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The effects of embodied rhythm and robotic interventions on the spontaneous and responsive social attention patterns of children with Autism Spectrum Disorder (ASD): A pilot randomized controlled trial

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Abstract

We compared the effects of 8-weeks of rhythm and robotic interventions with those of a comparison, standard-of-care intervention, on the spontaneous and responsive social attention patterns of school-age children with Autism Spectrum Disorder. Attention patterns were examined within a standardized pretest/posttest measure of joint attention (JA) and a training-specific social attention measure during early, mid, and late training sessions. The rhythm and comparison groups demonstrated improvements in JA. Social attention was greater in the rhythm followed by the robot and lastly the comparison group. The robot and comparison groups spent maximum time fixating on the robot and objects, respectively. Across sessions, the robot group decreased attention to the robot and increased attention to elsewhere. Overall, rhythmic movement contexts afford sustained social monitoring in children with autism.

Keywords

rhythm; robots; attention; autism; embodied interventions

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1. Introduction

Autism Spectrum Disorder (ASD) is characterized by persistent deficits in social communication skills and the presence of restricted and repetitive patterns of interests (American Psychiatric Association, 2013). Amongst the social impairments in ASD, atypical social attention is one of the primary impairments (Dawson, Bernier, & Ring, 2012). Children with autism show reduced eye contact (Rogers & DiLalla, 1990; Dawson et al., 2004), reduced interest in social stimuli (Maestro et al., 2002; Ozonoff et al., 2010), lack of response to name (Baranek, 1999; Osterling, Dawson, & Munson, 2002), reduced initiation of interactions (Bryson et al., 2007), poor sharing of interests with caregivers (Charman et al., 1998; Yoder, Stone, Walden, & Malesa, 2009), and impaired imitation skills (Bryson et al., 2007; Young et al., 2011). Deficits in social orienting and attention could have cascading effects on the social, cognitive, and language skills of children. For example, during caregiver-child interactions, children learn social skills such as turn taking, imitation, and sharing of interests (Dawson et al., 2004; Mundy & Hogan, 1994). Moreover, children learn functional skills such as brushing, using a spoon, riding a bicycle, etc. by observing and imitating the actions of others (Dewey, 1993; Mostofsky et al., 2006). Lastly, during triadic contexts involving the child, the caregiver, and interesting objects, children learn object labels and object affordances (Baldwin, 1995; Tomasello & Farrar, 1986). Overall, social attention abilities influence multisystem development in childhood. Given the pervasive attentional impairments in ASD, considerable research has focused on developing interventions to remediate attentional impairments. The focus of the present study was to compare the effects of two novel intervention approaches – rhythm and robotic – on the attentional patterns of school-age children with ASD.

Attentional impairments in children with ASD include a preference for non-social over social cues (Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998), difficulty disengaging attention (Landry & Bryson, 2004), and poor sharing of attention with others (Mundy & Hogan, 1994). Children with ASD have difficulties in spontaneously orienting to social stimuli (Dawson et al., 1998; Swettenham et al., 1998). For example, compared to typically developing children and children with Down syndrome, children with ASD had greater difficulty orienting to social stimuli including name calling and hand clapping compared to non-social stimuli such as a rattle or a jack-in-the-box (Dawson et al., 1998). Social orienting impairments are compounded by children's preference for non-social stimuli such as objects (Hutman, Chela, Gillespie-Lynch, & Sigman, 2012; Klin, Jones, Schultz, Volkmar, & Cohen, 2002). Twenty-month-old toddlers with ASD who watched a video of an adult-child play interaction demonstrated lower social attention levels and instead focused on background toys compared to control infants (Shic, Bradshaw, Klin, Scassellati, & Chawarska, 2011). Moreover, children have problems disengaging attention in the presence of competing stimuli (Courchesne et al., 1994). During a visual orienting task that required simultaneous attention to two stimuli, children with ASD had difficulty disengaging attention and instead fixated on only one of the stimuli for 20% of the trials (Landry & Bryson, 2004). Impaired social orienting, a preference for non-social stimuli, and difficulties in attention disengagement, have implications for the development of joint attention (JA), which is the ability to coordinate attention between social partners and interesting objects/

events using eye gaze and gestures (Bakeman & Adamson, 1984; Mundy, 2003). To engage in shared attention, children need to orient to their social partners and shift attention rapidly between social and non-social stimuli in their surroundings (Courchesne, Chisum, & Townsend, 1995; Dawson et al., 1998). Children with ASD have difficulties in both responding to attentional bids of others, referred to as responding to joint attention (RJA), as well as initiating bids to direct others' attention towards salient objects, called initiating joint attention (IJA) (Charman, 1998; Mundy, Sigman, & Kasari, 1990). It has been argued that social attention during periods of shared attention could be an indicator of treatment efficacy in children with autism (Dawson et al., 2012). Interventions that facilitate social attention can increase children's opportunities to learn from their environment and change their developmental trajectory.

Current autism interventions that facilitate social skills are broadly classified into contemporary behavioral interventions, developmental approaches, and social skill interventions (Lovaas, 1987; Rao, Beidel, & Murray, 2008; Vismara & Rogers, 2010). Contemporary behavioral and developmental interventions use a comprehensive framework to address impairments in multiple domains (Vismara & Rogers, 2010), whereas social skill interventions focus on facilitating specific social skills (Rao et al., 2008; Reichow & Volkmar, 2010). Contemporary behavioral interventions such as Pivotal Response Therapy (PRT) (Schreibman & Koegel, 1996; Steiner, Gengoux, Klin, & Chawarska, 2013), incidental teaching (McGee, Morrier, & Daly, 1999), and milieu teaching (Yoder & Stone, 2006) use principles of Applied Behavioral Analysis (ABA) including reinforcement, repetition, and incremental prompting (Granpeesheh, Tarbox, & Dixon, 2009; Lovaas, 1987) to facilitate social communication skills and reduce negative behaviors. For example, peer-mediated PRT led to an increase in peer interactions, JA, play, social initiations, and language skills in children with ASD (Pierce & Schreibman, 1995). In contrast to behavioral interventions, developmental approaches such as the Early Start Denver Model (Rogers & Dawson, 2010), Developmental Individual-Difference, Relationship-Based model (Greenspan & Wieder, 1997), play-based JA intervention (Kasari, Paparella, Freeman, & Jahromi, 2008), and those targeting socially synchronous behaviors (Landa, Holman, O'Neill, & Stuart, 2011) promote age-appropriate skills such as imitation, JA, pretend play, and communication. For example, a 6-month intervention promoting interpersonal synchrony led to greater improvements in imitation, JA, and shared affective skills compared to a control group (Landa et al., 2011). Lastly, social interventions such as social skill groups (Kroeger, Schultz, & Newsom, 2007), social stories (Karkhaneh et al., 2010), Socio-Dramatic Affective-Relational Intervention (Lerner, Mikami, & Levine, 2011), and social skills training (Rao et al., 2008) focus on interpersonal skills such as turn taking, social initiations, and response to questions. For example, a 5-week group social skill intervention where children were taught skills such as turn taking and cooperative play led to greater improvements in social interactions of children compared to a free play intervention (Kroeger, Schultz, & Newsom, 2007). Typically, behavioral interventions for autism are delivered for 30–40 hours per week (Landa, 2007). Although intensive in nature, these therapies do not necessarily capitalize on the strengths and predilections of children with autism. Therefore, there is a need to diversify contemporary autism interventions by

exploring therapies that tap into children's inherent strengths and are therefore enjoyable and motivating for them.

There is growing research on novel and motivating interventions, namely rhythm and robotic therapies, for children with ASD. Motivating and child-preferred contexts that facilitate interactions between children and their social partners are most effective in promoting social engagement (Kasari, Paparella, Freeman, & Jahromi, 2008; Landa et al., 2011). Not surprisingly, music-based rhythm interventions form up to 12% of all autism interventions and approximately 45% of all alternative treatments in school settings (Hess, Morrier, Heflin, & Ivey, 2008). Children with autism often have unimpaired musical skills or even relative strengths in musical domains (Heaton, 2003); therefore, music therapies can harness these strengths, and provide an enjoyable and non-intimidating medium to promote social communication skills (Gerettsegger et al., 2014, Srinivasan & Bhat, 2013). For example, a comparison of improvisational music therapy and toy play using a single subject comparison design suggested that music therapy led to greater initiation of interactions and more compliant responses compared to toy play (Kim, Wigram, & Gold, 2009). Robotic therapy is another intervention tool that capitalizes on children's interest in technology (Diehl, Schmitt, Villano, & Crowell, 2012; Robins, Dautenhahn, & Dubowski, 2006; Scassellati, 2007). In contrast to the complex and unpredictable nature of human interactions, children with ASD find the simple and predictable nature of robotic interactions reassuring and motivating (Scassellati, 2007). Therefore, it has been proposed that during robot-child interactions, children with ASD can practice social skills such as imitation and subsequently transfer learned skills to interactions with people (Dautenhahn, 2003; Duquette, Michaud, & Mercier, 2008; Robins, Dautenhahn, Te Boekhorst, & Billard, 2004; Scassellati, 2007; Tapus, Mataric, & Scasselati, 2007). Moreover, within robot-child-object contexts, the robot can promote JA by directing children's attention to salient objects in the environment (DeSilva, Tadano, Saito, Lambacher, & Higashi, 2009; Warren et al., 2013). Lastly, triadic interactions involving the robot and two children or the robot, an adult, and a child have been used to promote skills such as eye contact, turn taking, and conversation (Costa, Santos, Soares, Ferreira, & Moreira, 2010; Feil-Seifer & Mataric, 2009; Kozima, Nakagawa, & Yasuda, 2007; Robins, Dautenhahn, & Dickerson, 2009; Robins, Dautenhahn, Te Boekhorst, & Billard, 2005; Srinivasan & Bhat, 2013). To summarize, rhythm and robotic contexts are promising treatment tools. However, the current evidence in both fields is anecdotal at best. To date, studies have involved small sample sizes and have not included comparison groups or standardized assessments. There is an urgent need for randomized controlled trials (RCTs) using well-matched comparison groups and standardized assessments to examine the efficacy of rhythm and robotic therapies for children with autism.

The present study compared the effects of rhythm and robotic interventions to those of a standard-of-care, comparison intervention on the social communication, behavioral, and motor skills of children with ASD. The comparison group received standard-of-care tabletop activities that are typically used in school settings to promote social communication, academic, and fine motor skills in children with autism. To the best of our knowledge, ours is the first study to assess the effects of novel, movement-based interventions for children with ASD. We were therefore not sure of the outcome of the study, although, at the very

least, we aimed to demonstrate non-inferiority of the rhythm and robotic interventions compared to the standard-of-care intervention. We will report the effects of the rhythm, robotic, and comparison interventions on the social attention and verbal communication skills of children with ASD in the form of a two-part manuscript series. The current paper is the first of this series and is focused on reporting intervention effects on spontaneous and responsive social attention skills of children, assessed within a standardized test of JA administered before and after the intervention, and within a training-specific attention measure presented during early, middle, and late stages of the intervention. The effects of the interventions on the spontaneous and responsive verbal communication skills of children are reported in the second paper in this series. For this manuscript, our 3 main research aims were: (1) To identify *group differences* in attention patterns across sessions; we hypothesized that the rhythm and robotic groups would elicit similar or greater levels of social attention compared to the comparison group; (2) To assess *intervention-related changes* in attention patterns across sessions within each group; we expected all three groups to improve social attention skills over time; and (3) To examine *activity-related differences* in attention across training activities within each group. In each group, children engaged in different training activities with or without the use of objects. We expected that activities that promoted motor skills in the absence of props would elicit greater social attention, whereas activities that involved use of props would lead to greater object-directed attention.

2. Method

2. 1. Participants

Thirty-six children with ASD (32 M and 4 F, 20 Caucasian, 6 African American, 4 Asian, 3 Hispanic, and 3 of mixed ethnicity) between 5 and 12 years of age ($M (SD) = 7.63(2.24)$) participated (see Figure 1 for details of enrollment). Children were recruited through fliers posted online and onsite in local schools, services, and self/parent advocacy groups. Children were enrolled following written parental consent. The Institutional Review Board at xxxx approved the study. The Social Communication Questionnaire (SCQ) (Rutter, Bailey, & Lord, 2003) was used as a screener prior to enrollment. Eligibility was confirmed using the gold standard diagnostic assessment, the Autism Diagnostic Observation Schedule –2 (Lord et al., 2012) and clinician judgment during a clinical psychology evaluation. Four children with significant behavioral impairments or severe receptive language impairments that limited their comprehension of even simple instructions were excluded. Socioeconomic status was assessed using the Hollingshead scale (Hollingshead, 1975). Following enrollment, children were matched on age bands (4–5, 6–7, 8–9, and 10–12 years), level of functioning, and amount of prior services, and then randomly assigned to one of three groups – rhythm, robot, or comparison (see Table 1 for demographic characteristics and Figure 1 for details of treatment allocation) with twelve subjects in each group. We assessed children's level of adaptive functioning using the Vineland Adaptive Behavior Scales (VABS) (Sparrow, Cicchetti, & Balla, 2005). Overall, 82% of our sample had delays ($> 1SD$ below the mean) on the Adaptive Behavior Composite; specifically, 70% children had communication delays, 80% had delays in daily living skills, and 82% had delays on the socialization domain.

2. 2. Study Procedure

This pilot randomized controlled trial (RCT) was conducted over 10 weeks with the pretest and posttest sessions conducted in the first and the last weeks, respectively, and the training provided for four days per week (two expert and two parent sessions) during the intermediate eight weeks. Each session lasted for approximately 45 minutes. During the expert session, a trainer and an adult model interacted with the child within a triadic context (see Figures 2A, 2B, & 2C). The adult model was the child's confederate and practiced all activities with the child. In the robot group, the robot was the primary "trainer" and an adult human trainer controlled the robot. The triadic context between the child, trainer, and model provided multiple opportunities for promoting social skills such as eye contact, turn taking, and greeting/farewell as well as communication skills such as commenting, requesting, singing, and use of gestures. Moreover, the rhythm and robot groups promoted gross and fine motor skills including balance, coordination, manual dexterity, imitation, and interpersonal synchrony during joint action games (see Figures 2A & 2B). In contrast, the comparison group promoted fine motor skills including symmetrical and asymmetrical grips and pinches, coloring, drawing, gluing, and cutting (see Figure 2C). All sessions were videotaped for behavioral coding of social attention of children. In addition to expert training sessions, we encouraged parents to provide two additional home sessions per week for about 45 minutes each. Parents were asked to conduct similar activities using instruction manuals, necessary supplies, and in-person training each week. Parents and expert trainers maintained a training diary to document details of training including number of sessions completed, duration of each session, list of activities completed, child's affect, and details of activities children found difficult in the session. Out of the 32 total sessions, all families completed a majority of the sessions (% of sessions completed – Rhythm: $M (SD) = 73.18 (19.74)$, Robot: $M (SD) = 76.82(16.72)$, Comparison: $M (SD) = 80.21(15.27)$, p values >0.05).

2. 3. Testing protocol

We assessed changes in social attention on a standardized test of JA during pre/posttests and a training-specific measure of attention across the early, mid, and late training sessions.

2. 3. 1. Standardized test of JA (referred to as JTAT hereafter)—We used the Joint Attention Test (JTAT) (Bean & Eigsti, 2012), modified with permission of Dr. Eigsti, to assess changes in responsive JA from the pretest to the posttest session. To the best of our knowledge, the JTAT is the only valid and reliable measure of JA in school-age children. The original JTAT was composed of 6 naturalistic bids (4 verbal and 2 non-verbal/gestural prompts). To balance out the number of verbal and gestural items, we modified the JTAT to add 3 more gestural items of waving bye, giving a low five, and giving a high five during naturalistic interactions. Therefore, the modified JTAT uses 4 verbal and 5 gestural examiner-initiated bids to assess children's attentional and verbal responses (see Table 2). During the administration, a novel examiner seated in front of the child across a table evoked the social bids to specific objects arranged at distinct locations. The JTAT bids were interspersed between other standardized measures administered during the testing visit to make the interactions naturalistic. If the child did not respond to the examiner's initial bid, additional prompting was provided. Children's responses were scored on a scale from 0 to 5

with higher scores indicating better performance. A point was awarded for each of the following responses – (1) Correct action based on bid type as shown in Table 2 (for example, for a “high five” bid, the correct action was to give the examiner a “high five”), (2) eye contact, (3) a look to the face/appropriate direction, (4) a smile, and (5) a verbal response. Two coders coded the entire dataset after establishing intra-rater reliability above 90% and inter-rater reliability of greater than 85% using 20% of the dataset. The sum of the response scores across all items was calculated as a total response score (maximum score = 38). Three children in the study (one child from each group) did not have JTAT data.

2. 3. 2. Training-specific measure of Social Attention—We also examined training-specific changes in attention patterns within the intervention context. An expert coder coded an early (session 1), a mid (session 8), and a late (session 16) training session for each child using OpenShapa (Github Inc.) video coding software. Intra-rater reliability above 90% and inter-rater reliability above 85% was established based on 20% of the dataset. We coded the duration of time across an entire session for attention to: 1) social partners (the trainer, adult model, and caregiver), 2) the robot (for the robot group only), 3) objects (picture board, props, musical instruments, and art-craft supplies), or 4) elsewhere (attention to any other space or object in the room, including furniture or walls). Each bout of social attention was classified as spontaneous (child initiated looking behavior without any prompting) or responsive (child looked at social partner in response to a comment/question/prompt by partner).

2. 4. Training Protocol

Children were randomly assigned to one of three groups – rhythm, robotic, or comparison. All groups incorporated training principles from ABA (Lovaas, 1987), such as graded prompting, repetition, and reinforcement, from Treatment and Education of Autistic and related Communication-Handicapped Children (TEACCH) (Mesibov, Shea, & Schopler, 2004), such as providing a structured environment and consistent trainers, and from the Picture Exchange Communication System (PECS) (Bondy & Frost, 2003), by using picture boards to facilitate transitions between training activities. Children had multiple opportunities for free play and spontaneous exploration of the supplies. All trainers were pediatric physical therapists or physical therapy/kinesiology graduate students. All trainers and models received significant training from the last author and ABA experts.

To assess treatment fidelity, a naïve coder randomly chose and coded one early (sessions 1–5), mid (sessions 6–11), and late (session 12–16) session for each child using a comprehensive checklist developed to assess trainer and model behaviors (see Appendix 1 for details). This coder evaluated (1) accurate completion of critical components of training activities (maximum score = 74 points), (2) trainer and model behaviors including instructions, prompts, and trainer/model affect (scored on a scale of 1 to 5 with 1 indicating poor quality and 5 indicating highest quality), and (3) child’s compliance (scored on a scale of 1 to 5 with 1 indicating poor interest and 5 indicating maximum interest). Overall, across all groups, training activities were completed accurately across sessions (Rhythm: 92.16%(8.32), Robot: 90.73%(17.7), Comparison: 91.51%(5.67)), trainers and models demonstrated greater than optimal adherence to the training protocol (Rhythm: 4.68(0.39),

Robot: 4.36(0.34), Comparison: 4.65(0.27)), and children showed moderate to high levels of compliance across sessions (Rhythm: 3.27(1.14), Robot: 2.67(0.79), Comparison: 3.95(0.81)).

Next, we will discuss the training activities in each group. Our aim was to compare the effects of novel movement-based interventions to the current standard-of-care intervention for children with ASD. Therefore, the comparison group was designed to mimic the types of sedentary activities that children typically receive during ABA-based therapy sessions with a focus on academic and communication skills. In contrast, the rhythm and robot group engaged in whole-body movement-based games. Moreover, since we wanted to compare the effects of a human-delivered versus a robot-delivered intervention, we included similar types of activities in the rhythm and robot groups with the important distinction that a human trainer delivered the training activities in the rhythm group and the robot trainer delivered activities in the robot group. Overall, we designed training activities with an aim to standardize the treatment contact time across groups.

The rhythm group engaged in singing and synchronous whole-body imitation games (see Figure 2A). Note that we would like to distinguish this intervention from music therapy, which is often provided by certified music therapists. However, our training activities relied on rhythmic elements in music and involved synchronization of body movements and words to the beat of music; therefore, we refer to this group as the ‘rhythm group’. Training activities in this group included a “hello” song to greet social partners, an action song involving finger play, beat keeping involving whole body movements to a beat, music making that included structured and free games that involved playing musical instruments, moving game involving whole body interpersonal synchrony games, and a farewell song to bid farewell to social partners (see Table 3). Session themes included start and stop, steady beat, turn taking, slow and fast, and soft and loud.

The robot group engaged in whole-body imitation and interpersonal synchrony games with a 23-inch humanoid Nao robot and a mobile Rovio robot (see Figure 2B). Training activities included a “hello” game to greet the robot and social partners, a warm up game involving body stretches, an action game involving rhythmic upper and lower body interpersonal synchrony games, a drumming game involving simple and complex drumming sequences, a walking game to trace letters and shapes on the floor by following Rovio, and a farewell game to bid goodbye to the robot and social partners (see Table 3). Session themes again included start and stop, steady beat, turn taking, slow and fast, and soft and loud.

The comparison group engaged in sedentary tabletop activities promoting academic, social communication, and fine motor skills (see Figure 2C). Training activities included a “hello” game to greet the trainer and model, reading an age-appropriate book while taking turns with social partners, building creations using supplies such as play-doh, duplos, and Zoob, a theme-based arts and crafts activity involving drawing, coloring, cutting, and pasting, cleanup activity where children cleaned up the workspace, and lastly, a farewell activity to bid goodbye to social partners (see Table 3). For the building and art-craft activities, children were given a visual model of the final creation and a pictorial instruction sheet outlining

steps to make the creation. Session themes included the solar system, vegetables and fruits, weather and seasons, water bodies, and basic shapes.

2. 5. Statistical analysis

Prior to all inferential statistics, dependent variables were examined for deviations from the assumptions of normality and sphericity. Data from the JTAT satisfied all assumptions. Dependent *t*-tests were used to compare pretest versus posttest total response scores within each group. Since the training-specific attention measure was not normally distributed and had outliers, a square root transformation was applied on these data. Repeated measures ANCOVA was conducted on transformed variables with Attention target (social partner, robot, objects, elsewhere), Activity type (5 activities per group – *Rhythm*: social interaction including hello and farewell songs, action song, beat keeping, music making, and moving game; *Robot*: social interaction including hello and farewell games, warm up game, action game, drumming game, and walking game; *Comparison*: social interaction including hello and farewell games, reading, building, arts and crafts, and cleanup), and Session (early, mid, late) as within-subjects factors and Group as a between-subjects factor. For this analysis, the duration of children's social attention in the early session was added as a covariate, since we wanted to control for baseline differences in social attention across groups. A second ANOVA assessed type of social attention across groups, with Attention type (spontaneous, responsive), Activity type (5 activities per group as listed above), and Session (early, mid, late) as within-subjects factors and group as a between-subjects factor. Post-hoc *t*-tests assessed significant main and interaction effects. In case of a significant main and interaction effect involving a factor, we have reported on the interaction effect only. Greenhouse Geisser corrections were applied to variables that violated the sphericity assumption. Effect sizes are reported using partial eta-squared (η_p^2) and standardized mean difference (SMD) values (using Hedge's *g*) (Hedges, 1981). We will also report confidence intervals (CI) of the SMD values as calculated using the spreadsheet designed by Huedo-Medina & Johnson (Huedo-Medina & Johnson, 2011). Significance was set at $p = 0.05$.

3. Results

3. 1. Generalized changes in the JTAT

The rhythm group showed improvement in total response scores on the JTAT from pretest to posttest (see Figure 3, $p = 0.005$, SMD = 0.55, CI (SMD) = -0.13 to 1.24). Nine out of 11 children followed this group trend. The robot group did not show improvements on the JTAT ($p = 0.27$, SMD = 0.25, CI (SMD) = -0.38 to 0.89). The comparison group showed improvement in the JTAT total response scores from the pretest to posttest (see Figure 3, $p = 0.004$, SMD = 0.71, CI (SMD) = -0.01 to 1.43). Nine out of 11 children followed this group trend. Note that there were no between-group differences on the JTAT.

3. 2. Training-specific changes in attention patterns to different targets

A repeated measures ANOVA indicated main effects of activity type ($F(4, 132) = 23.06$, $p < 0.001$, $\eta_p^2 = 0.41$), attention target ($F(3, 99) = 113.06$, $p < 0.001$, $\eta_p^2 = 0.77$), and group ($F(2, 33) = 95.46$, $p < 0.001$, $\eta_p^2 = 0.85$), as well as significant interaction effects of activity type $\times$ group ($F(8, 132) = 10.57$, $p < 0.001$, $\eta_p^2 = 0.39$), attention target $\times$ group ($F(6, 99) =$

178.36, $p < 0.001$, $\eta_p^2 = 0.92$), session $\times$ attention target ($F(3.68, 121.58) = 4.32$, $p = 0.003$, $\eta_p^2 = 0.12$), session $\times$ attention target $\times$ group ($F(12, 198) = 2.57$, $p = 0.003$, $\eta_p^2 = 0.14$), activity type $\times$ attention target ($F(6.93, 228.70) = 62.03$, $p < 0.001$, $\eta_p^2 = 0.65$), activity type $\times$ attention target $\times$ group ($F(24, 396) = 33.34$, $p < 0.001$, $\eta_p^2 = 0.67$), and session $\times$ activity type $\times$ attention target ($F(10.70, 353.23) = 1.87$, $p = 0.04$, $\eta_p^2 = 0.05$). We analyzed the 3-way interactions of session $\times$ attention target $\times$ group and activity type $\times$ attention target $\times$ group using post-hoc t -tests. We will report the results of these analyses as between-group differences and within-group changes in attention.

3. 2. 1. Between-group differences—Both the rhythm and robot groups demonstrated greater attention to social partners and to elsewhere compared to the comparison group in the early, mid, and late sessions (see Figures 4A, 4B, & 4C, p values < 0.01 , range of SMD values = 1.09 to 4.50). In contrast, the comparison group attended more to objects compared to the rhythm and robot groups in the early, mid, and late training sessions (see Table 3, p values < 0.001 , range of SMD values = 4.63 to 8.37). Lastly, the rhythm group directed greater attention to social partners and objects compared to the robot group in the early, mid, and late sessions (see Figures 4A & 4B, p values < 0.001 , range of SMD values = 1.73 to 3.37).

3. 2. 2. Within-group effects in the Rhythm group—There were no overall improvements in social attention across sessions. However, there were session-specific differences in attention. During the early session, the rhythm group attended more to social partners, followed by objects, with least attention directed elsewhere (see Figure 4A, p values < 0.03 , range of SMD values = 1.03 to 2.04). In the mid and late sessions, the rhythm group demonstrated greater attention to social partners compared to objects and elsewhere (see Figure 4A, p values < 0.003 , range of SMD values = 1.19 to 1.96). In terms of activity-related differences, during all activities except music making, children directed maximum attention to social partners followed by elsewhere with least attention to objects (see Figure 5A, p values between < 0.001 to 0.02). In contrast, during music making, children primarily attended to objects, followed by social partners, and last to elsewhere (see Figure 5A, p values between < 0.001 to 0.02). In terms of social attention, it was greatest during social interaction, action song, and beat keeping activities (see Figure 5A).

3. 2. 3. Within-group effects in the Robot group—There was an increase in attention to elsewhere from early to late (SMD = 1.11, CI (SMD) = 0.27 to 1.95) as well as mid to late sessions (SMD = 1.04, CI (SMD) = 0.22 to 1.86) (see Figure 4B, p values < 0.02). Individual data suggested that 9–10 out of 12 children followed the group trends. The robot group also showed a reduction in attention to the robot from early to mid (SMD = -0.73 , CI (SMD) = -1.46 to -0.01) and early to late sessions (SMD = -0.96 , CI (SMD) = -1.75 to -0.17) (see Figure 4B, p values < 0.05). Specifically, 10–12 children followed this group trend.

In terms of session-specific differences, the robot group directed maximum attention to the robot followed by social partners and elsewhere with least attention to objects in the early, mid, and late sessions (see Figure 4B, p values between < 0.003 and 0.04, range of SMD values = 0.30 to 3.26). In terms of activity-related differences, during the warm up and

action games, the robot group showed greater attention to the robot followed by elsewhere and social partners, with least attention to objects (see Figure 5B, p values between < 0.001 and 0.007). During the drumming game, children directed maximum attention to the robot and least attention to elsewhere and objects (see Figure 5B, p values between 0.004 and 0.02). The highest levels of social attention were seen during the action game, drumming game, and social interaction phase (see Figure 5B).

3. 2. 4. Within-group effects in the comparison group—There were no intervention-related changes in attention patterns in this group. However, in terms of session-specific differences, the comparison group spent maximum time attending to objects compared to social partners and elsewhere across the early, mid, and late sessions (see Figure 4C, p values < 0.001 , range of SMD values = 5.39 to 8.17). In terms of activity-related differences, the comparison group looked more at objects compared to elsewhere and social partners in the reading, building, art-craft, and cleanup activities (see Figure 4C, p values < 0.001). Similarly, the comparison group directed greater attention to objects and elsewhere than to social partners during the social interaction phase (see Figure 5C, p values < 0.01). The social interaction, reading, and cleanup activities elicited greatest social attention (see Figure 5C).

3. 3. Training-specific changes in spontaneous and responsive patterns of social attention

Repeated measures ANOVA indicated main effects of activity type ($F(4, 132) = 54.49$, $p < 0.001$, $\eta_p^2 = 0.62$) and attention type ($F(1, 33) = 22.36$, $p < 0.001$, $\eta_p^2 = 0.40$), as well as interaction effects of activity type $\times$ group ($F(8, 132) = 35.71$, $p < 0.001$, $\eta_p^2 = 0.68$), attention type $\times$ group ($F(2, 33) = 15.77$, $p < 0.001$, $\eta_p^2 = 0.49$), activity type $\times$ attention type ($F(3.17, 104.64) = 9.60$, $p < 0.001$, $\eta_p^2 = 0.23$), and activity type $\times$ attention type $\times$ group ($F(8, 132) = 9.14$, $p < 0.001$, $\eta_p^2 = 0.36$). We report results from post-hoc analyses of activity type $\times$ attention type $\times$ group as between-group differences and within-group changes in social attention patterns.

3. 3. 1. Between-group differences—(see Figure 6) As mentioned before, the rhythm group demonstrated highest overall levels of social attention, followed by the robot group with least social attention in the comparison group. Along the same lines, in terms of attention type, the duration of spontaneous social attention was greatest in the rhythm group, followed by the robot group, with least spontaneous attention in the comparison group (see Figure 6, p values < 0.001 , range of SMD values = 1.87 to 3.09). Similarly, children spent greater time in responsive social attention episodes in the rhythm and robot groups compared to the comparison group (see Figure 6, p values < 0.001 , range of SMD values = 0.23 to 1.86).

3. 3. 2. Within-group changes—The rhythm group engaged in greater duration of spontaneous versus responsive social attention, especially, during the social interaction, beat keeping, and moving game activities (see Figure 6 & Table 4, p values between < 0.001 and 0.01). In contrast, during music making, the rhythm group engaged in greater responsive social attention (see Table 4, $p = 0.004$). The robot group engaged in predominantly

responsive versus spontaneous social attention across all activities (see Figure 6 and Table 4, p values < 0.001). The comparison group engaged in greater responsive versus spontaneous social attention across all activities (see Figure 6 and Table 4, p values < 0.003).

4. Discussion

4. 1. Summary of results

We conducted a pilot RCT to compare the effects of two novel movement-based rhythm and robotic interventions with those of a standard-of-care comparison intervention on the social attention patterns of 36 children with ASD. At the very least, we aimed to demonstrate non-inferiority of the novel interventions compared to the standard-of-care intervention. For this purpose, we examined *group differences*, *intervention-related changes*, and *activity-related differences* in social attention. The rhythm group engaged in greater social attention compared to the other groups across sessions after controlling for baseline levels of social attention during all activities except music making, which elicited greater object-directed attention. Children in the rhythm group did not show improvements on the within-intervention measure of social attention; however, they improved their performance on the JTAT from the pretest to the posttest. Moreover, children engaged in greater spontaneous versus responsive attention episodes in each session. The robot group had levels of social attention that were lower than the rhythm group but still greater than the comparison group. Children also directed maximum attention to the robot compared to other attention targets in a majority of the activities. With training, children showed a reduction in attention to the robot with a concurrent increase in attention towards elsewhere; moreover, no intervention-related improvements were seen on the standardized and training-specific measure of social attention. Children in the robot group also engaged in greater responsive compared to spontaneous social attention. The comparison group directed maximum attention to objects/training supplies during all the training activities. There were no significant changes on the training-specific measure of social attention; however, children improved their performance on the JTAT from the pretest to the posttest. The comparison group showed greater responsive compared to spontaneous social attention.

4. 2. Training-specific changes in attention patterns of the Rhythm group

The rhythm group demonstrated greater social attention compared to the other groups after controlling for baseline values of social attention during all activities except music making. The very nature of the training activities may have elicited sustained social monitoring. Children were encouraged to practice novel dual and multilimb interpersonal synchrony- and imitation-based games with social partners. Typically developing children learn complex motor skills by observing the demonstrations of a skilled model (Weeks & Anderson, 2000). To accurately synchronize movements spatially and temporally with social partners, children have to continuously monitor them and dynamically adapt their movements to match up with their adult partners. Given the task demands of the training activities, children may have engaged in high levels of social monitoring. Previous research suggests that imitation and interpersonal synchrony-based activities promote sustained social attention in children with ASD (Escalona, Field, Nadel, & Lundy, 2002; Landa et al., 2011). These findings are also consistent with literature on the positive effects of music on social engagement in autism

(Finnigan & Starr, 2010; Kim et al., 2008; Wimpory et al., 1995). For example, 12 sessions of music therapy led to greater improvements in eye contact, imitation, and turn taking skills in a child with autism compared to a non-musical play-based intervention (Finnigan & Starr, 2010). Music may help improve cooperation and bonding between people (Overy & Molnar-Szakacs, 2009). Joint actions involving music making, singing, and dancing lead to a shared affective experience, which can evoke prosocial behaviors (Kirschner & Tomasello, 2010; Overy & Molnar-Szakacs, 2009; Wiltermuth & Heath, 2009). For example, 4-year-old typically developing children showed greater spontaneous cooperative and empathetic behaviors towards their peer when they engaged in a joint music making activity versus when they engaged in story-telling games (Kirschner & Tomasello, 2010). Overall, engagement in enjoyable, socially synchronous activities within rhythmic contexts promoted sustained social monitoring in children with ASD.

During the music making activity, children focused more on objects used in training including musical instruments such as drums and xylophones. Given the easy access to objects, children may have engaged in greater visual fixation on objects. Moreover, the practice of complex drumming and xylophone patterns required sustained monitoring of the instruments. These findings are consistent with the results from the comparison group, which suggest that engaging in predominantly object-based activities led to preferential attention to objects. This also fits with existing literature suggesting that in the presence of competing social and non-social stimuli, children with autism prioritize non-social stimuli at the cost of social stimuli (Klin et al., 2002; Sasson, Turner-Brown, Holtzclaw, Lam, & Bodfish, 2008). This could be attributed to their social orienting deficits (Dawson et al., 2004) and their impairments in attention disengagement (Landry & Bryson, 2004), which are discussed in detail below.

Lastly, in terms of attention type, children engaged in greater duration of spontaneous compared to responsive social attention. Although children with ASD demonstrate impairments in both RJA and IJA, difficulties in RJA remit to a great extent over development (Mundy, Sigman, & Kasari, 1990; Mundy, 2003). However, impairments in IJA are more severe, persist in late childhood, and are associated with future outcomes in adolescence, such as the ability to form peer relationships (Mundy & Hogan, 1994; Mundy, 2000). Contemporary behavioral and developmental autism interventions are very effective in promoting RJA with limited success in enhancing IJA skills (Kasari, 2002; Whalen & Schreibman, 2003). Our study suggests that socially embedded, music and movement activities can promote spontaneous engagement between children and their social partners. Other studies have also reported improvements in child-initiated social engagement following music-based therapies (Kim et al., 2008; Kim et al., 2009; Stephens, 2008; Wigram, 2002; Wimpory, et al., 1995). For example, 12-weeks of improvisational music therapy sessions led to greater improvements in the spontaneous initiation of JA in 10 children with ASD compared to toy play sessions (Kim et al., 2008). