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Research Paper

Knowing versus doing: Children's social conceptions of and behaviors toward virtual reality agents

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ABSTRACT

Virtual reality (VR) can blur fantasy and reality for children by replacing their physical world with artificial stimuli. This immersive technology often includes intelligent and interactive embodied agents. In this within-participant study, we investigated 5- to 9-year-old children's ($N = 25$) social conceptions of and behaviors toward embodied agents in VR that represented different probabilities of existence in their daily lives (i.e., a probable child, an improbable giraffe, and an impossible Muppet). Participants rated the child and the giraffe agents significantly higher as social living beings than they rated the Muppet agent. When tasked with walking up to each embodied agent, significantly more children chose to approach the giraffe agent first rather than the child and Muppet agents. However, children stood significantly closer to the child agent, and significantly more children spontaneously reached out to try to touch the Muppet agent. Finally, children expressed strong emotions (amazement, excitement, happiness, fear, worry) toward all three embodied agents, with the giraffe evoking the most positive and the Muppet the most negative emotions. These results show that types of embodied agents in VR significantly impact children's conscious and unconscious social conceptions and behaviors differently, with implications for future interventions.

1. Introduction

With each passing year, children in early to middle childhood (5- to 12-years of age) gain greater access to interactive and immersive technologies, like virtual reality (VR). For instance, in Sweden in 2015 McDonalds provided kid's meals boxes that could be transformed into a VR headset. In the United States in 2017, 65% of 8- to 10-year-old children reported being fairly to extremely interested in trying VR, with 54% being familiar with the technology (Yamada-Rice et al., 2017), and by 2021 one in six 8- to 12-year-old American children reported using VR (Rideout et al., 2022).

Although children and youth increasingly engage in online VR environments (Maloney et al., 2020), many parents worry about the content their children are exposed to in VR (Yamada-Rice et al., 2017). Children in early to middle childhood may be particularly sensitive to the perpetual realism of VR, as they are still developing a mature understanding of the probability of events occurring and distinctions between fantasy and reality (Claxton and Ponto, 2013; Woolley and Ghossainy, 2013). Evidence points to VR provoking stronger negative emotions in children in this age range compared to adults (Cadet and Chainay, 2021; Cadet et al., 2022; Silva et al., 2022), and young children mistake impossible events in VR as possible (Schmitz et al., 2020; Segovia and Bailenson, 2009). In addition, VR experiences influence preschool and elementary school-aged children's perceptions, emotions, and behaviors more intensely than less immersive experiences (Bailey, Bailenson, Obradović, & Aguiar, 2019; Schmitz et al., 2020; Segovia and Bailenson, 2009).

Within VR environments, children are likely to interact with embodied agents that represent the various character types commonly found in children's media. For example, a VR experience using an animated children's television show character, Doctor McStuffins, reduced children's anxiety before a medical procedure (Gold et al., 2021). Differing from characters on 2D screens, fully immersive virtual reality (VR), blocks out children's sensory information from the physical world and replaces it with artificial stimuli (Cummings and Bailenson, 2016; Kobayashi, Ueno, & Ise, 2015), creating the illusion that virtual agents are physically present, thus blurring the line between fact and fiction. Most of the literature in children's interactions with embodied agents emphasizes 2D screen interactions, making it is unclear what children's social-emotional responses will be in response to popular

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character types in VR. In the present study, we investigate 5- to 9-year--old children's (a) positive social ontological understandings of, (b) emotional responses to, and (c) social behaviors toward VR agents that represent different levels of probability of existence in children's daily lives (probable, improbable, and impossible).

Child-computer interaction (CCI) continues to grow as an important research agenda with the aim of improving the lives of children. Thus, a deep and nuanced examination of VR is necessary to develop positive entertainment experiences and interventions for children. Our study contributes to the CCI and human-computer interaction discussion on the impact of immersive technology and virtual agents on children's behaviors and perceptions by reporting on (a) how the type of embodied virtual agent impacts children's social behaviors, (b) how children conceptualize different types of embodied agents in immersive media, (c) children's emotional perception of embodied agents in VR and the language they use to describe them, and (d) insights on the use of characters for VR interventions aiming to positively impact children's behaviors, perceptions and emotions, including the appropriate use of VR for children.

1.1. Related work

Embodied agents in VR will likely be the future of children's entertainment, education, health care, and potential careers such as using AI-powered embodied agents to moderate content in online social VR environments (Fiani et al., 2023). While VR experiences have been shown to improve children's lives, such as in education and medicine (Mikropoulos and Natsis, 2011; Shahrbanian et al., 2012), it is unclear how virtual embodied agents typically found in children's media impact their social perceptions, emotions, and behaviors. Examining children's perceptions of and social behaviors towards embodied agents in VR can provide researchers and designers insights on leveraging embodied agents to improve children's lives, creating safe and enjoyable experiences.

1.2. Character type and children's preferences of embodied virtual agents

Children in early to middle childhood often develop positive social connections (e.g., parasocial relationships) with virtual agents, providing them with companionship, (Tukachinsky et al., 2020), and improving their social and academic learning (Calvert et al., 2020; Chase et al., 2009; Ryokai et al., 2003). Children in this age range prefer and pay greater attention to characters that are children, puppets, animals, and animated characters (Alwitt, Anderson, Lorch, & Levin, 1980; Anderson & Kirkorian, 2013; Anderson and Levin, 1976; Schmitt, Anderson, & Collins, 1999), and compared to adults, place greater emphasis on their ideal virtual agent as being friendly and approachable (Van Brummelen et al., 2023). For instance, a virtual embodied agent modeled from Dora the Explorer, a children's television character, helped improve 4- to 6-year-old's math skills (Calvert et al., 2020).

The social realism of virtual agents will be an important factor to consider when developing positive VR experiences for children (Brunick et al., 2016). *Social realism* refers to the likelihood that an entity or event exists without one resorting to fantastical thinking—that their existence in the physical world is plausible (Rosaen and Dibble, 2008). The child, animal, and puppet characters preferred by children and commonly found in their 2D screen media experiences, can represent different levels of social realism. Research on characters on 2D screens shows that the greater the social realism of television characters, the greater the positive emotional attachment 5- to 12-year-old children feel toward them (Brunick et al., 2016; Rosaen and Dibble, 2008), with older children preferring characters high in social realism. However, children in early to middle childhood are also sensitive to the perceptual cues of virtual agents, and ill-designed virtual agents can evoke negative emotions (Brunick et al., 2016; Tinwell & Sloan, 2014). Even adults experience negative emotions towards virtual embodied agents low in social realism (Mousas et al., 2018).

Not only does the level of social realism of characters matter for children, but also the technology in which they experience them. For instance, research shows that children prefer *voice-only* virtual agents to be artificial (i.e., robot; Van Brummelen et al., 2023), but prefer *embodied* virtual agents in VR to be humanlike (Fiani et al., 2023). More research is needed to understand children's social-emotional experience of embodied virtual agents in VR based on character types commonly found in children's 2D media experiences, and how they describe those experiences in their own words. Understanding the intersection of the social realism of embodied agents and immersive technology, like VR, will provide greater insight on children's developing positive social-emotional experiences in children's future media.

