’s artificial intelligence in interactions with Neo.

Happily, in real life, agents do not chase humans with intent to harm. However, similar to Mr. Smith, agents typically take on human-like forms to facilitate computer-user communication. Agents do not have intelligence, but thanks to underlying programming, they can interact intelligently with users. Algorithmic instructions similar to decision trees embedded into programming directs an agent’s responses based on the user’s actions. For example, an algorithm could direct an avatar to present positive reinforcement after users correctly respond to a task. *The example about the agent Mr. Smith also offers a nuanced distinction between using the terms “agent” and “avatar.” As described in the Matrix, the use of “agent” implies that the locus of control for computer-user interactions is driven by the computer, rather than the user.* When humans have control over computer-user interactions, the term avatar is used (Morkes, Kernal, & Nass, 1999). Sometimes the two terms are used interchangeably in the popular literature and even some peer-reviewed research. For this review, we have chosen to use “agents” when the computer program makes decisions in response to the users’ interactions.

Accordingly, through using spoken language, text, and nonverbal communication such as facial expression, eye gaze, and gestures like pointing, agents are virtual characters who can interact with users to be friends, collaborators, or instructors/coaches. Agents can use these communicative characteristics to simulate and project emotions such as happiness, confusion, sadness, and empathy. Avatars and agents offer the potential to interact with a computer more naturally, similar to how we interact with other people. When agents are “embodied,” that is, having bodies or aspects of bodies, they do not always take human form. In fact, if an agent looks “too human,” it can trigger unease or revulsion in human users, a concept known as the *uncanny valley* (Mori, 1970). Users can communicate with agents through speech, gestures, typing, or using touchscreens. Agents respond with verbal and nonverbal language based on programmed decision trees or algorithms (Provoost, Lau, Ruwaard, & Riper, 2017).

It is worth noting that many users today have experience with “nonembodied” agents that have become common in home appliances, such as Amazon Echo and Google Home, as well as agents built into our smartphones, such as Siri. However, user expectations for the utility of these agents who do not project nonverbal language and emotion are misaligned

with the reality of and limitations of these types of agents (Luger & Sellen, 2016). This body of research emphasizes the importance of interactive agents who have multimodal (i.e., multiple) communication channels allowing for interaction that includes both spoken language *and* nonverbal gestures.

Perhaps most importantly, compared to nonagent administered applications and games, the combination of interaction and responsive communication connects users to computer systems in a manner that can provide an element of motivation and engagement. Initially focused on improving computer user experiences for adults in the general population, agents can help humans learn strategies for many pursuits, including managing anxiety or learning a new language. More recently, research has expanded to focus on how agents can improve quality of life and outcomes for various people, including children with IDD.

1.1 The history of agents

To fully appreciate the possible uses for preventative intervention administered by agents in IDDs, it is helpful to have a brief history of their advent and evolution. Agent development began in the late 1990s and early 2000s. One of the earliest pioneering agents was August, who served as a museum guide in Sweden (see Fig. 1A; Gustafson et al., 1999). To develop August, researchers characterized how naive users responded to the system and how they adapted their speech when August could not comprehend them. Researchers then studied the nonverbal cues associated with topic shifts in discourse and incorporated these results into Rea, a real estate agent who communicated through speech and gesture (Fig. 1B; Cassell et al., 2001).

The following year, Pelachaud et al. (2002) presented Greta, an agent for patients with medical questions (Fig. 1C). SmartKom was a multimodal agent, meaning it used speech, gesture, and facial expression (Fig. 1D; Wahlster, 2003). Kopp et al. (2003) presented Max, a 3D agent who helped human users complete virtual assembly tasks (Fig. 1E). Max was also notable for multimodal communication, communicating with speech, gesture, and facial behaviors, made possible in part by a software system that smoothly linked these functions together (Kopp & Wachsmuth, 2004). Like August, Max was also employed as a museum guide (Kopp, Gesellensetter, Krämer, & Wachsmuth, 2005). Analysis of museum conversation logs indicated that museum-goers typically used human-like communication strategies with Max. In Max's case, he was displayed at human-like size on a static screen, standing face-to-face with museum-goers, and equipped with camera-based visual perception.



Fig. 1 A chronological timeline of early agents in the literature. (A) August (Gustafson, Lindberg, & Lundeberg, 1999), (B) Rea (Cassell, Nakano, Bickmore, Sidner, & Rich, 2001), (C) Greta (Pelachaud, Carofiglio, De Carolis, de Rosis, & Poggi, 2002), (D) SmartKom (Wahlster, 2003), (E) Max (Kopp, Jung, Lessmann, & Wachsmuth, 2003). (F) AutoTutor-3D (Graesser, Li, & Forsyth, 2014).

Somewhat newer is AutoTutor and its several variations, such as AutoTutor-3D. AutoTutor uses an agent represented by a talking head to prompt students' explanations regarding higher-level concepts such as physics and computers (Fig. 1; Graesser et al., 2014). An agent named Diana builds upon this previous work in meaningful ways. Like Max, but unlike the other agents mentioned above, Diana uses a full-sized, full-body, human-like agent with a shared perceptual space representing realistic objects (Wang et al., 2017).

1.2 What are the benefits of using agents?

The efficacy and benefits of agents has been the subject of much research. It is generally recognized that agents engage users more actively, and by being a social presence, may increase motivation. Early evidence from a health education intervention suggested that participants who do not

typically like interacting with computers reported enjoying interactions with an agent, and that patients with inadequate health literacy improved their knowledge (Bickmore et al., 2010). Compared to adults in a no-agent condition, adults told a story by either an agent with a humanoid image or an agent that looked like a gorilla demonstrated better memory (Beun, De Vos, & Witteman, 2003). This finding suggests that a factor other than anthropomorphism elicited better memory performance. Furthermore, eye-tracking research indicates that humans treat agents as social, conversational partners (Louwerse, Graesser, McNamara, & Lu, 2009).

In the educational context, agents are effective for diverse uses and designs, including learning foreign languages (Wik & Hjalmarsson, 2009) and solving math problems (Tamayo-Moreno & Pérez-Marín, 2017). In contrast to students in a no learning support or a nonconversational support condition, students using an agent-based e-learning program demonstrated improvements of one full letter grade or more (Kumar & Rose, 2010). Graesser et al. (2014) described agents that simulate human tutoring, with an emphasis on AutoTutor. Empirical evidence suggests that AutoTutor and similar natural-language computer tutors produce learning gains comparable to trained human tutors in various subjects (Graesser et al., 2014). In one direct comparison, Auto Tutor-3D yielded a significant improvement in learning over a strictly conversational interface for students; and a version of AutoTutor that was emotionally empathetic aided learning better than one that was not emotionally responsive (Graesser et al., 2014).

1.2.1 How might agents benefit preventative intervention for children with IDD?

Children can engage with agents to participate in (1) specific therapeutic or educational activities to facilitate development and learning, or (2) engage in “serious” games which involve embedding activities to improve targeted outcomes such as early cognitive abilities and language, in a motivating game format. The advantages of these systems are particularly well-aligned with the movement in the field of IDDs to shift to a preventative intervention stance. For example, a child with an etiology-specific IDD and delays in working memory could potentially access a preventative intervention where an agent offers working memory practice on a motivating platform and proactively links these skills to quantitative concepts and reading comprehension to optimize academic achievement trajectories.

Children and youths with IDD may benefit from frequent practice and instruction in many domains such as joint attention, executive function, and receptive language. New findings describing child outcomes in IDDs emphasize the opportunity for agent-based therapies. A recent meta-analytic study indicates that children and youths with IDDs engaging in noncomputer interventions benefit from more frequent practice and instruction to acquire quantitative skills (Schnepel & Aunio, 2021). Similar dose-response relationships have been found in executive function intervention for school-aged children with Down syndrome (Bennett et al., 2013) and language-based behavioral intervention (Neil & Jones, 2019). Relatedly, researchers have argued that once-weekly therapy is inadequate to improve outcomes for children with IDDs (Neil & Jones, 2019). However, more intervention does not guarantee greater benefits for children with IDDs as some participants may benefit differentially based on individual variability such as underlying exploratory abilities (Fey, Yoder, Warren, & Bredin-Oja, 2013).

While much is left to be learned about the intensity, frequency, and dosage of intervention approaches for children and youths with IDs, agent-based programs demonstrate promise in supporting frequent dosage/practice. Moreover, agent preventions and interventions could be personalized to a child's strengths/challenges and educational/therapeutic objectives. Many computer and tablet-based games and programs offer frequent practice opportunities with similar adaptive tasks. However, agent interventions and preventions may offer additional social motivation, performance, and resilience in recovering from errors.

These potential agent advantages have been highlighted in a simple intervention to teach the rules of using capitalized words. While targeting school-aged children with typical development, these findings underscore potential benefits in using agent interventions that should be investigated in IDDs. In this approach, correct responses elicited joy and occasionally happy dances from the agent. Incorrect choices prompted expressions of sadness or comic falls. More importantly, compared to a group equated for chronological age who engaged in a nonagent condition, participants in the agent condition *spent more than twice the amount of time engaging with the program, logged more than three times the number of tasks, and made more than three times the amount of recoveries following a mistake* (Berkling, Fawaz, Zundel, & Abdennadher, 2019). *Furthermore, the agent group was half as likely to give up during the game as the non-agent group.*

These results indicate that working along with an agent as a collaborator could potentially reduce performance stress, increase task engagement, and increase persistence following errors which may be significant factors in understanding the value of agent-administered interventions for children with IDD. In the next section, we focus on the extant evidence characterizing the use of agents to enhance developmental outcomes in children with IDDs.



