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EFFECT OF INTERACTIONS BETWEEN A CHILD AND A ROBOT ON THE IMITATION AND PRAXIS PERFORMANCE OF TYPICALLY DEVLOPING CHILDREN AND A CHILD WITH AUTISM: A PRELIMINARY STUDY[1,2]

SUDHA M. SRINIVASAN,
Physical Therapy Program, Department of Kinesiology, Neag School of Education Center for Health, Intervention, and Prevention

Center for Ecological Study of Perception and Action, Department of Psychology University of Connecticut

KATHLEEN A. LYNCH,
Physical Therapy Program, Department of Kinesiology, Neag School of Education Center for Health, Intervention, and Prevention

Center for Ecological Study of Perception and Action, Department of Psychology University of Connecticut

DEBORAH J. BUBELA,
Physical Therapy Program, Department of Kinesiology, Neag School of Education Center for Health, Intervention, and Prevention

Center for Ecological Study of Perception and Action, Department of Psychology University of Connecticut

TIMOTHY D. GIFFORD,
Center for Ecological Study of Perception and Action, Department of Psychology Center for Health, Intervention, and Prevention University of Connecticut

ANJANA N. BHAT
Physical Therapy Program, Department of Kinesiology, Neag School of Education Center for Health, Intervention, and Prevention

Center for Ecological Study of Perception and Action, Department of Psychology University of Connecticut

Summary.

Interactions between a robot and a child (robot-child interactions) provide a unique context to engage children in whole body movements through a reciprocal imitation game. The effects of a novel, 8-session, robot-child interaction protocol on the imitation and praxis skills of 15 typically developing children and one child with autism between 4 and 7 years of age were examined. A

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[1]Address correspondence to Anjana Bhat, PT, Ph.D., Assistant Professor in Kinesiology, Neag School of Education, University of Connecticut, 358 Mansfield Road, U2101, Storrs, CT 06269 or (anjana.bhat@uconn.edu).

quasi-experimental observational comparison of pretest and posttest performance was conducted. A task-specific robot imitation test and a standardized praxis measure were coded for changes in imitation and praxis errors at pretest and posttest. All children showed improvements in task-specific imitation and generalized praxis. Interpretation is limited by the lack of a control group. These findings serve as a foundation for further investigation of robot-child interactions as a potential training tool for children with dyspraxia.

The use of robots as clinical assistants has created new opportunities for individuals with special needs by facilitating patient skills and promoting functional independence while reducing the burden on clinicians. Assistive robotics is a field that promotes the use of robots as aids for humans and it has expanded its scope to the area of neuro-rehabilitation (Feil-Seifer & Matarić, 2005). There are primarily two types of assistive robots: hands-on or socially non-interactive and hands-off or socially interactive. Hands-on, socially non-interactive robots such as MIT-Manus (Interactive Motion Technologies, Inc., Cambridge, MA), Autonomous Robotic Manipulation[3] [ARM; Defense Advanced Research Projects Agency (DARPA)], Mirror Image Movement Enabler [MIME]; incorporates a PUMA S60 robot, Staubli Unimation, Inc., Duncan, SC (Lum, BBurgar, Van der Loos, Shor, Majmundar, & Yap, 2006)], Lokomat (Hocoma AG, Volketswil, Switzerland), and Lokohelp (Woodway AG, Switzerland) provide assistance to patients through physical contact. For example, the MIT-Manus has been used to enhance reaching patterns of a hemiparetic upper limb and the Lokomat has been used to facilitate treadmill training of the hemiparetic lower limb (Prange, Jannink, Groothuis-Oudshoorn, Hermens, & IJzerman, 2006; Kwakkel, Kollen, & Krebs, 2008; Hidler, Nichols, Pelliccio, Brady, Campbell, Kahn, *et al.*, 2009). In contrast, hands-off, socially interactive robots such as Pearl the Nursebot (Montemerlo, Pineau, Roy, Thrun, & Verma, 2002), Care-O-Bot® (Fraunhofer, IPA), and Clara (Kang, Freedman, Matarić, Cunningham, & Lopez, 2005) have been used for social interactions with patients. These robots can provide nursing care in a stroke or cardiac convalescent care unit (Kang, *et al.*, 2005), or act as companions to reduce depression in the elderly (Fasola & Matarić, 2010). Taken together, robots appear to be a promising tool to support clinicians by augmenting conventional interventions.

In the field of pediatrics, assistive robots have been used in education and rehabilitation. Robots may facilitate mathematical, scientific, and problem-solving skills (Klassner & Anderson, 2003), as well as language skills in typically developing children (Kanda, Hirano, Eaton, & Ishiguro, 2004; Chang, Lee, Chao, Wang, & Chen, 2010). Few studies have used robots to facilitate motor skills in typically developing children; however, humanoid robots or robots with human features have been used to facilitate motor and social skills in children with Autism Spectrum Disorders (ASDs; Robins, Dautenhahn, te Boekhorst, & Billard, 2004, 2005; Billard, Robins, Nadel, & Dautenhahn, 2007; Duquette, Michaud, & Mercier, 2008; Feil-Seifer & Matarić, 2008; Pierno, Mari, Lusher, & Castiello, 2008; Diehl, Schmitt, Villano, & Crowell, 2011). Children with ASDs showed shorter movement durations and earlier peak velocities when they imitated a robot model compared to a human model,

[3]Incorporates a PUMA 560 robot, Staubli Unimation Inc., Duncan, South Carolina (Lum, Burgar, Van der Loos, Shor, Majmundar, & Yap, 2006).

suggesting that they may be better at emulating actions of a robot due to its social simplicity (Pierno, *et al.*, 2008). Children with ASDs also exhibit proactive social behaviors such as social attention, turn taking, imitation, and verbal communication during robot interactions, behaviors which are not observed during interactions with other people or toys (Robins, *et al.*, 2005; Duquette, *et al.*, 2008). For example, Robins, *et al.* (2005) reported that children with ASDs spontaneously looked, approached, touched, and imitated the simple arm and leg motions of a humanoid robot called Robota. However, a recent systematic review on the clinical use of robots in children with ASDs indicated that most of the studies were exploratory and reported anecdotal or observational data on a few subjects. Moreover, a majority of the studies did not use standardized tests for assessing the outcomes, did not report on the reliability of their measures, and lacked appropriate statistical analyses (Diehl, *et al.*, 2011). This study is a first step to addressing these limitations in the literature. The overall aim of this study was to evaluate the effects of a structured and well-developed imitation training protocol with a humanoid robot on the imitation and praxis skills of 15 typically developing children and one child with autism between 4 and 7 years of age. This was a feasibility study using a systematic pretest-posttest design as well as standardized tests in typically developing children and a child with autism. These data will serve as a foundation for a larger, randomized controlled trial in children with ASDs.

Praxis is defined as the ability to plan and execute simple and complex gestures and action sequences (Ayres, 1985; Njiokiktjien, Verschoor, Vranken, & Vroklage, 2000). Praxis is important for facilitating social interactions, learning complex motor activities, and promoting functional independence in children. Praxis is a relatively broad concept that encompasses the ability to perform “gestures or actions during imitation,” “gestures or actions on verbal command,” and “gestures or actions during tool use” (Mostofsky, Dubey, Jerath, Jansiewicz, Goldberg, & Denckla, 2006). Praxis skills progress from simple, one-step actions by four years of age, to complex, multi-step actions by seven years of age (Dewey, 1995). Children show fewer errors in the force, amplitude, and spatial patterns of complex actions over development (Dewey, 1993). “Praxis on imitation” is an important developmental skill with implications for motor development. For example, preschool and school-age children learn complex motor skills such as jumping, skipping, and sports by observing and imitating other adults and peers (Hayes, Hodges, Scott, Horn, & Williams, 2007; Murata & Tan, 2009). Similar to praxis, imitation abilities are first observed in simple, familiar, and meaningful actions and then expand to the imitation of complex, novel, and meaningless actions over development (Kokkinaki & Kugiumutzakis, 2000; Jones, 2007; Vanvuchelen, Roeyers, & De Weerdt, 2011). Improvements in praxis and imitation abilities with development are attributed to better visual perception of other’s actions, better proprioceptive awareness of one’s own body, better memory, better motor capabilities, and better matching of others’ actions onto one’s own body (Jones, 2007).

Children with ASDs present with serious imitation and praxis deficits from early in life (Rogers, Hepburn, Stackhouse, & Wehner, 2003; Mostofsky, *et al.*, 2006). Moreover, imitation and praxis impairments correlate with the severity of autism as well as language development in autism (Stone & Yoder, 2001; Dziuk, Gidley, Apostu, Mahone, Denckla, & Mostofsky, 2007). As mentioned earlier, there is some evidence on how robots could facilitate imitation skills in children with ASDs (Robins, *et al.*, 2005; Duquette, *et al.*, 2008). Children with ASDs paired with a robot were better at imitating body movements and familiar actions than those paired with a human mediator, suggesting that robot-child interactions seem to be a promising tool to teach children "praxis on imitation" (Duquette, *et al.*, 2008). In the present study, the imitation training protocol with the robot, Isobot facilitated "praxis on imitation" for a range of gross motor actions based on karate and dance. Hence, the first aim of this study was to evaluate training-related changes in imitation skills within a task-specific context involving Isobot, using a custom testing protocol. In addition, the second aim of the study was to assess generalization of imitation to novel contexts such as copying an adult, using a standardized praxis measure, the postural praxis subtest of the Sensory Integration and Praxis Test (SIPT).

Taken together, the present study evaluated the effects of eight sessions of imitation training with Isobot on the imitation and praxis skills of typically developing children and one child with autism between 4 and 7 years of age using a pretest-posttest design.

Hypothesis 1.

Typically developing children would make fewer errors in the posttest than the pretest in the task-specific, robot imitation test. Children with autism would have more errors than the typically developing children; however, they would show improvements in imitation performance following training.

Hypothesis 2.

Typically developing children would show improvements in generalized praxis using the SIPT, with fewer praxis errors in the posttest compared to the pretest. Children with autism would show poor praxis performance compared to the typically developing children; however, they would have some training-related improvements.

METHOD

Participants

Typically developing children (*N* = 15; 9 boys and 6 girls) between 4 and 7 years of age (*M* age = 5.8 yr., *SD* = 1.3) participated in this study. In addition, one 7-year-old, low-functioning male child diagnosed with autism was observed. The diagnosis of "autism" was confirmed based on the child's performance on the Autism Diagnostic Observation Schedule (ADOS), the gold-standard diagnostic tool for autism as well as clinical judgment (Lord, Rutter, DiLavore, & Risi, 1999). In terms of verbal communication, the child with autism labeled objects, produced echolalic vocalizations, and followed simple imitation commands such as "you do this/your turn". However, the child had difficulties with eye contact, as well as reciprocal verbal communication. Of the families recruited, one family was Asian, one was Hispanic, and the remaining were Euro-American. All children were recruited through the University of Connecticut community listserv and local daycare centers. Children were admitted into the study following written parental consent approved by the University of Connecticut Institutional Review Board.

The study was conducted over six weeks. The pretest and posttest sessions were conducted during the first and last week of participation. Children engaged in imitation games with the robot during the intermediate four weeks, with two training sessions per week for a total of eight training sessions (Table 1). Only three children missed one training session due to scheduling conflicts.

Measures

The testing protocol included a task-specific test of imitation called "the robot imitation test" that involved copying the robot's actions as well as a generalized test of praxis, the Postural Praxis subtest of the Sensory Integration and Praxis Test (Ayres, 1988), which involved copying a novel human tester's actions (Table 1). The last author, a trained pediatric physical therapist, administered all the tests. Video data were collected for both tests using an oblique view that included the robot, the child, and the tester (Fig. 1B).

Robot Imitation Test.—A task-specific test of imitation, the Robot Imitation Test (Fig. 1 & Appendix 1, p. 902) was undertaken to evaluate the task-specific changes in imitation of simple and complex robot actions following training. Both the pretest and posttest involved three conditions: the baseline condition, the robot-led condition, and the child-led condition. In the baseline condition, the robot greeted the child or danced to music to attract the child's attention. The child was free to observe or copy the robot. This condition did not elicit imitation behaviors in the majority of the children and therefore was not further analyzed. In the robot-led condition, each child copied five novel karate actions performed by the robot that were not included in the training sessions - the Guard, the Kick, the Punch, the Chop, and the Armshake (Fig. 1B & Appendix 1, p. 902). The actions varied in complexity based on the number of steps and limbs involved. The Chop involved a unilateral arm motion; three other actions, the Guard, Kick, and Punch, involved multilimb motions, and the Armshake was a multilimb and multistep action. Each action was performed on the right and left sides of the body except the Armshake, which could only be performed on the right side due to technical limitations of the robot. In the child-led condition, the child was asked to recall and demonstrate the five actions to the robot so that the robot would then copy the child (Fig. 1B).

The scoring procedure for the Robot Imitation Test comprised assigning a total score to each action based on the number of steps involved, with scores ranging from 3 to 8, due to varying action complexity (Appendix 1, p. 902). We calculated a total error score based on the components or steps missed by the child. These raw error scores were converted to percent error scores and then averaged across the five actions to provide the average percent imitation error per child, per session, for both the robot-led and child-led conditions. The second author coded all data for this test after establishing her own reliability and also inter-rater reliability with the first author using intra-class correlation coefficients (ICCs). Intra-rater reliability for percent error was above 90%, and inter-rater reliability was above 80% across the five actions using 20% of the entire dataset.

Generalized Test of Praxis.—The 16 novel non-functional actions of the postural praxis subtest of the Sensory Integration and Praxis Test (SIPT, Ayres, 1988, Appendix 2) were used to evaluate the generalized changes in "praxis on imitation" skills with a novel human tester for gross motor (11 of 16) and fine motor actions (5 of 16) following training. The SIPT is a standardized, normed, reliable, and valid measure used in children from 4 years to 8 years of age (Ayres, 1988). Permission was purchased and received from Western Psychological Services for research-based use of this assessment. Each child copied the 16 postures after tester demonstration. A coding scheme was developed based on the error classification proposed by Dewey (1993).

The scoring procedure for SIPT was based on the five error categories, defined as follows. *Modulation errors* occurred when the movement was insufficient or exaggerated based on the child's effort/force and range of motion compared to the tester's demonstration. *Directness errors* occurred when the child used an inefficient and indirect path of motion compared to the tester's demonstration. *Body-part errors* occurred when the child used incorrect body parts compared to the tester's demonstration. *Spatial errors* occurred when the child's placement and orientation of all body parts within each posture was incorrect compared to the tester's demonstration. *Total error* for each action was defined as a summed error across all categories with a maximum of four errors per test item. Each action was scored as correct (0) or incorrect (1) within each error category. A sum total error was calculated across all 16 actions. The first author coded all the videos after establishing intra-rater and inter-rater reliability with the third author using 20% of the entire dataset. Intra-rater and inter-rater reliability of 90% and above was achieved for all error categories using ICCs. While establishing inter-rater reliability, the consensus coding approach was used to agree upon scores.

Training Procedure

During the training sessions, children progressed from simple, two-step actions involving unilateral or dual-limb motions to complex, four-step patterns involving multilimb motions based on karate or dance action themes. The two-action themes were alternated across sessions. During each session, the child interacted with a 7-inch tall, commercially available, humanoid robot called Isobot (Tomy, Inc., Tokyo, Japan) and an adult trainer who controlled the robot via a control software and laptop system (Fig. 1A). In terms of spatial arrangement, the robot and the child stood facing each other and the trainer was seated on the side to facilitate the interaction (Fig. 1B). Each session involved three training conditions that were similar to the testing conditions: the baseline condition, the robot-led condition, and the child-led condition (Table 1).

In the baseline condition (2 min.), the robot performed a greeting or a bow for the karate theme or a hula dance for the dance theme sessions. Next, the trainer described the theme for the day and the actions to be done in the next two phases. In the robot-led condition (12–14 min.), the child was asked to "copy the robot." During each session, the children imitated five karate or dance actions performed by the robot. The children were allowed to practice the actions. If the child performed an obviously different movement, the child was asked to watch the respective moving body segment of the robot. Each action was assigned a verbal label, for example, a backhand or a roundhouse kick. In terms of feedback, an accurate visual reference was provided by the robot's actions. In the child-led condition (8–10 min.), the trainer asked the child to remember and demonstrate the actions he/she learned in the robot-led condition so that the robot would copy him or her. In terms of feedback, we first provided a listing of verbal labels for the various actions to trigger the child's memory. If the child did not remember the action, the tester offered verbal cues to describe an action, for example, described the limb(s) involved or direction of motion based on the verbal label. If the child failed to demonstrate the action, then the tester demonstrated the action partially from the seated position and asked the child to show it to the robot. When the child completed an action, he or she was given positive verbal reinforcement. At the end of each demonstration, the tester triggered the robot to perform the appropriate action. At the end of each session, children received small toys for completing the session and also had the opportunity to control the robot with the remote control upon request. At the end of all testing and training sessions, families received $50 as reimbursement for participation.

Statistical Analysis

The statistical analysis was done using SPSS Version 16.0 (SPSS, Inc., Chicago, IL). The changes in task-specific, percent imitation errors were assessed using a repeated measures analysis of variance (ANOVA) with test (pretest, posttest) and condition (robot-led, child-led) as the within-subjects factors. Since obvious differences in performance of children were observed during the robot-led and child-led conditions, it was decided to evaluate this by adding condition as a factor in the ANOVA. The Kolmogorov-Smirnov test for normality was not statistically significant, indicating a normal distribution. In addition, there were no violations of sphericity (Mauchly's test). Evaluation of extreme values using Q-Q plots revealed no outliers. We conducted *post hoc t* tests to further assess the differences if there was a significant interaction effect between the two factors (test and condition). Effect sizes are reported as omega squared. All data are reported as means and standard deviations. Due to the nominal nature of the SIPT scores, we assessed training-related changes in generalized praxis errors using the non-parametric, Wilcoxon's signed rank test. Statistical significance was set at $p < .05$ for all analyses.

RESULTS

The first hypothesis of task-specific improvements in imitation performance was examined by comparing the pretest and posttest performance in the Robot Imitation Test. The ANOVA indicated a main effect of test ($F_{1,14} = 11.8$, $p = .004$, $\omega^2 = 0.40$), a main effect of condition ($F_{1,14} = 19.5$, $p = .001$, $\omega^2 = 0.53$), and a test × condition interaction effect ($F_{1,14} = 5.5$, $p = .034$, $\omega^2 = 0.22$). Typically developing children had fewer errors in the posttest ($M = 30.6$, $SD = 14.1$) compared to the pretest ($M = 40.8$, $SD = 22.7$). In addition, typically developing children had fewer errors in the robot-led condition ($M = 27$, $SD = 9.0$) compared to the child-led condition ($M = 44.4$, $SD = 23.0$). *Post hoc* analysis of the statistically significant test x condition interaction indicated that typically developing children showed greater training-related improvements in the child-led condition compared to the robot-led condition ($p < .05$) as shown in Fig. 2. The low-functioning child with autism engaged in the training sessions and frequently copied the robot. In the robot-led condition, his average percent imitation errors were lower in the posttest compared to the pretest (pretest = 63.9 and posttest = 26.8) suggesting better imitation. In the child-led condition, his average percent imitation errors did not change with training (pretest and posttest = 90), suggesting difficulties in action recall.

The second hypothesis of a generalized improvement in praxis was tested by comparing pretest and posttest performance on the SIPT. The Wilcoxon's test indicated that typically developing children performed fewer body-part, spatial, and total errors in the posttest compared to the pretest, as shown in Fig. 3 (body-part: $Z = -2.55$, spatial: $Z = -2.37$, total: $Z = -2.01$, $p < .05$). The low-functioning child with ASD had 50 errors within the pretest which is significantly greater than the average performance of the typically developing children ($M = 30.2$, $SD = 9.8$). Following training, the total praxis errors of the child with autism decreased by 20 points (total errors, pretest = 50 and posttest = 30). Specifically, modulation errors decreased by 3 points, directness errors decreased by 5 points, body-part errors decreased by 6 points, and spatial errors decreased by 6 points. Taken together, both the typically developing children and the child with autism showed significant generalized improvements in "praxis on imitation" when copying actions of a novel adult tester.

DISCUSSION

While robots have been used to facilitate social interactions in children, their effect on promoting motor imitation skills is unclear. The purpose of this preliminary study was to evaluate the imitation and praxis effects of eight sessions of interactions between a robot and typically developing children as well as one child with autism, using a task-specific Robot Imitation Test and a generalized test of praxis. Typically developing children had fewer errors in the task-specific imitation of robot actions during the posttest compared to the pretest, and fewer errors during actions copied in the robot-led condition compared to the child-led condition. Typically developing children had fewer spatial, body-part, and total errors when copying human actions using the generalized test of praxis in the posttest compared to the pretest. Compared to the typically developing children, the low-functioning child with autism had more errors during imitation of robot actions as well as human actions during the pretest. However, by the posttest, the child with autism had improved his imitation of robot actions during the robot-led condition and human actions in the generalized test of praxis. The child with autism had no training-related improvements in his ability to recall actions during the child-led condition.

Typically developing children were expected to improve their imitation of the robot's actions within the task-specific, Robot Imitation Test as seen by fewer percent imitation errors. Children did improve their imitation of the robot's actions in the posttest compared to the pretest. This is one of the only studies to systematically examine improvements in motor imitation performance in typically developing children following interactions with a humanoid robot. The only other study used a creature-like robot named Keepon, which was reported to increase spontaneous social interactions, self-initiated imitation, and social bonding (Kozima, Nakagawa, & Yasuda, 2007). A few other studies report anecdotal evidence on how robots may facilitate social skills, such as imitation and joint attention, in children with autism (Miyamoto, Lee, Fujii, & Okada, 2005; Robins, *et al.*, 2005; Kozima, *et al.*, 2007; Duquette, *et al.*, 2008). A longitudinal observation of four children with ASDs found that the children steadily increased their approach to and imitation of the humanoid robot, Robota (Robins, *et al.*, 2005). In a different study, low-functioning children with autism paired with a robot showed more emotional expressions to the robot whereas they showed greater imitation and verbal communication when paired with a human (Duquette, *et al.*, 2008). This was attributed to the limited motor capabilities of the humanoid robot and the unidirectional nature of the robot imitation context (Duquette, *et al.*, 2008). In contrast, the current study used a highly agile, humanoid robot with the ability to perform complex, multilimb, multistep patterns during a reciprocal imitation game. The findings of improved imitation accuracy following robot-child interactions may be attributed to the greater capabilities of the Isobot.

In the present study, typically developing children showed greater errors in the child-led condition compared to the robot-led condition. The robot-led condition facilitated "action practice," i.e., the child observed and copied the robot's actions and received an immediate visual model before performing each action. In contrast, the child-led condition facilitated "action recall," i.e., the child had to remember the actions learned during the session based on verbal labels and verbal cues. Poor performance during recall of an action, compared to its imitation, may be attributed to retroactive interference from other actions practiced during the robot-led condition. Retroactive interference is a well-studied concept in the motor control literature and refers to the time spent performing other actions after practicing an original action, which will interfere with the recall of the original action (Magill, 2007). Interestingly, typically developing children showed greater improvements in the child-led than the robot-led condition of the test. As mentioned previously, we had provided verbal labels for all the robot actions that the children were required to imitate. The strategy of triggering the memory of an action using verbal labels may have helped overcome the interference during action recall (Magill, 2007). For example, children learning sports often benefit from verbal cues about the entire pattern or its components during observational learning (Janelle, Champenoy, Coombes, & Mousseau, 2003). Training-related improvements in the child-led condition are likely due to the improved ability of children to recall actions based on the verbal labels offered by the trainer.

The typically developing children were expected to carry over their imitation skills developed during robot imitation training to copying human actions during the generalized test of praxis. The children had fewer body-part errors and spatial errors during the posttest compared to the pretest. The majority of the actions in the praxis test were gross motor in nature (11 out of 16). The robot-child interactions may have facilitated gross motor imitation due to the trained karate and dance actions. Imitating the robot's actions provided opportunities to perceive actions of others and practice bilateral and multilimb coordination within a context of an imitation game. Young children 4 to 7 years of age lack multilimb coordination as well as social coordination i.e., the ability to follow and match their actions with others (Wolff, Kotwica, & Obregon, 1998; Getchell, 2006; Kleinspehn-Ammerlahn, Riediger, Schmiedek, van Oertzen, & Lindberger, 2011). Complex movement patterns such as asymmetrical, multilimb motions become stable and consistent later in life compared to symmetrical, dual-limb patterns (Wolff, *et al.*, 1998; Getchell, 2006). Similarly, pairs of young, typically developing children showed less synchronous drumming with their partner compared to pairs of older, typically developing children (Kleinspehn-Ammerlahn, *et al.*, 2011). In our study, children may have enhanced their bilateral coordination and social monitoring abilities following the imitation game with Isobot. This may have contributed to the generalization of imitation skills to a novel context such as the SIPT, wherein the children copied novel actions done by a human tester.

The child with autism was expected to have poor imitation and praxis skills compared to the typically developing children and to improve his imitation and praxis performance following the short-term, imitation training. The child with autism clearly improved his imitation performance when copying the robot's actions, as well as when copying human actions. However, he did not show any improvements in the child-led condition of the Robot Imitation Test. Children with autism present with social impairments such as reduced eye contact, reduced social monitoring of others' gestures and actions, as well as poor turn-taking during social interactions (Mundy & Sigman, 2006; Gernsbacher, Stevenson, Khandakar, & Hill-Goldsmith, 2008). They also present with imitation difficulties from as early as 20 months of age (Charman, Swettenham, Baron-Cohen, Cox, Baird, & Drew, 1997). Praxis impairments are strongly correlated with the core social communication impairments of children with ASDs (Dzuik, *et al.*, 2007). Children with autism also present with motor impairments during a variety of multilimb and bilateral coordination skills involving upper and lower extremity use (Ghaziuddin & Butler, 1998; Green, Baird, Barnett, Henderson, Huber, & Henderson, 2002; Jansiewicz, Goldberg, Newschaffer, Denckla, Landa, & Mostofsky, 2006; Bhat, Landa, & Galloway, 2011). Hence, it was not surprising to find substantial imitation and praxis errors across a range of complex multilimb and bilateral actions in the child with autism. It was encouraging to see that a short-term training protocol of robot imitation led to improvements in imitation of robot actions. Generalization skills are often lacking in children with autism (Landa, 2007); it was promising to see that the child showed generalized improvements in copying human actions following training. Training may have directly affected the child's social monitoring, turn taking, imitation, and/or praxis abilities. Other factors that could have improved include attentional focus, as well as increased compliance, both of which are atypical in children with autism (Allen & Courchesne, 2001; Goldstein, Johnson, & Minshew, 2001; Mazefsky, Pelphrey, & Dahl, 2012). However, this child with autism did not improve his action recall abilities during the child-led condition. Declarative learning and memory are used during action recall (Magill, 2007) and the autistic child's intellectual delay may have impaired his ability to understand what was asked of him or to recall the actions practiced. Taken together, the findings from the typically developing children as well as one child with autism indicate the potential value of robot-child interactions to facilitate imitation and praxis in school-age children who present with praxis impairments.

Interpretations of this preliminary study are limited due to a lack of control group, lack of a retention test, and the small number of training sessions. In addition, the limited movement repertoire of the Isobot restricted the types of imitation experiences for the children. We were able to show that robots can be used to engage children in imitation-based activities, and training-related changes can be identified using coding schemes. Robot-child interactions could be a motivating and valuable context for children with social as well as imitation/praxis impairments. Currently, we are further evaluating this technology by conducting a randomized controlled trial involving an extended and intense training protocol children with ASDs.

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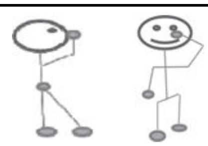
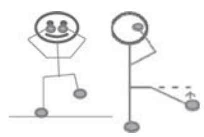
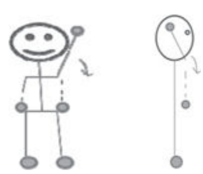
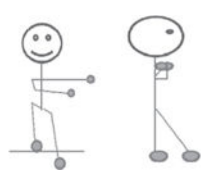
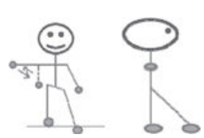
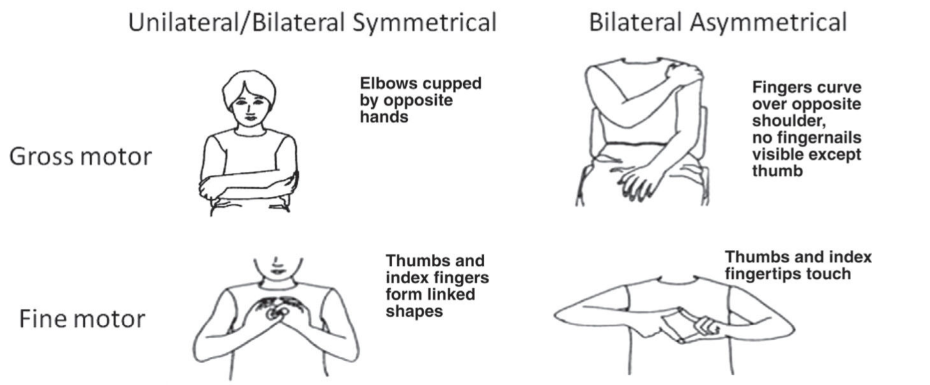
Appendix

APPENDIX 1

Five Robot Actions of the Robot Imitation Test Along With a Description of Component Motions

Action & Total Score	Figure	Description	Coding
Left & right guard (6)		In the left guard, the robot covers its face with the left hand and steps back with the right leg. In the right guard, the robot covers its face with the right hand and steps back with the left leg.	Arm score: 3: Mirrored, exact arm movement 2: Unmirrored, exact arm movement 1: Attempted an arm movement 0: No movement Leg score: 3: Mirrored, exact leg movement 2: Unmirrored, exact leg movement 1: Attempted an leg movement 0: No movement
Left & right kick (6)		In the left kick, the robot moves both hands in front of its face and kicks forward with its left leg. In the right kick, the robot moves both hands in front of its face and kicks forward with its right leg.	Arm score: 3: Mirrored, exact arm movement 2: Unmirrored, exact arm movement 1: Attempted a arm movement 0: No movement Leg score: 3: Mirrored, exact leg movement 2: Unmirrored, exact leg movement 1: Attempted a leg movement 0: No movement
Left & right chop (3)		In the left chop, the robot lifts its left arm up with the elbow slightly bent, then straightens the elbow, and brings the arm down. In the right chop, the above sequence is carried out with the right arm.	Arm score: 3: Extended elbow along with exact arm movement 2: Mirrored, exact arm movement without elbow extension 1: Unmirrored, exact arm movement 0: No movement
Left & right punch (7)		In the left punch, the robot extends both arms to the left, asymmetrically, and steps forward with the left leg. In the right punch, the robot extends both arms to the right, asymmetrically, and steps forward with the right leg.	Arm score: 4: Mirrored, exact asymmetrical arm movement 3: Unmirrored, exact asymmetrical arm movement 2: Symmetrical arm movement 1: Only one arm used to punch 0: No arm movement Leg score: 3: Mirrored, exact leg movement 2: Unmirrored, exact leg movement 1: Attempted a leg movement 0: No movement
Armshake (7)		In the armshake, the robot steps forward with its right leg. It moves its left hand in front of its chest and then it bends and straightens its left elbow 3 times, as if shaking its arms.	Arm score: 4: Mirrored and synchronized arm movement 3: Mirrored, unsynchronized arm movement 2: Unmirrored, synchronized arm movement 1: Unmirrored, unsynchronized arm

Action & Total Score	Figure	Description	Coding
			movement 0: No arm movement Leg score: 3: Mirrored, exact leg movement 2: Unmirrored, exact leg movement 1: Attempted some leg movement 0: No leg movement



APPENDIX 2.

EXEMPLAR GROSS MOTOR AND FINE MOTOR, SYMMETRICAL AND ASYMMETRICAL ACTIONS OF THE GENERALIZED TEST OF PRAXIS (SIPT)

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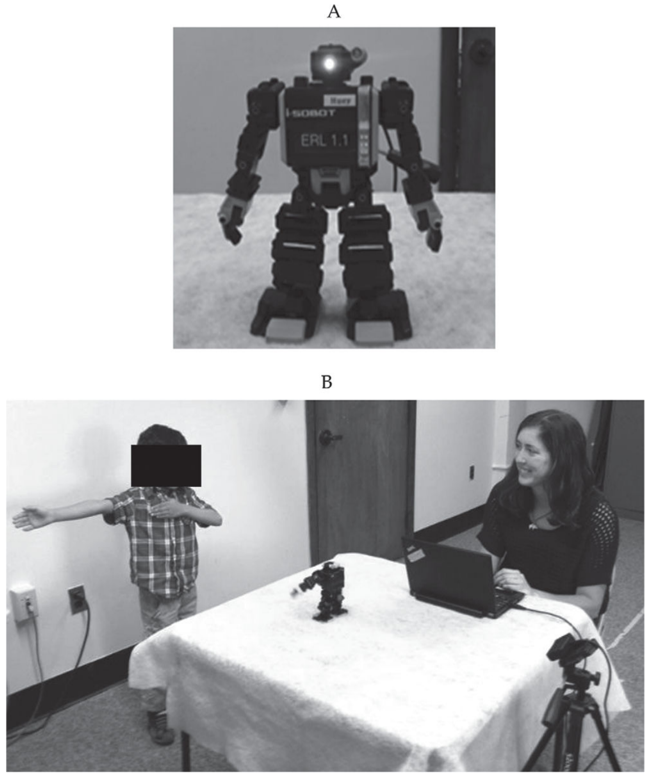

FIG. 1.

A. The 7-inch humanoid robot Isobot. B. The experimental setup including the child, the robot, and an adult using the laptop control system. The child is imitating the robot's action.

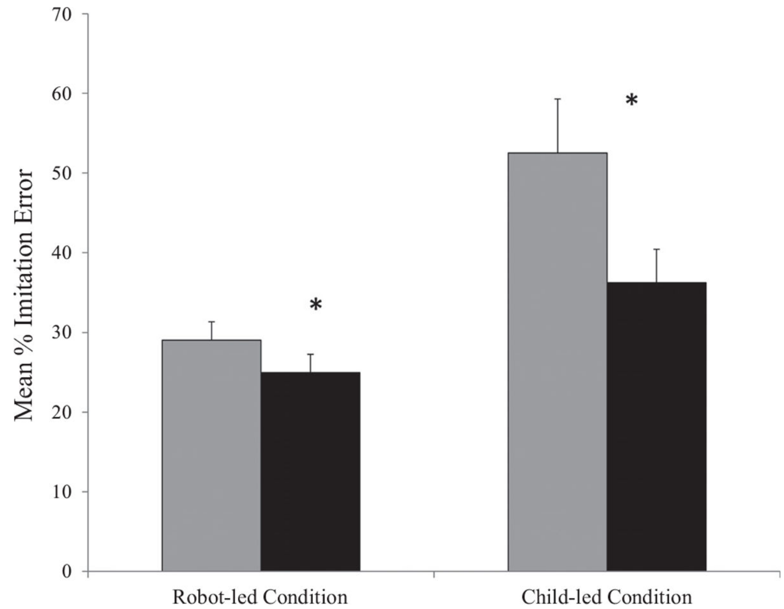

FIG. 2.

The average percent imitation error in the robot-led and child-led conditions of the task-specific Robot Imitation Test during the pretest (gray bars) and posttest (black bars) in typically developing children. Imitation errors for each child were averaged across the five actions: Chop, Kick, Guard, Punch, and Armshake. *Difference statistically significant at $p < .05$.

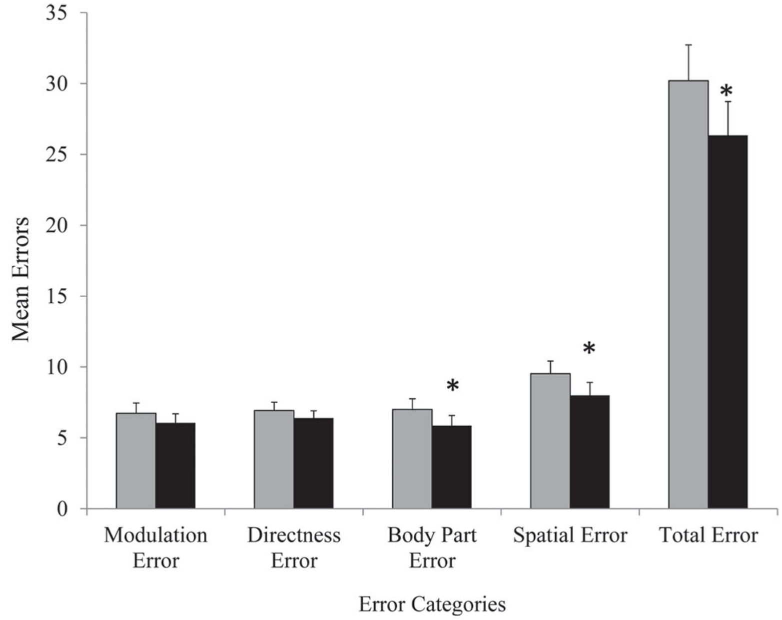

FIG. 3.

Praxis errors at pretest (gray bars) and posttest (black bars) in the five different error categories: modulation errors, directness errors, body-part errors, spatial errors, and total errors for all actions of the generalized test of praxis (SIPT) in typically developing children. *Statistically significant difference at $p < .05$.

TABLE 1

Timeline For the Testing and Training Protocol

Pretest Week 1 (Visit 1)	**Training Weeks 2–5 (Visits 2–9)**		**Posttest Week 6 (Visit 10)**
1. Robot imitation test: duration: ~30 min.	Duration: 4 weeks @ 2 sessions per week, ~30 minutes per session		1. Robot imitation test: duration: ~ 30 min.
2. Generalized praxis test: duration: ~15 min.	Actions: 5 actions per session. Karate and dance theme actions. Simple, one-step actions (13%) with unilateral or symmetrical (27%), dual-limb (25%) motions and complex, multi-step actions (87%) with asymmetrical (73%), multilimb (75%) motions.		2. Generalized praxis test: duration: ~15 min.
	Conditions		
	Baseline (2 min.)	Robot greets child or dances to music	
	Robot-led (12–14 min.)	Child copies robot's actions	
	child-led (8–10 min.)	Child recalls actions and per-forms them back to the robot	