1.3. Children's ontological understanding of embodied virtual agents

Arguably related to social realism, ontological understanding refers to having "a system of boundaries which allows for a basic categorization of an entity along the lines of its perceived features and attributes" (Festerling and Siraj, 2020, p. 29). Children's conceptualizations of artificial entities, like embodied virtual agents can impact their decision making and their social behaviors (Claxton and Ponto, 2013; Kahn et al., 2012; Kahn Jr et al., 2004; Woolley and Ghossainy, 2013). For example, preschoolers who categorize media figures in television shows as trusted are more likely to learn and transfer their newly acquired knowledge (Schlesinger et al., 2016). According to the New Ontological Category Hypothesis, children develop unique conceptualizations of social interactive technologies that blur the line of animacy (Kahn et al., 2011; Severson and Carlson, 2010). For instance, children categorize social robots as having a specific type of intelligence (Jipson and Gelman, 2007), view disembodied conversational agents (i.e., smart speakers) as friendly and trustworthy (Druga, Williams, Breazeal, & Resnick, 2017), and apply a moral ethic in the treatment of social robots (Barker et al., 2018; Kahn et al., 2012). Compared to social robots less insights exist on children's ontological understanding of embodied agents in VR as positive social living beings. In contrast to social robots, VR creates the illusion that embodied agents are physically present without possessing a physical body. This illusion is achieved by providing children with a wide first person view of the content, stereoscopic vision that enhances seeing 3D objects, and allowing them to interact with the virtual environment with their bodies via tracking (Bowman & McMahan, 2007; Cummings and Bailenson, 2016).

Children's age and the tendency to anthropomorphize non-human entities are two factors that could impact children's perceptions of embodied agents in VR. By the age of 5, children typically distinguish fantasy from reality in media (Woolley and Ghossainy, 2013), and can accurately categorize artificial entities as alive or not alive. However their abilities for ontological understanding of artificial entities (Goldman et al., 2023), younger children's ontological understanding has yet to reach the same level as adults (Wright et al., 2015). These age trends persist in children's perceptions of VR experiences and interactions with embodied virtual agents. For example, preschool aged children are more likely to confuse VR content as real than elementary aged children (Segovia and Bailenson, 2009), and 5-year-old children are more likely to falsely claim that an embodied virtual agent can see them compared to 7- and 9-year-olds (Claxton and Ponto, 2013).

In addition to age, children's tendency to apply human qualities to nonhuman entities (to anthropomorphize them), will likely influence their social ontological understanding of embodied agents as social living beings—the greater the tendency of 5- to 9-year-old children to anthropomorphize a social robot, the more they apply social attributes to it (Severson and Lemm, 2016), with a stronger tendency among younger children (Manzi et al., 2020). Furthermore, the tendency to anthropomorphize artificial entities is a stable trait that varies among individuals (Waytz, Cacioppo, & Epley, 2010). We predicted that children would accurately identify the embodied agents as social living beings based on their level of social realism as they get older, considering children's tendency to anthropomorphize non-human entities. Specifically, we hypothesized that the children would rate the child agent higher as a living social being than the giraffe and the Muppet and that they would rate the giraffe significantly higher as a social living being than the Muppet.

1.4. Children's automatic and spontaneous behaviors towards virtual agents

Observable social behaviors are often utilized to understand users' social and psychological experience of embodied virtual agents in VR as communicating abstract concepts, such as presence, as self-report is challenging for adults (Slater, 2004), let alone children. Researchers have studied the length of time during which children orient their gaze toward the television as an indicator of their preferences (Anderson & Kirkorian, 2013; Schmitt et al., 1999), and children's approach behaviors like interpersonal distance to characters could act as an equivalent in immersive virtual environments like VR.

VR allows children to move their entire body, and interpersonal distance has commonly been used to measure comfort and preferences with embodied virtual agents among adults, with closer distances as an indicator of greater comfort levels (Bailenson, Blascovich, Beall, & Loomis, 2003; Llobera, Spanlang, Ruffini, & Slater, 2010; Yaremych and Persky, 2019). While limited research currently exists, studies show that children engage in a variety of automatic and spontaneous social behaviors towards embodied virtual agents in VR such as attempting to touch, speak to, or even become the agents (Bailey et al., 2019; Schloss, Bailey, & Tripathi, 2021). In addition, in Kahn et al.'s (2006) study, children engaged in more apprehensive and exploratory behaviors toward a robotic dog than a stuffed dog (both rated the same as social living beings), suggesting that artificial entities that appear real catalyze children's social-emotional behaviors.

Children's social behaviors toward embodied virtual agents in VR can be viewed as a direct reflection of evolutionary functions of the appetitive and aversive motivational systems. The appetitive system encourages approach behaviors that help an organism find food and potential mates. The aversive motivational system initiates avoidance behaviors to protect the individual organism from danger (Bradley & Lang, 2007; Lang, 2006). Some researchers have argued that humans' general base level consists in a weak activation of the appetitive system (Bradley and Lang, 2007). In response to relatively neutral stimuli, people tend to engage in approach behaviors. However, dangers quickly activate the aversive system as a line of defense. Children's motivational approach behaviors, such as characters they select to approach first and how close they stand to characters can be used to measure children's preference of agents of different types of social realism.

Children's preferences for embodied virtual agents in VR based on their level of social realism can be linked to their ability to predict if the embodied agent represents a friend or foe in VR. A study by Yip et al. (2019) found that 7- to 11-year-old children used the appearance and predictability of interactive technologies to determine if they felt positively or negatively towards the technology. Embodied agents high in social realism, such as a child character, would resemble peers and would be more likely to activate approach behaviors. A wild animal, such as a giraffe, that children likely recognize but have less probability of having direct interactions outside of a zoo context (and thus less predictable as a friend or foe) would likely activate some positive approach behaviors. At the low end of social realism, a fantastical puppet such as a Muppet, even more potentially challenging to predict as a friend or foe, would be even less likely to activate approach behaviors. We hypothesized that significantly more children would choose to approach an embodied child first rather than the giraffe and Muppet agents, with the giraffe chosen first significantly more often than the Muppet. Furthermore, we hypothesized that children would stand closest to the child character, the giraffe character the next closest, and stand the farthest from the Muppet character.

2. Method and materials

2.1. Study overview

In this study, we examined 5- to 9-year-old children's positive social conceptions of and behaviors and emotions toward VR embodied virtual agents that represent different levels of probability of existing in their daily lives: probable, improbable, and impossible. Using a head-mounted display (HMD), children interacted with a child embodied agent (i.e., probable), a giraffe embodied agent (i.e., improbable), and a blue fuzzy Muppet embodied agent (i.e., impossible). In VR, interacting with a child embodied agent represents high social realism (probable), interacting with a giraffe suggests a moderate level of social realism (improbable), and interacting with a Muppet, a type of puppet, would indicate the lowest level of social realism (impossible). Children (a) interact with other children in their everyday lives at home or in school; (b) have had some face-to-face exposure to a wild animal like a giraffe, such as at a zoo, but not up close indoors in their typical day; and (c) have never interacted with a Muppet character type, apart from a costumed individual, as a living social being in the physical world.

The three VR embodied virtual agents appeared simultaneously in the virtual environment, randomly assigned to one of three equidistant positions in a semicircle within the children's line of sight (Fig. 1). We measured children's (a) preferences on which agent to approach first, second, third, as well as children's interpersonal distance to, emotional perception of, and spontaneous physical behaviors towards each of the embodied agents. We selected the age range of 5- to 9-years to gain a nuanced observation on how variance in age-related preferences for characters, and maturity in ontological understanding of artificial entities contributed to children's experience of VR embodied agents.

Finally, to determine the impact of the VR on children's wellbeing we examined children's emotional and physical distress levels before and after the experience. VR makes fantastical characters appear perceptually real and salient, more so than less immersive media, and the type of embodied agent that children encounter could impact the type of emotions children experience. For example, an unfamiliar embodied agent in VR could provoke a negative response because VR's perceptual realism might create the illusion of encountering a stranger in the physical world. Another negative physical side effect of VR's perceptual realism is the experience of simulator sickness or cybersickness (Hoeft et al., 2003; Kennedy et al., 1993), so we measured the children's physical

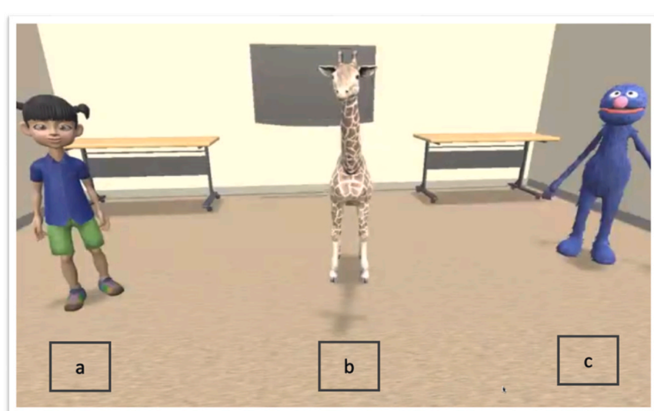

Fig. 1. VR Embodied virtual agents by Character Type. Children interacted in VR with three different character types based on their everyday occurrence in the physical world: (a) child embodied agent (probable), (b) a giraffe embodied agent (improbable), and (c) a Muppet embodied agent (impossible). The system randomly assigned each embodied agent to one of three locations within the participant's view, equidistance from each other and the participant.

distress before and after the VR experience. However, VR experiences shorter than 30 min have not been found to have negative, lasting physical effects for children (Kozulin, Ames, & McBrien, 2009; Neveu, Blackmon, & Stark, 1998; Yamada-Rice et al., 2017). We used moderately familiar characters to minimize emotional distress among children, and the VR experience was less than 20 min.

2.2. Experimental design

A within-participant and repeated measures design (Fig. 2) measured children's (a) emotional distress and physical distress levels (before and after the VR experience), (b) approach preferences to each character (e.g., agent they approached first, interpersonal distance to each character within VR), (c) emotional perception of each character (within VR), (d) their children's assessment of the characters as positive social living beings (within VR), and (e) spontaneous physical behaviors towards each character (within VR). Children's tendency to anthropomorphize and age acted as potential covariates. The study used both quantitative and qualitative methods.

2.3. Embodied agent selection

We selected embodied agents based on the three types of characters commonly found in 2D media (e.g., television), children, animals, and puppets, that draw most of children's attention (Anderson & Kirkorian, 2013). Because children can have strong emotional responses to VR content (e.g., Cadet et al., 2022) and are sensitive to the perceptual cues of characters (e.g., Tinwell & Sloan, 2014), we selected characters that would likely be familiar and comforting to children, to avoid evoking fear. A team of four researchers discussed and selected the various types of agents used in the study. The child agent represented a child character in children's animated shows, and for each study session, the researcher selected a child character that looked closet to the child participant (we created 13 diverse child agents to select from).

For the animal agent, we decided on a non-predatory animal familiar to children. Because all the agents were scaled to be the same size of each participant, and the animal needed to be found in the wild as relatively large, we chose a young giraffe. Finally, we selected a Muppet, a type of puppet character found in a popular children's television series (e.g., Anderson and Levin, 1976). We selected the blue Muppet as a character as children were somewhat familiar with, but not necessarily the most popular (i.e., Grover™ versus Elmo™), as not to have more recognition and popularity than the child and animal character types. To determine that the embodied virtual agents were moderately familiar, a researcher assessed children's familiarity of each character before the VR experience (i.e., recognition above 50% chance).

By using the position of the HMD along the *y*-axis, the system scaled the embodied virtual agents to the height of each child. We programmed each embodied agent with small idle animations and to turn to make eye contact with the children. The idle motions consisted of the characters shifting weight slightly, small head movements, and in the case of the character and giraffe eye blinking, and with the child and the Muppet moving their arms slightly. The animations and behaviors of the agents were kept simple as to not conflate the characters' specific actions with the character type, as the behaviors of artificial entitles can intensify emotional experiences of them (Mori, MacDorman, & Kageki, 2012; Tinwell et al., 2011).

2.4. Virtual reality equipment and environment

The children wore the Oculus Rift consumer-version (CV1) HMD, which contains a gyroscope, an accelerometer, and a magnetometer that tracks translation (*x*-, *y*-, *z*-axis) and orientation (roll, pitch, yaw) movements. The VR environment (Fig. 1) presented a replica of the physical lab space (a large room with two desks and a large TV screen at the front, a small couch to the side, and a desk at the back of the room). An external screen (i.e., a television screen connected to a computer) mirrored the children's virtual viewpoint so that parents or guardians could see their child's experience.

2.5. Participants

For this study, we recruited 28 children aged 5-to 9-years from a midsized city in the southern U.S. Children with a seizure disorder, epilepsy, or any condition that would make them susceptible to disorientation or dizziness were excluded, but no parents reported their children as having any of those conditions. Two children were excluded for stopping the experiment early and one for removing the HMD several times during the VR experience, so the final sample comprised of 25 participants for analysis. Parents identified their children's gender identity (girl, boy, nonbinary, gender not listed), born sex (female, male), birthdate, and race/ethnicity. No parents reported differences in

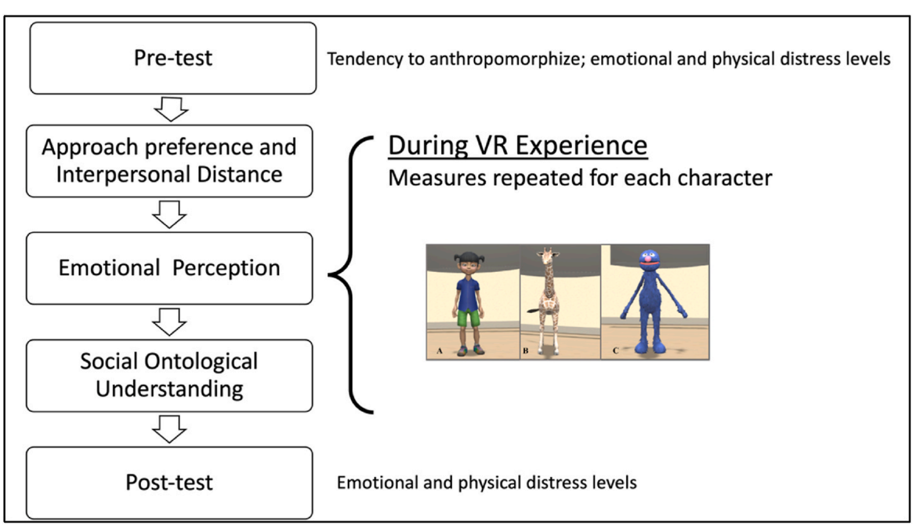

Fig. 2. Study design and flow. A within-participant and repeated measured design measured children's experience before, during, and after the VR experience. While in VR, children approached and stood in front of a character, then a researcher assessed their emotional perception and ontological understanding of the character. Children then repeated this with each of the remaining two embodied agents. Children's emotional and physical distress levels were measured before and after the experience.

their child's gender identity and born sex: Eight were girls (32%) and 17 were boys (68%). The sample consisted of two 5-year-olds, five 6-year-olds, six 7-year-olds, three 8-year-olds, and nine 9-year-olds. The children's mean age on the day they started the experiment was 95.13 months ($SD = 13.66$, median = 94.13). The children's reported races or ethnicities were 4% Asian ($n = 1$); 4% Black, Latinx/Hispanic and Native American/First Nation ($n = 1$); 4% Black and White ($n = 1$); 4% East Asian and White ($n = 1$); 4% Latinx/Hispanic ($n = 1$); 12% Latinx/Hispanic, Asian, and White ($n = 3$); and 68% White ($n = 17$). Finally, parents reported their children's prior VR usage as minimal, with 56% ($n = 14$) never having used it, 40% ($n = 10$) having used it less than once a month, and 4% ($n = 1$) having used it several times a month.

2.6. Measures

2.6.1. Demographic information (pretest)

Parents and guardians reported their children's birthdate, gender identity, born sex, race/ethnicity, and previous experience with VR.

2.6.2. Recognition of character types (pretest)

Children were shown a printed picture of the character types from the virtual environment, one at a time (child, giraffe, Muppet). A researcher asked the children whether they recognized what was in the picture: "Do you know what this is a picture of? Do you know who this is? Who is this? What's its name?" Response options were "yes," "no," or "sort of." If they responded with "yes" or "sort of," the children were assessed as having recognized the character.

2.6.3. Tendency to anthropomorphize (pretest)

The Individual Differences in Anthropomorphism-Child Form (IDAQ-CF) was used to measure the children's tendency to give nonhuman objects or entities human-like attributes (Severson and Lemm, 2016). The IDAQ-CF's 12 questions assess children's anthropomorphism of technologies, animals, and inanimate objects according to aliveness, movement, sociality, perceptual capabilities, and morality. The measure consists of three subscales measuring children's tendency to anthropomorphize technology, inanimate nature, and animals. The procedure from Severson and Lemm, 2016 Study 2, was used, with one adaptation—children responded with "yes" or "no" instead of using thumbs up or thumbs down images. For children that answered with "no" to the initial branching question, their response was coded as "0." The follow-up responses to "yes" were coded as "a little bit" = 1, "a medium amount" = 2, and "a lot" = 3. Higher scores indicate greater endorsement of anthropomorphic beliefs.

2.6.4. Approach preference (during treatment)

Children's preferred character type was assessed by identifying the embodied agent that children walked up to first at the start of the VR experience. After the three VR agents appeared, a researcher told the children, "Now I would like you to walk up to any character. You can get as close as you want."

2.6.5. Interpersonal distance (during VR treatment)

Interpersonal distance was calculated as the minimum distance (in meters) at which children stood facing each embodied agent while in VR, measured as the distance along the z-axis in the HMD's head tracking data and sampling the tracking data at 25 Hz. All children started at the same place in the physical room and the virtual room. The agents were placed in the virtual environment such that children were unable to walk around to the other side of the VR agent. Smaller numbers indicated closer interpersonal distance.

2.6.6. Social ontological understanding (during treatment)

Eight questions from the Attribution Interview assessed children's categorization of the different embodied virtual agents as positive living social beings (Severson and Lemm, 2016). These questions were adapted from previous research in which 5-, 7-, and 9-year-olds assessed the social attributes of robots (Jipson and Gelman, 2007; Severson and Lemm, 2016). Two questions assessed views of animacy (i.e., alive, real); two questions assessed mental states (i.e., think, feel sad or happy); two questions assessed perception (i.e., hearing, seeing); and two questions assessed social rapport with each character (i.e., like the character, character likes you). Response options were "no" = 0, "sort of" = 1, and "yes" = 2. For children who initially answered with "I don't know," we followed up once with "if you had to choose." For children that responded with one of the three response options, the researcher followed up with, "Why do you think that?" Within the interview, some children asked the researcher what they meant by "Is x a real x." In these cases, the researcher responded with, "What do you think? Do you think x is a real x?" A mean score was calculated across all eight questions, and higher scores indicated higher ratings for social attributes.

2.6.7. Spontaneous physical behavior (during treatment)

After the children approached each embodied agent, we observed their spontaneous physical behaviors. Using Braun and Clarke's (2006) method for thematic analysis, we identified attempts to touch or enter the embodied virtual agents as the children' most common behavior ($n = 22$, 88%). We coded children as trying to spontaneously touch an embodied agent if they (a) clasped or clapped their hands in the air in front of them, (b) extended a hand as if patting or petting the embodied agent, (c) brought their hands upward in an arc toward the HMD to touch the embodied agent, (d) kicked a foot or stepped out toward the embodied agent, or (e) waved their arms back and forth in the area where the agent was located in the virtual environment. First, two researchers developed initial codes and codebook for children's social behaviors across all videos. Next, they coded four videos at a time, and compared their codes. They reconciled any differences by reviewing the video footage together. In cases of disagreement ($n = 2$), a third rater provided the tie breaking vote to address the unresolved issues.

2.6.8. Emotional perception of embodied virtual agents (during treatment)

After children approached and faced an embodied agent, the researcher asked, "What are you feeling when you see this character?" Again, applying Braun and Clarke's (2006) method to analyze children's responses, we first created initial codes for each character type, and then generated themes across character types. An open-ended question was used to identify the language that children used to describe their emotional experience of the embodied agents, and researchers did not correct children when they answered the question with "I don't know" or any answer that did not describe emotion (e.g., I can't touch him; I can't feel anything).

2.6.9. Emotional distress (pre- and posttest)

We adapted three questions from the PEDs-QL 4.0 Emotional Functioning subscale to assess children's emotional distress before and after the VR experience (Varni et al., 2001). The questionnaire assessed how afraid, sad, and worried children felt in the moment. First, we used a branching procedure with "yes" or "no" response options, followed up with the options of "a little," "some," or "a lot." The researcher read each question aloud, and the children responded verbally or by pointing at the response option scale. This scale was presented as an image of three water glasses: small (approximately 1/6th full), medium (approximately 1/3 full), and large (approximately 2/3 full). Children that answered the initial branching question with "no" had their response rated as "0." For children that first responded with "yes," their follow up responses were rated as "a little" = 1, "some" = 2, and "a lot" = 3. Mean scores were calculated across all three questions with separate scores calculated for the pre- and posttest questionnaires respectively. Higher scores indicate greater emotional distress.

2.6.10. Physical distress (pre- and posttest)

The children responded to four questions assessing their level of physical discomfort before and after the virtual experience. The questions were adapted from simulator sickness questionnaires designed for adult and child populations (Hoeft et al., 2003; Kennedy et al., 1993), and assessed how much pain children felt in their head, tummy, and eyes as well as level of dizziness. A branching procedure used "yes" or "no" responses, followed up with "a little," "some," or "a lot." The researcher used the same procedure and scale option utilized for assessing children's emotional distress. Children's physical distress levels were calculated as a mean score across the four questions, with scores calculated separately for pre- and post-experience time points. Higher scores indicate greater physical distress.

2.7. Procedure

Parents and guardians provided written permission, and children verbally assented to participate in the study. Children completed a pretest questionnaire measuring their tendency to anthropomorphize nonhuman entities as well as their emotional and physical distress levels. Before entering the VR experience, a researcher assessed children's recognition of the three different character types by showing a printed picture of each character. After the questionnaire, children completed the practice questions in the social ontological understanding interview.

The researcher placed the HMD onto children's heads. The virtual room first contained three different colored spheres in the children's view. The children completed an orientation phase in which they identified the different spheres. The researcher adjusted the headset if children reported not seeing the spheres or if their view was askew on the external screen (i.e., televisions screen connected to a computer). The child embodied agent presented to each participating child was selected by the researcher running the session. The child agent was selected from one of 13 possible child character 3D models that appeared similar to each child participant's appearance. Every child embodied agent wore a blue t-shirt, green shorts, and multicolored shoes.

After the orientation phase, to present the VR agents, the researcher told the children that the characters were "coming out to play," and with a computer keypress the embodied virtual agents grew from the location of the spheres (randomly assigned across the three locations). After the spheres disappeared and the characters stopped growing, the researcher instructed the children to approach an agent to assess the children's approach preference. Once children stopped in front of an agent and were facing it, the researcher assessed their initial emotional perception of the character type and then their social ontological understanding of the agent as a positive social living being. After completing the social ontological understanding interview, researchers assisted the children back to their starting position, and the children completed the same process with the other two agents. The entire VR experience lasted 20 minutes or less. Finally, the researcher removed the children from the VR experience and assessed their emotional and physical distress levels with the posttest questionnaire. The children received a $20 gift card and a small prize (i.e., a sticker) for participating in the study. The Institutional Review Board approved all aspects of the study.

3. Results

3.1. Data analysis

Mixed-effects models were used to examine both additive and interaction effects. If there was no significant differences between models, the additive model was used. The child embodied agent served as the comparison variable for comparing the probable character type with the improbable and impossible character types. The children's age was entered as age in months on the day they started the study. Children recognized all three characters significantly above chance: 76% recognized the child character, $\chi^2(1, N = 25) = 6.76$, $p = 0.01$; 100% recognized the giraffe; and 84% recognized the Muppet, $\chi^2(1, N = 25) = 11.56$, $p = 0.001$.

Applying Braun and Clarke's (2006) six phases of thematic analysis, we examined children's reasoning for their ontological understanding selection, spontaneous behaviors, and initial emotional impressions of each of the agents during the VR experience. Initial codes were first completed for each character type (child, giraffe, Muppet), and similar codes were grouped together to form themes across all character types (with definitions for coding each theme). The process was repeated four times to finalize themes and a codebook. We used an iterative coding process, with the primary goal of identifying common themes, and according to the McDonald et al. 's (2019) guidelines for qualitative data analysis in HCI, inter-rater reliability is not necessary nor needed (McDonald et al., 2019).

3.2. Approach preference

Chi-square was used to test for significant differences in the type of embodied agent (child, giraffe, Muppet) that children walked up to first. Pairwise proportion tests used the Bonferroni *p*-value adjustment. Character type significantly affected children's approach preferences: 64% approached the giraffe first ($n = 16$), 24% approached the Muppet first ($n = 6$), and 12% approached the child first ($n = 3$) first, χ^2 (2, $N = 25$) = 16.68, $p = 0.0002$, Cramer's $V = 0.47$. Pairwise comparisons showed that significantly more children approached the giraffe embodied agent first as opposed to the child agent ($p = 0.001$) and the Muppet agent ($p = .03$). Finally, there was no significant difference between children approaching the child agent first and the Muppet agent first ($p = 1.00$; Table 1.).

3.3. Interpersonal distance

The range of minimum distances was 0–2.85 m ($N = 24$; $M = 0.59$ m, $SD = 0.54$ m). One child was excluded from the interpersonal distance

Table 1
Children's social behaviors towards and perceptions of embodied agents in VR by age.

Social Response	Age Group			All ages (N = 25)
	5-to 6-year-olds (n = 7)	7- to 8-year-olds (n = 9)	9-year-olds (n = 9)	
Approach Preferences				
Walked to First				
Child	0	1	2	3
Giraffe	5	6	5	16
Muppet	2	2	2	6
Walked to Second				
Child	2	4	3	9
Giraffe	1	2	3	6
Muppet	4	3	3	10
Walked to Third				
Child	5	4	4	13
Giraffe	1	1	1	3
Muppet	1	4	4	9
Interpersonal Distance (in meters): $M(SD)$				
Child	0.26 (0.21)	0.41 (0.24)	0.49 (0.31)	0.39 (0.26)
Giraffe	0.45 (0.38)	0.56 (0.29)	0.61 (0.33)	0.55 (0.32)
Muppet	0.39 (0.28)	0.51 (0.33)	0.84 (0.46)	0.59 (0.40)
Social Ontological Understanding: $M(SD)$				
Child	0.85 (0.67)	1.09 (0.60)	0.54 (0.48)	0.82 (0.60)
Giraffe	1.1 (0.68)	0.91 (0.55)	0.79 (0.64)	0.90 (0.60)
Muppet	0.81 (0.52)	0.62 (0.48)	0.44 (0.38)	0.60 (0.46)
Spontaneously Touched				
Child	4	6	4	14
Giraffe	5	7	7	19
Muppet	6	8	6	20

data for being more than three *SD*s above the mean. Children who moved close enough to the embodied agent so that the HMD entered any part of the 3D model received a minimum distance measurement of 0 m, because there was no distance between their virtual self and the VR agent. Smaller numbers indicated closer interpersonal distance.

A mixed-effects linear regression model tested the effect of character type (child, giraffe, Muppet) and children's age (in months) on their interpersonal distance to the embodied virtual agents. Character type and age were fixed factors, with participant as a random factor. There was a significant effect of character type on children's interpersonal distance (Fig. 3): Children stood significantly closer to the child embodied agent ($M = 0.39$ m, $SD = 0.26$; Fig. 3) than to the giraffe agent ($M = 0.55$ m, $SD = 0.32$ m; $b = 0.16$, $t = 2.23$, $p = 0.03$) and to the Muppet agent ($M = 0.59$ m, $SD = 0.40$ m; $b = 0.20$, $t = 2.82$, $p = 0.01$). Planned orthogonal contrasts showed no significant difference in how close children stood to the giraffe in comparison with the Muppet ($b =$ -0.02, $t = -0.58$, $p = 0.56$). However, there was a significant difference in interpersonal distance when comparing the distance to the child agent with the average minimum distance of both the giraffe and Muppet agents ($b = 0.06$, $t = 2.91$, $p = 0.01$), such that children stood closer to the child agent. Finally, there was a significant overall effect of age on how close children stood next to the VR agents ($b = 0.01$, $t = 3.10$, $p = 0.004$), with children standing farther away from the agents as they got older.

3.4. Social ontological understanding

We also tested the impact of character type (child, giraffe, Muppet) on children's view of the embodied virtual agents as positive social living beings (social ontological understanding). Children's responses to the questions ranged from 0 to 2, with a mean score of 0.77 and a standard deviation of 0.56. Higher scores indicated higher ratings as social living beings.

There was a significant negative correlation between children's overall tendency to anthropomorphize nonhuman entities and their rating of the embodied virtual agents as social living beings, $r(61) = -0.37$, $p = 0.003$. However, this significant association with children's social ontological understanding was driven by children's tendency to anthropomorphize animals, with the animal subscale ($N = 25$, $M = 1.73$, $SD = 0.72$) from the larger questionnaire assessing children's tendency to anthropomorphized nonhuman entities was significantly negatively associated with children's social ontological understanding score, $r(64) = -0.43$, $p = 0.0003$. There were no significant associations between children's social ontological understanding and children's tendency to anthropomorphize technology ($N = 25$, $M = 0.42$, $SD = 0.56$; $r(64) = 0.06$, $p = 0.61$) nor their tendency to anthropomorphize inanimate nature ($N = 25$, $M = 0.34$, $SD = 0.36$; $r(67) = -0.16$, $p = 0.19$). Thus, we only included the animal subscale and age in as covariates in the model to examine the impact of character type on children's social ontological understanding of VR agents.

The effects of character type (child, giraffe, Muppet), children's age (in months), and their tendency to anthropomorphize nonhuman entities (animal subscale only) on children's social ontological understanding ratings of embodied virtual agents were tested in a mixed-effects linear regression model. Character type, age, and the tendency to anthropomorphize were fixed factors, with participant as a random factor. Results showed a significant effect of character type (Fig. 4): The child embodied agent ($n = 23$; $M = 0.82$, $SD = 0.60$) was rated significantly higher as a positive social living being than was the Muppet agent ($n = 24$; $M = 0.60$, $SD = 0.46$; $b = -0.21$, $t = -2.26$, $p = 0.03$; Fig. 4). However, there was no significant difference in how children rated the child agent ($n = 23$; $M = 0.82$, $SD = 0.60$) versus the giraffe ($n = 22$; $M = 0.90$, $SD = 0.60$; $b = 0.07$, $t = 0.79$, $p = 0.43$) as social living beings. Planned orthogonal contrasts showed that children rated the giraffe as a social living being significantly higher than the Muppet ($b = 0.14$, $t = 3.03$, $p = 0.004$). No significant difference existed between how children rated the child agent as a social living being in comparison with the average for the giraffe and Muppet ($b = -0.02$, $t = -0.82$, $p = 0.42$).

There was a significant negative association between participants' tendency to anthropomorphize animals and their social ontological understanding scores (b -0.33, $t = -2.77$, $p = 0.01$): As children's tendency to anthropomorphize animals increased as measured by the animal subscale, their ratings of the embodied virtual agents as social living beings decreased. Finally, the effect of age on children's social

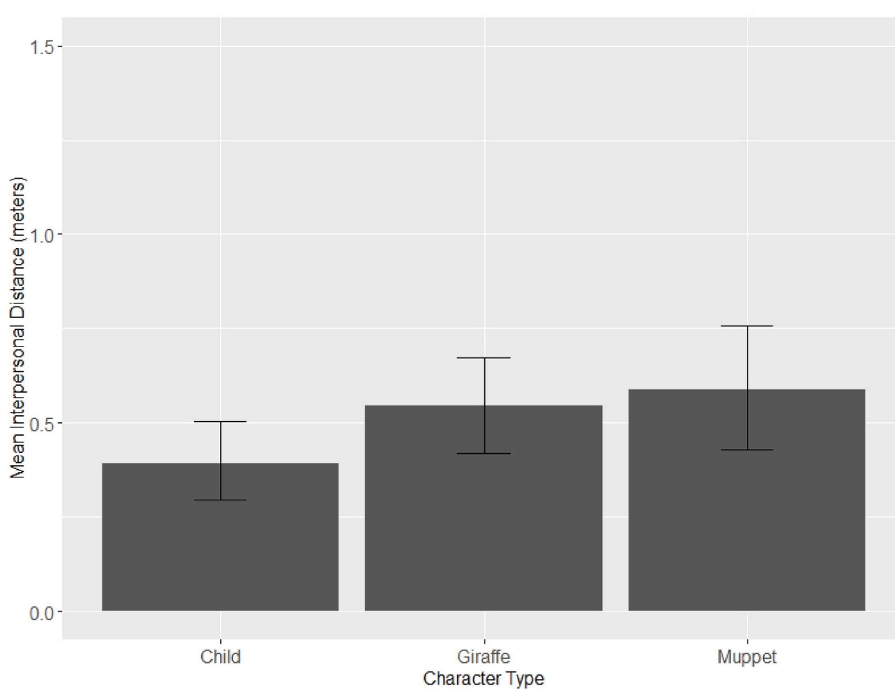

Fig. 3. Children's interpersonal distance to VR embodied agents. The minimum distance that children stood toward each embodied agent while in VR. Shorter distances represent closer interpersonal distance.

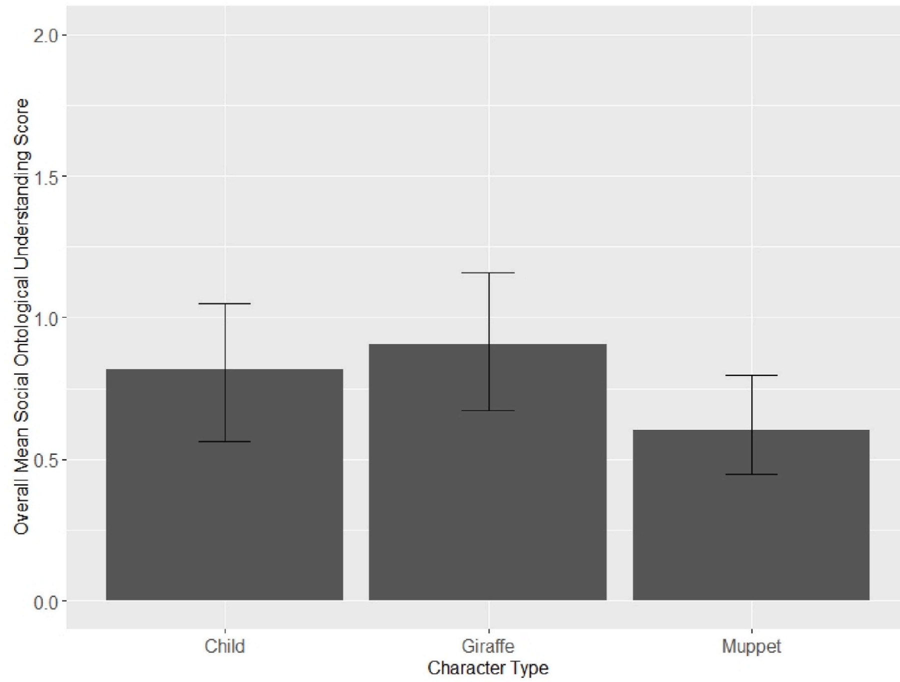

Fig. 4. Social ontological understanding score.
Children's ratings of different VR embodied virtual agents as social living beings. Higher mean scores indicate higher ratings of the character as a positive social living being.

ontological understanding disappeared, as there was no significant effect of age on children's social ontological understanding scores ($b = -0.01$, $t = -0.95$, $p = 0.35$).

3.5. Spontaneous behaviors

The children's most common spontaneous behavior consisted of attempts to touch or enter the VR agents ($n = 22$; 88%). Using a mixed-effects binomial logistic regression model, we tested whether character type (child, giraffe, Muppet) affected children's likelihood to attempt to touch an embodied agent, with character type as a fixed factor and participant as a random factor. Character type significantly increased the likelihood that children spontaneously attempted to touch the agent (Table 1). Children were significantly more likely to attempt to touch the Muppet ($n = 20$, $M = 0.80$, $SD = 0.41$) than the child agent ($n = 14$, $M = 0.56$, $SD = 0.51$; $b = 1.97$, $z = 2.08$, $p = 0.04$). There was a greater likelihood of children's trying to spontaneous touch both the giraffe and Muppet agents in comparison to only trying to touch the child agent alone ($b = 0.59$, $z = 2.22$, $p = 0.03$). However, there was a close but non-significant likelihood of children's attempting to touch the giraffe agent ($n = 19$, $M = 0.76$, $SD = 0.44$) compared to the child agent ($n = 14$, $M = 0.56$, $SD = 0.51$). Finally, there was no difference in the likelihood of children's spontaneously attempting to touch the Muppet agent compared to the giraffe agent ($b = -0.19$, $z = -0.44$, $p = 0.66$). Overall, children were more likely to engage in spontaneous touching behaviors towards the giraffe and Muppet embodied agents.

3.6. Emotional perception of characters

In exploring children's emotions towards the different types of embodied virtual agents, analysis showed a wide range of emotional responses across the three different character types, with 59 unique reports (each response represented one child; Table 2). Analyses excluded 16 instances of responses (across five children) when children either responded with "I don't know," or described the appearance or behavior of the embodied virtual agents or attempting to touch them (e.g., "It is fuzzy," "I cannot feel it"). Emotions fell under four main designations: (a) positive emotions (happiness, amazement, liking the character, curiosity), (b) neutral emotions (calm, normal, typical), (c) uncertainty (confusion, hesitation, unsure), (d) negative emotions (fear, worry, weirdness, creepiness, anger), and (e) conflicting emotions (happiness and fear, amazement and creepiness). Most children reported emotions at extreme ends; 40% of children's total responses described

Table 2
Children's emotional perception of embodied agents in VR by age.

Emotional Response (N = 59)[a]	Age group			All ages
	5- to 6-year-olds	7- to 8-year-olds	9-year-olds	
Positive (i.e., happy, curious, amazed)				
Child	2	2	3	7
Giraffe	3	3	5	11
Muppet	1	3	1	5
Neutral				
Child	2	1	0	3
Giraffe	0	0	0	0
Muppet	1	0	0	1
Negative (i.e., weirdness/creepiness, fear, anger)				
Child	2	3	2	7
Giraffe	0	1	1	2
Muppet	1	4	7	12
Uncertain (i.e., unsure, confused, hesitant)				
Child	0	2	3	5
Giraffe	0	2	0	2
Muppet	0	2	0	2
Conflicting (i.e., amazement and creepiness; happiness and fear)				
Child	0	0	0	0
Giraffe	0	0	2	2
Muppet	0	0	0	0

[a] 15 responses, across five children, were excluded for focusing on either physically touching the embodied virtual agents or describing the agents' appearance.

feeling positive ($n = 24$), and 35% described negative emtoions perceptions ($n = 21$). Fewer instances occurred of children feeling uncertain (15%; $n = 9$), neutral (7%; $n = 4$), and conflicting (3%; $n = 2$).

Out of the 24 positive emotions for the VR agents, the giraffe garnered the most positive emotional descriptions at 45% ($n = 11$). Children often described feeling happy, amazed, and curious when viewing the animal. In reaction to seeing the giraffe, for example, one child described feeling "Awesome, because it looks so real" (P11). Another child exclaimed, "Whoa! Happy. It's cool" (P13). The child agent garnered the second most positive response at 33%, and the Muppet agent the fewest at 21%. In contrast, the Muppet agent evoked the most negative responses, 57% ($n = 12$). Many children described feeling "creeped out" (P1) or "very uncomfortable" (P4) when viewing the Muppet. One child went so far as to say, "Kind of scared because he is creepy" (P7). The giraffe agent did not evoke any feelings of calmness, normalcy, or comfortability, whereas the child ($n = 3$) and Muppet ($n = 1$) agents did. Instead, children reported conflicting feelings when viewing the giraffe agent: "Kinda creepy. Weird, amazed, realistic, wow!" (P2). Across all character types, the children reported feeling unsure, confused, or hesitant in viewing the embodied virtual agents: "Oh my God! Don't know" (P18, referring to the child agent); "I don't know, kind of hesitant because [I] feel like it's kinda real" (P20, referring to the giraffe agent); "Confused a lot because I don't know him. What is he?" (P20, referring to the Muppet agent). The child embodied agent evoked the most uncertain emotions, at 50% ($n = 5$).

3.7. Emotional distress

To examine how the VR experience impacted children's emotional well-being, we used a mixed-effects linear regression model to compare children's emotional distress score pre- and post-experience. The time of the experience was a fixed factor and participant was a random factor. Higher scores indicate greater emotional distress. The pretest mean score for the 25 children was 0.31 ($SD = 0.47$), and their mean scores ranged from 0 to 1.67. The posttest mean score was 0.13 ($SD = 0.32$), and posttest means ranged from 0 to 1.33. There was a significant effect of time on children's emotional distress ($b = -0.17$, $t = -2.36$, $p = 0.03$). Children reported significantly less emotional distress after the VR experience ($n = 25$; $M = 0.13$, $SD = 0.47$) than they did before the VR experience ($n = 25$; $M = 0.31$, $SD = 0.32$).

3.8. Physical distress

Finally, physical distress pretest scores ranged from 0 to 1 and posttest scores ranged from 0 to 1.25. To examine the impact of the VR experience on children's physical well-being, we used a mixed-effects linear regression model to compare children's physical distress scores pre- and post-experience. The time of the experience was a fixed factor and participant was a random factor. Higher scores indicate greater physical distress. There was no significant difference between children's physical distress levels before ($n = 25$; $M = 0.09$, $SD = 0.23$) and after ($n = 24$; $M = 0.12$, $SD = 0.28$) the VR experience ($b = 0.05$, $t = 0.79$, $p = 0.44$).

4. Discussion

Our study provides insights on children experiences and preferences of VR embodied agents based on their probability of occurring in their everyday lives. Children respond to embodied agents in VR in a variety of socially and emotionally motivated ways, demonstrating that the character type of embodied virtual agents impacts children's conscious (i.e., social ontological understanding, approach preferences, subjective emotions) and unconscious (i.e., interpersonal distances, spontaneous touching behaviors) responses differently. First, children accurately categorized the various types of embodied agents based on their level of plausibility (probable, improbable, and impossible), implying that children in this age range can consciously distinguish various levels of plausibility of embodied agents in VR's perceptually realistic environments. Furthermore, that VR experiences with simple environments and interactions with embodied agents have a low risk of children confusing reality from fantasy, and utilizing these designs in VR can be appropriate for using VR with young children as well as with children experiencing other mental vulnerabilities such as cognitive developmental delays, trauma, or mood disorders. In addition, the findings confirmed that VR in short doses does not cause significant emotional and physical distress, and any emotional discomfort felt during the VR experience can be short lived. In fact, children reported less emotional distress after completing the experience, likely due to initial uncertainty about what would happen in the VR experience.

Second, when children made conscious decisions about the embodied virtual agents, they consistently identified the giraffe as a positive social living being. Specifically, significantly more children approached the giraffe agent first, rated it highly as a social living being, and felt the most positive emotions towards the giraffe. For their unconscious responses, children stood the closest to the child embodied agent and engaged in a high level of spontaneous touch behaviors towards the Muppet. Third, children's unconscious social behaviors towards the embodied agents may have been triggered by their emotions and their understandings of social norms. In our study, children's emotional perceptions varied by the embodied agents' level of social realism: a moderately novel, improbable embodied agent (i.e., giraffe) elicited strong positive emotions, versus a moderately novel and impossible embodied agent like a Muppet evoked strong negative emotions versus a moderately novel probable child embodied agent elicited a broader range of emotions. Similarly, a study by Mousas et al. (2018) showed that adults felt negative emotions toward embodied agents low in social realism. The results of our study provide insights on how embodied virtual agents in VR impact children's social perceptions, emotions, and behaviors, with implications for research and design of future VR interventions for children.

4.1. Leveraging embodied agent design for future VR interventions

For the design and study of interventions' effectiveness, children's preferences for embodied agents needs to be defined and measured in a variety of ways to fit the purpose of the VR experience. Our findings show that children demonstrate character preference in a variety of ways, through comfort, excitement, and curiosity, which can be leveraged for different types of VR interventions. The results of our study showed that moderately novel, improbable animal embodied virtual agents like a giraffe provoke excitement, approach behaviors, and spontaneous touch behaviors. This result mirrors a study Lopez-Mobilia and Woolley (2016) in which children sought information about an improbable animal more often than about a possible or impossible animal. VR experiences aimed at promoting discovery learning would benefit from leveraging an improbable embodied agent like a giraffe in the beginning of a VR experience to elicit positive emotion and spark physical action. For example, children could physically interact physically with an improbably embodied agent to practice science hypothesis testing.

The Muppet embodied agent also elicited exploratory actions from children. However, children felt the most negative towards this specific type of character. Children may have used touch to confirm the reality of a perceptually real, and unpredictable fantastical creature. To reduce the risk for negative emotions, VR interventions may want to avoid introducing impossible anthropomorphized characters like Muppets as the first agent that children encounter. However, it may still be worthwhile to include a Muppet embodied agent. For example, an adventure game using a fantastical improbable could help children manage uncomfortable emotions or to practice acting in the face of adversity. Children expressed the widest range of emotions and stood the closest to the child character, suggesting that a child embodied agent could be used for intimate VR experiences, such as with mental health interventions. Having an embodied agent that evokes intense positive or negative emotions immediately, as in the case of giraffe and the Muppet, for example, may be inappropriate for children seeking help to overcome trauma or phobias.

The future design of embodied virtual agents in immersive media, like VR, based on children's media content, will need to consider how the perceptual realism that the technology creates intersects with type of character, and children's age. Children in our study likely experienced the uncanny valley (Mori et al., 2012), feeling emotional discomfort from viewing an artificial entity with humanlike qualities that has a mismatch of perceptual cues between realism and artificiality (Kätsyri et al., 2015; MacDorman et al., 2009; Tinwell & Sloan, 2014). For instance, when describing their negative emotional reaction to the Muppet and the child character, children often used the term "creepy," a term often associated with the uncanny valley. The child and Muppet models both skewed on the human side of the spectrum which according to the uncanny valley theory can contribute to triggering feelings of discomfort when there is a mismatch. The Muppet in our study was an anthropomorphized creature that moved neither like a human nor like an existing animal, and in general in our study elicited the most negative emotions and the farthest interpersonal distance. The design for our 3D Muppet was based on the puppet that it represented in a children's television show, and its internal bone structure and movement reflected those of a puppet and not a human form. Therefore, the Muppet character moved more like a puppet and less like a human, resulting in the artificial movement of a highly realistic model. The child character represented a highly probable character type, children often encounter other children in their daily lives and have extensive experience on observing human child behaviors and have a high standard on how they expected the agent to move.

Our results reinforce previous research on the importance of incorporating embodied agents high in realism, particularly behavioral realism, to socially influence users (Blascovich et al., 2002). For example, in a study by Tinwell and Sloan (2014), children experienced the uncanny valley phenomenon when the behaviors of human-like virtual characters deviated from human-like behaviors. Immersive media-technology, like VR, may intensify the uncanny curve (such as the behavior of an entity), and children may require an even higher standard of behavioral realism in VR compared to 2D media to overcome the uncanny valley effect. The model of social influence in immersive virtual environments contends that for an embodied agent to socially influence adult users it needs to be high in realism, particularly behavioral realism (Blascovich et al., 2002). Extending this work, our study suggests that both behavioral realism and social realism are important when designing embodied agents to socially influence children positively. To incorporate a highly fantastical creature, designers need to emphasize the behavioral realism as opposed to photorealism for an anthropomorphized character that is neither a human nor a based on an animal if they want to elicit positive emotion. Using a wild animal like a giraffe or a child embodied agent will likely create a positive initial experience for group that consists of children 5- to 9-years of age.

While our results show similar trends within each age group, there are some differences across the various ages, and the use of embodied agents in VR will need to be tailored for different age groups. While all ages approached the giraffe first most often and stood the closest to the child embodied agent, the 5- and 6-year-olds in our study seemed to seek out the novel aspects of the VR experience. Fifty-seven percentage of 5- to 6-year-olds approached the Muppet second compared to 33% of 7- to 8-year-olds and 33% of 9-year-olds. The younger age group even stood slightly closer to the Muppet than the giraffe embodied agent. In contrast, older children in our study had more of a negative reaction to the Muppet than the youngest group, standing the farthest away from the Muppet and often expressing negative feelings toward the anthropomorphized creature. VR experiences for older children would benefit from designing or utilizing embodied agents higher in social realism while interventions focused on younger children (i.e., 5-to 6-year-olds) could incorporate an anthropomorphized creature. Replicating research with characters in 2D media, our results confirm that older children prefer characters higher in social realism (Rosaen and Dibble, 2008).

Finally, our study demonstrated ways to measure children's preference of virtual embodied agents to fit the specific goals of VR interventions. Researchers and designer can use social ontological understanding and emotional perception to gauge children's initial perception of embodied characters as positive social living being (accounting for children's age). Approaching and children's spontaneous physical behaviors can be utilized to identify if VR embodied agents engage children's exploration. In addition, measuring children's positive or negative emotional perceptions will help distinguish if children's exploratory behaviors reflect curiosity or apprehension. Finally, interpersonal distance can be used to identify children's comfort and intimacy levels with an embodied agent.

4.2. Limitations and future directions

We examined the impact of character type on children's social conceptions of and behaviors and emotions toward embodied virtual agents in VR. The results should be considered given their limitations, which suggest areas for future study. First, children interacted with a small number of embodied virtual agents representing three different character types. Although this has provided initial insight on children's reactions, future studies would benefit from greater stimulus sampling. Second, the VR interaction represented an initial introduction to various embodied virtual agents; including other social interactions with the VR agents could influence children's conceptions and social behaviors. Studies with greater social interaction and repeated exposure could provide additional insight on how the type of embodied agent impacts children's persistence in a VR intervention or on how greater behavioral realism might reduce negative emotions. Another limitation of the study is that the 3D models utilized in the project did not have the same level of photorealism. For example, the child agent represented characters typically found in children's television shows and had a more cartoonish appearance than did the giraffe. While Blascovich et al. (2002), contend that behavioral realism overrides photorealism in socially influencing adults, the intersection of photorealism and behavioral realism may be important for children. While the study provided insights on the type of language children use to describe their emotional perceptions of embodied agents in VR, some children interpreted how they felt seeing the embodied agents as physically touching them. Future studies would benefit from using validated measures designed for children that reflect the types of emotions we observed. Finally, researchers and designers could gain additional insights by asking children to explain their social perceptions and behaviors.

4.3. Conclusion

The future of children's media will involve interactive, immersive technologies like VR. VR continues to expand in arcades, filmmaking, news stories, and dining experiences (Robbins, 2018; Wohlsen, 2015). Research continues to demonstrate great potential for VR interventions, and the development and design of this tool will impact how children process and conceptualize information in the future.

5. Selection and participation

Child participants were recruited to participate through posted and electronic flyers in schools, community centers, and libraries. Parents that contacted the research team about participating in the study were emailed a description of the study and completed an exclusion criteria questionnaire assessing children's physical suitability for the study. Parents that reported children with a seizure disorder, epilepsy, or an illness that would make them susceptible to dizziness or orientation were informed that their child would not be able to participate in the study for safety reasons.

For children participating in the study, a researcher read an assent script to children and children gave verbal assent to participate. Parents read and signed a parental permission form consenting for their children to participate in the study. During the assent and consent processes, researchers informed children and parents that their participation was voluntary and that they could stop at any time without penalty. In addition, parents had the option not to have their children video and/or audio recorded during the study as well as to stay in the research lab room for the duration of the study. The audio and video files were collected for data coding children's behaviors, and to confirm that notes were accurate. The recordings were only used by trained research personnel for research purposes. The University of Texas at Austin's Institutional Review Board reviewed and approved all aspects of the study.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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