2. Do agents improve developmental outcomes for children with IDDs?

Given the implications for lifelong challenges in learning, health, and adaptation, research examining the potential for agents in IDDs has been focused on social pragmatic skills and nonverbal communication such as eye gaze, language development, literacy skills, early learning, and motor abilities. By examining the existing research addressing agent interventions applicable to children with IDDs, we can identify lacunas and suggest future research to advance methodological approaches and evidence.

2.1 Social communication and interaction

A preponderance of the agent-based intervention research in IDDs has focused on children and youths with autism spectrum disorder (ASD) to target pragmatic social skills with promising pilot study findings. Early work indicated that school-aged children with ASD who are verbal can have lengthy talks with agents and can also use nonverbal gestures such as pointing with both the agent and the human examiner (Black, Flores, Mower, Narayanan, & Williams, 2010). School-aged children with ASD are more likely to take turns in storytelling and introduce or maintain conversational topics with an interactive virtual peer than an actual human peer ($n = 6$; Tartaro & Cassell, 2008).

Not only are youths with ASD able to interact with agents, pilot findings in this area point to a potential preference for agent interactions over human ones. Compared to interacting with an actual peer, adolescents with ASD were more likely to converse and introduce new topics with an agent (Didehbani, Allen, Kandalaf, Krawczyk, & Chapman, 2016). These participants with ASD ($n=30$, 7–19 years of age) also demonstrated more competent narrative conversational skills following participation in a 10 session (60-mins each) multicomponent intervention system, including role-playing with a socially interactive agent (Didehbani et al., 2016).

The researchers emphasized that social training via a computerized agent platform offers a unique additional advantage since it is easy to create different virtual contexts such as school or a store within a platform. Therefore, interacting with agents in different contexts may support skill transfer into real-world settings.

2.1.1 Adaptive intervention interfaces to build social competencies

Another potential advantage of using agent-based approaches is the ability to embed adaptive tasks, which become increasingly more challenging as the user's performance improves. Researchers piloted just such a program using scaled social communication and social interaction challenges presented by an interactive agent. The agent's name was Rachel and she was created to look like a school-aged child (Mower, Black, Flores, Williams, & Narayanan, 2011). After a warm-up game, Rachel presented four different challenges: an emotional face or voice identification, emotional storytelling requiring a child to select in-order or out-of-order stimuli, identification of missing emotional facial features, and mismatched facial identification presented with increasingly challenging questions. Child responses were either completed verbally or completed using gestures (e.g., choosing missing or mismatched emotions). Each level focused on aspects of emotions related to being angry, happy, sad, or scared. Two school-aged children with ASD diagnoses participated in the intervention successfully, and both showed frequent responsive interactions to Rachel's questions (Mower et al., 2011).

Despite the promise of the Rachel system, we found no follow-up research. One reason may be related to the procedures. In this pilot study, the researchers employed what is known as a *Wizard of Oz* or *Oz* paradigm, a common methodology used when developing interactive agents (Mower et al., 2011; Tartaro & Cassell, 2006, 2008). In this methodological approach, children believe that the agent can see, hear, and interact with them. However, the responses of the agent are directed by *Oz*, a human using a control panel or keyboard with specific actions from a pre-determined range of options. So, a human selecting actions for the agent can drive the agent's actions during the development phase of a system when speech recognition or language processing is not yet fully integrated. Therefore, given that the Rachel system relied on expressive speech responses from the child users, this could have added exceptionally high speech recognition and language processing demands to the project development that were possibly not completed or put aside in service of more promising projects.

Researchers have also combined the adaptive potential of agent interventions with physiological measures. A pilot study of adolescents with ASD ($n = 9$) highlighted the enhanced utility of adapting task skill levels based on both the youths' task performance and their physiologically informed anxiety levels (Kuriakose & Lahiri, 2016). In this study, agent-administered social problem-solving tasks became more challenging based on two conditions: (a) previous correct performance, or (2) an algorithm derived from previous correct performance plus real-time physiological anxiety measurement, as assessed by skin temperature and pulse rate. Here is a simple example of how the physiological data influenced algorithms for determining the tasks offered. If performance was correct and anxiety measurements were low, the system would offer a new task at a higher level. Users with correct performance but recordings of high anxiety were offered other tasks at the same level before increasing the task demands. In contrast to task adaptation based solely on performance, youths with ASD advanced to higher levels of the program when the advancement of tasks was informed by anxiety + performance.

Another adaptive intervention platform incorporated physiological measures detecting real-time variations in eye physiology, including blink rate, visual fixation, and pupil diameter paired with an agent. In this pilot study, adolescents with ASD who had IQs in the typical range engaged in two sessions (Lahiri, Bekele, Dohrmann, Warren, & Sarkar, 2015). The virtual reality social tasks featured the voices of local adolescents narrating stories on a range of topics, including movies and trips. The agents could point and move in the virtual reality environment. Tasks were adjusted adaptively based on the participants' eye physiology and the participants' performance (e.g., asking correct questions). Similar to Kuriakose and Lahiri (2016) description, results from this study demonstrated that the participants improved social performance and demonstrated increased duration of viewing faces when using the physiology-informed algorithm to advance through the intervention tasks.

Interventions including physiological data are particularly intriguing as children and youths with many types of IDD, such as Prader Willi syndrome can experience anxiety at higher rates than the general population (Skokauskas, Sweeny, Meehan, & Gallagher, 2012). Additionally, dysregulation is another state that might benefit from physiologically informed data. Taken as a whole, the inclusion of agents and physiological data represent new approaches to optimizing outcomes for youths with ASD.

2.1.2 Questions regarding the mechanisms of change in agent interventions for youths with ASD

Computers and screen-time activities are of particular interest for many children with ASD (Carter, Hyde, Williams, & Hodgins, 2016), and agents have elicited unexpected social responses from children with this developmental disability. For example, agents projecting positive affect from Kurikose's study (2017) were observed to initially elicit *increases* in physiologically measured anxiety from adolescent participants with ASD. However, this anxiety response decreased over time. Additionally, compared to behaviors demonstrated during interactions with (human) examiners, school-age participants diagnosed with ASD demonstrated more smiles and less fidgeting when interacting with an agent (Black et al., 2010). Differences in developmental age, measures, intervention procedures, and perhaps prior experience with agent-based intervention could be plausible explanations for these varying responses. Despite efforts to create agents that communicate verbally and nonverbally in ways that motivate their human partners, the differential responses to agents as illustrated by this work, highlight intriguing questions underlying these pilot findings. Compared to human interactions, are agent images and social interactions less challenging to process and interpret for school-aged children with ASD? Do agents scaffold attention or reduce cognitive load?

Research examining a small sample of school-aged children with ASD ($n = 12$; ages 6–10 years) lends insight into these issues. The researchers manipulated agents' visual image complexity with stylized cartoon features, computer-generated animation, and realistic video images. The agents' facial movements were also varied to enlarge or minimize their facial movements (Carter et al., 2016). Results indicated that agents with exaggerated facial movements but not complexity yielded improvements in the child's eye gaze and gestures. These studies suggest that specific aspects of agent designs may be significant when creating interventions for children and youth with ASD. However, more research with larger sample sizes will be necessary to understand which agent factors facilitate more socially competent outcomes.

2.1.3 Avatars embedded in a more extensive therapeutic context for ASD

Researchers embedded an agent social intervention into a broader, in-person social group program. Children attended the program for 2h weekly over 11 weeks, with each child participating in the agent intervention component

for approximately 4 weeks. The agent-administered intervention incorporated the school-aged, nongender specific agent Sam from Tartaro and Cassell's earlier work (e.g., 2008). Children ages 8–12 years with ASD interacted with Sam face-to-face, created new social behaviors for Sam, and selected the best social responses for Sam's social interactions. After children engaged in the agent part of the intervention, they then experienced guided practice with their peers in the social group. Preliminary results indicated that the participants' reciprocity skills increased during role-playing activities after interacting with the agent. However, while these results support proof of concept, the researchers emphasized that much more work was needed to manualize the intervention and pilot it.

2.1.4 Joint attention

Research characterizing joint attention in ASD demonstrated that compared to a group of typically developing students ($n = 24$) equated for chronological and IQ, school-aged children with ASD ($n = 24$) responded to and initiated joint attention tasks at similar levels. However, the group with ASD used different eye tracking strategies and demonstrated attenuated recognition memory (Little, Bonnar, Kelly, Lohan, & Rajendran, 2016). A more recent study investigated levels of agent cues within a virtual reality format to elicit joint attention in school-aged children with ASD ($n = 6$) and a group of children with typical development equated for chronological age ($n = 10$; Jyoti, Gupta, & Lahiri, 2019). The agent facilitated joint attention to regard an object by using a hierarchy of cues including gaze, head turn with gaze, head turn with finger-pointing, and a shimmering visual called a sparkle effect that emitted from the object. Results indicated that the sparkle effect elicited the highest proportion of joint attention from the group with ASD ($\sim 90\%$), and the use of gaze alone elicited no correct responses from the ASD group.

It is challenging to compare the somewhat divergent findings from these two studies. On the one hand, Little et al.'s (2016) results suggest that school-age children might demonstrate joint attention skills on par with their peers, and on the other hand, based on Jyoti et al.'s (2019) study, school-aged children also appeared to benefit from explicit cues like the sparkle effect to elicit joint attention. Joint attention emerges in early development and underpins language and social skills (Hahn, Loveall, Savoy, Neumann, & Ikuta, 2018). Given the high prevalence of joint-attention challenges associated with ASD, taking a prevention science approach with

agent-administered preventative intervention with children who demonstrate vulnerabilities may minimize downstream challenges in language and social interactions. Finally, given Little et al.'s (2016) observation that children with ASD used different eye tracking strategies for joint attention might signify the potential for agent systems to be utilized in screening and assessment given that systems can be designed to record and visualize child users' nonverbal gestures, eye gaze, and other movements in real-time.

In summary, there is a significant focus on agent-administered interventions in ASD. This focus may be related to the high interest in technology observed in many individuals with ASD and the high prevalence of this disorder. Given the higher-level tasks described in this section and the fact that IQ or developmental age was largely unreported, it appears that most programs targeted children with minimal or no cognitive impairment. Therefore, this relatively larger focus on developing agents for use by individuals with ASD may also reflect a bias for creating program interfaces for users who have more developmentally competent levels of function and language. However, overall the research on using this technology with children and youths with ASD demonstrates that agent-administered preventative intervention can engage in frequent, adaptive practice. It also offers the ability to incorporate physiological data, manipulate facial expressions (i.e., over-playing facial features to improve interpretation) and context, which may enhance beneficial outcomes.

2.2 Language, literacy skills, and sign language

Avatar-based interventions can support language development and literacy foundations. In fact, given the ability for systems to provide multiple opportunities for practice that can be calibrated to present challenges as users become more accomplished, agents may be a promising addition to language learning and therapeutic contexts. For example, researchers developed a hairless agent named Baldi who provided positive, emotive feedback regarding correctly identifying (receptive language) or saying new vocabulary (expressive language), including verbs such as “chasing” and objects such as “wrist.” Participants were school-age children with ASD who had reading levels in the kindergarten to first-grade level ($n = 8$; 9–12 years of age; Bosseler & Massaro, 2003). Results indicated that students increased their vocabulary significantly from baseline after 10 30-min sessions for an average of eight sessions each. Furthermore, the students demonstrated that they remembered 85% of their new vocabulary 30-days following the

intervention. In a follow-up including six children from the original pilot study, results using a multiple baseline methodology indicated that the children's improvements in vocabulary were associated with the periods when they engaged with the program (Bosseler & Massaro, 2003).

2.2.1 Sight word reading

In a pilot study examining the effects of using an agent paired with a computer program that had automatic speech recognition, youths with ASD ($n = 3$, 19–20 years with IQs in the “mild to moderate range”) participated in a sight-reading intervention. The researchers described their agent interface as a “pedagogical agent” (Saadatzi, Pennington, Welch, Graham, & Scott, 2017). Using a multiple-baseline across participants design, results indicated that the three participants could learn new sight words and maintain them after the intervention period. Beyond the encouraging findings, the study represents significant progress in using agent technology, given that it targeted individuals with mild to moderate intellectual disability and a computer program that could also successfully process the participants' expressive language.

2.2.2 Sign language applications

Avatars also could be well-suited to facilitating sign language acquisition, given their ability to produce gestures and reinforce participant-generated gestures with appropriate facial expressions. The game *CopyCat* was a pioneering version of such a system designed to improve child use of American Sign Language (ASL). It used gesture recognition that allowed Deaf children or those with hearing impairment to practice signing to direct a cat agent's actions. Therefore, the agent executed game commands communicated by the child's sign language (Lee et al., 2005). However, the cat agent did not communicate sign language to the child. *CopyCat* used pre-recorded video clips of an actual human to help demonstrate the signs needed to give the cat agent directions (Lee et al., 2005). Researchers conducted a pilot study with school-aged Deaf children ($n = 7$). Using an *Oz* paradigm, the outcomes highlighted that children could use sign language to elicit character actions for at least 20 min. Children preferred directing the cat to perform activities (e.g., catch the butterfly) instead of asking the agent questions (e.g., Are you hungry?). Unfortunately, no follow-up studies related to this system were reported.

More recently, a new system that elevated this pioneering work to include using a signing agent paired with virtual reality glasses to represent

the user's own hands has demonstrated promising results in pilot studies teaching ASL to young adults who do not know it (Quandt, 2020). Based on user feedback from the earlier studies, future iterations will include system error monitoring to provide the users with corrective responses when needed.

Concerning supporting learning for Deaf children, agents also have been used to translate traditional texts into sign language to support social science curriculum for third- to fifth-grade Deaf students in Turkey ($n = 25$; Yorganci, Kindiroglu, & Kose, 2016). In contrast to text-only materials, results indicated that the students demonstrated higher accuracy rates on content-related questions when they accessed the curriculum supported through an agent signing the content in addition to having the text (Yorganci et al., 2016). Similarly, using another sign-language translation program integrating an agent, school-aged Deaf students ($n = 6$) nearly doubled their ability to decode the written format of sign language (Bouزيد, Khenissi, & Jemni, 2016).

This concept of translation to support learning for Deaf children was recently broadened to create holographic agents with virtual reality glasses. In this feasibility design, Deaf children ($n = 5$, 7–10 years of age), two math teachers, and two hearing parents participated in a math lesson presented in a research lab while wearing virtual reality glasses. The glasses allowed them to view the agent's signing the lesson (word-by-word English signing in contrast to ASL). All child and adult participants reported wanting to use the agents again, and both the teachers and parents expressed wanting to incorporate the agents into their everyday context (classroom and home, respectively; Adamo-Villani & Anasingaraju, 2017).

2.3 Early learning and motor abilities

Less research has been focused on using agent-based interventions to support cognitive development and motor abilities in children with IDD. However, research has begun to focus on aspects of early learning, particularly matching, classification, and early quantitative concepts which has applications for individuals with IDD. Additionally, some initial work has targeted improving motor skills. Below, we describe each of these domains in more detail.

2.3.1 Cognition

An intriguing intervention addressing early memory and declarative knowledge combined agents with touchable objects. This pilot study integrated an

expressive farmer agent with objects that children could touch and move on a table. Additionally, the system could “see” and process the child’s movement of the objects in real-time. The intervention included two classes of typically developing preschoolers (one with 3- to 4-year-olds and one with 4- to 5-year-olds, no sample size reported) and school-aged children with IDD ($n = 6$; [Cerezo, Marco, & Baldassarri, 2015](#)). The participants with atypical development included one with multiple disabilities, one with West syndrome, two with Down syndrome, one with ASD, and one with attention-deficit hyperactivity disorder (ADHD). All children engaged in a game using the farmer agent to follow simple one and two-step directions and use visual-perceptual skills to locate matching objects. The pilot results indicated that (1) compared to the typically developing participants, children with IDDs benefited from teacher support to frame the activity and provide additional scaffolding such as modeling the actions; and (2) the agent appeared to have a significant role in facilitating engagement for children with IDDs, including the agent’s emotional feedback such as laughing and dancing for positive reinforcement and sadness for negative feedback.

This intervention design is noteworthy as it paired an agent with touchable objects and targeted early cognitive abilities for school-aged children with IDDs. The ability to incorporate physical objects may be vital in early cognitive development, given the importance of manipulating objects to support the development of mental representations ([Cerezo et al., 2015](#)). Additionally, researchers have emphasized the importance of considering the types of challenges associated with specific clinical groups to enhance engagement, such as incorporating a teacher or caregiver to assist a child’s engagement as demonstrated in this study, or such as using short instructions and uncluttered backgrounds for children with ADHD ([Cerezo et al., 2019](#)).

2.3.2 Motor abilities

A pilot study with 6- to 8-year-old boys with ASD who were described as having “medium-low” (p. 119) levels of function demonstrated that all users successfully engaged with a system designed to improve motor abilities related to imitation, body awareness, and motor planning ([Garzotto, Gelsomini, Oliveto, & Valoriani, 2014](#)). The participants ($n = 5$) engaged in approximately six 10-min sessions while accompanied by a therapist. The system featured an agent that looked like a shadow of the child engaged in the game. The child would be challenged to use their body to imitate the same body position as the agent’s, with the system providing real-time

feedback. According to the procedures, the agent had no interactive features, but the system provided motivating and corrective feedback. Findings indicated that all five participants successfully engaged in the therapeutic game, with each participant demonstrating improvements in producing more efficient movements from the start to end of each session and in performance from the first to last session (Garzotto et al., 2014). While the researchers suggested that this intervention could also promote social skills when used with children, they did not report results related to this outcome. This study is notable for targeting young students with IDD who, according to the authors' descriptors of "medium-low" functioning, experienced more significant developmental challenges than most participants targeted in this body of research. The researchers also reported parental feedback indicating that their children could better engage in daily living skills following the intervention.

2.4 Summary

Collectively, the evidence introduced here suggests several potential applications for utilizing agent-based computer approaches to enhance social interactions and skills, foundational literacy skills, aspects of language, cognition, and motor abilities. From the computer science perspective, agents are not replacements for interventionists, educators, or parents. Agent-based interventions have the potential to help children and youths with IDD manage stress while learning new skills, improve developmental outcomes, and persist in high-frequency practice. In the next section, we review opportunities to further develop this technology for children with IDD.



3. Future directions

The state of inquiry on this literature demonstrates a drive to use technology with targeted groups who could benefit the most—children with IDD. Growing evidence indicates that agents have an exceptional ability to enhance existing therapeutic and educational approaches by providing opportunities for high-frequency practice and motivating interaction that potentially enhances persistence and performance. However, much work is still needed. At present, the research on using agents in intervention and pedagogical approaches have addressed many significant domains, including social communication (Lahiri et al., 2015), foundational literacy skills (Saadatzi et al., 2017), and motor abilities (Garzotto et al., 2014) to name a few. However, there is a paucity of focused, programmatic research

methodically examining the beneficial effects for children and youth with IDD. Therefore, intentional focus regarding rigorous research designs targeting individuals with IDD is urgently needed. In the below sections, we review recommendations to advance research in this area.

3.1 Optimizing research designs

While noteworthy for their pioneering contributions, the research incorporating agents, whether through game-like intervention or more instructive approaches, primarily uses pilot studies with small sample sizes. Therefore, most of the research reviewed here is in the pilot stage of intervention development, with few studies resulting in planful, programmatic research with efficacy and effectiveness studies. Additionally, most studies rely on chronological age to describe their participant characteristics, leaving out data such as developmental age, clinical diagnosis specifics, and race/ethnicity. Incorporating detailed participant characteristics and larger sample sizes are required to evaluate these interventions' effects and generalizability. Conversely, if smaller sample sizes are warranted during iterations of intervention development, planful use of a multiple baseline design could be a feasible option to understand intervention effects (e.g., [Bosseler and Massaro, 2003](#); [Saadatzi et al., 2017](#)).

Another point for consideration when contemplating applications for children with IDD, is that most research examining agent interventions has focused on children with IDD who have relatively more competent cognitive abilities. There is less agent research on children with IDD who experience greater levels of challenges. Creating programs for those who are very developmentally young will likely offer participants greater beneficial outcomes, given that the effects of relative strengths or challenges can mount over time ([Fidler, Daunhauer, Will, Gerlach-McDonald, & Schworer, 2016](#)). Researchers have noted that children who have not yet developed symbolic thinking may have difficulty interacting with agents ([Bossavit & Arnedillo-Sánchez, 2019](#)). Nevertheless, researchers have not methodically examined the relationship of developmental age with the use of agents or with the use of specific types of agents (e.g., a teacher or a collaborator) or specific agent systems (e.g., agent vs agent + tangible objects as applied in [Cerezo et al., 2015](#); [Cerezo et al., 2019](#)). Additionally, targeted preventative intervention outcomes should align with children's educational objectives and be embedded in broader services and schools to enhance relevancy and transfer of skills to everyday life ([Lynch et al., 2021](#)).

3.2 Optimizing therapeutic agents and program design

Most IDD's are caused by neurogenetic syndromes that often have an associated phenotypic profile, leading to a high probability of having some outcomes in contrast to others, such as working memory issues in children with Down syndrome (e.g., [Daunhauer, Will, Schworer, & Fidler, 2020](#)). However, future research should also consider the individual variability of participants with neurogenetic syndromes in understanding outcomes and mechanisms of change. For example, some children with challenges in working memory and strengths in visual processing may benefit from agent systems pairing verbal instructions with visual reinforcement ([King, Lemons, Davidson, Fulmer, & Mrachko, 2020](#); [Lemons et al., 2015](#)).

Another challenge of using “therapeutic” agents with developmentally young children will likely be integrating automatic speech recognition. While interactive computer games, toys, and learning games have been spurring technological advances in speech recognition, computers have more difficulty recognizing speech produced by children than adults. Further complicating this area is that most automatic speech recognition research that includes children has focused on typically developing children ([Claus, Gamboa Rosales, Petrick, Hain, & Hoffmann, 2013](#)).

The research to date suggests that in earlier stages of development, children use a high degree of variability in speech production and the use of multimodal speech (e.g., speech plus gestures such as hand or head movements; [Montanari, Yildirim, Andersen, and Narayanan \(2004\)](#)). In addition to the broad range of speech production in early development, a significant barrier to researching automatic speech recognition is the attention span of children at this age and how it affects methodological logistics, given that children are not yet able to read speech samples ([Claus et al., 2013](#)).

To our knowledge, [Saadatzi and colleagues' \(2017\)](#) study is one of the few to effectively integrate automatic speech recognition within an agent system for individuals with IDD's. However, these participants were young adults who likely have expressive speech abilities that have benefitted from previous therapies and life experience. Much more research is needed regarding how automatic speech recognition works with young children with IDD's, many of whom experience speech delays, to understand if this is a feasible engagement mode for children with IDD's.

Nevertheless, some agent systems may already afford individuals with attenuated expressive speech an alternative form of communication. A recent study has focused on computerized systems that “see” the participants in real-time, allowing children to use broad gestures to communicate with

agents such as pointing, sweeping a hand to one side of the screen, or closing a fist to grab an object before moving it. Compared to a group of students equated for age, early elementary-aged students ($n = 70$, M age = 6.9 years) interacting with agents remembered classifications of shapes and colors, as well as reordering and identifying sequenced patterns longer (Gelsomini, Leonardi, & Garzotto, 2020). Researchers have suggested that children's use of gestures and other sensorimotor actions are foundational to thinking and cognition (Gelsomini et al., 2020). Furthermore, other systems have piloted child gestures to interact with agents to support learning, such as systems related to museum exhibits (e.g., Ball, Ahn, & Johnsen, 2019). Using broad gestures instead of language to interact with an agent may be a useful approach to apply to children with IDD. It reduces the potential burden of the child having to use expressive language and eliminates the challenge of having a computer system accurately process spoken language.

3.3 Community-based participatory approaches

Although many studies report children's engagement and responses as part of pilot studies, including stakeholder input from the inception of the intervention's design is largely absent from this literature. Boyd et al. (2018) provided a model for this. The researchers sought end-user stakeholder input in creative ways throughout the intervention development phase that would ultimately target social communication in children with ASD, 8–14 years, using augmented reality. For stakeholders, they recruited a group of adults with various IDDs, including those with social pragmatic challenges. The team then used a card sort with the stakeholders to identify social communication challenges in the work context, choosing the top three most frequently chosen challenges to target—proximity to social partner, voice volume, and duration of time spent talking. Then the researchers created a visual/paper version of the system and two computerized versions of this augmented virtual reality intervention that focused on participants being able to toggle performance for their agent like volume using a soundbar, and time spent talking was indicated by changing an icon from red to green. The proximity of social distance was manipulated by choosing from concentric zones around the agent. All design iterations of the intervention involved stakeholder feedback and subsequent intervention revisions such as reducing visual distractions in the chosen computerized background reflected this input (Boyd et al., 2018).

Community-based participatory research is a complementary framework to include stakeholder input applicable to agent interventions for individuals with IDD. From this perspective, it is essential for researchers to partner with stakeholders such as community practitioners, parents, and members to identify relevant research priorities, develop and implement interventions, and communicate research findings (Riggs, Rigles, Schworer, & Fidler, 2020). Therefore, using this approach, researchers, and stakeholders, for example, could collaborate to address phenotypic outcomes associated with a neurogenetic syndrome with an agent-based intervention that can have salient, positive outcomes for the members. There is currently a paucity of information to guide our understanding of how interventionists, educators, and parents may view agent interventions. Findings examining interventionists' likelihood of using robot technology for children with IDDs might offer some insight. In this research, interventionists indicated that perceived usefulness was a significant factor in guiding their decisions to incorporate the robots into intervention sessions (Conti, Di Nuovo, Buono, & Di Nuovo, 2017). This finding underscores the significance of applying community-based participatory research methods to agent intervention development. Finally, related to buy-in, researchers should consider the availability of technology and costs and the types of devices needed when designing systems to optimize access for as many targeted users as possible (Lynch et al., 2021).



4. Summary and conclusions

Avatars are virtual agents who are interactive and act intelligently to be the social embodiments of computer programs. Avatars can play the role of allies, tutors, and teachers and may provide a social motivation to persist in challenging intervention tasks and educational approaches. The research on agents as an adjunct to existing therapies and educational approaches for children with intellectual and developmental disabilities is growing. Rather than being viewed as a replacement for therapist-child, teacher-child, or parent-child interactions, this technology is an innovative addition to “business as usual,” as seen in early intervention services and school-based therapies. Many developmental domains that would benefit from high-frequency practice, such as executive function, could be particularly well-aligned with this technology and a preventative intervention stance. Importantly, agents could be a pivotal methodology in taking a more

proactive approach to preventing downstream sequelae such as behavioral problems by creating more equitable access to programs administered in a format that supports task persistence and performance.

To date, primarily pilot-level data indicates promising intervention effects, but the field has a paucity of projects that have engaged in all levels of intervention research from development to implementation. The systems and technologies integrated into these interventions are complex, which is likely part of the challenge. Additional projects that include rigorous research design, thoughtful adaptations to target developmentally young abilities and individual variability, community-based participatory methodologies, and multi-disciplinary teams are needed to inform this approach.

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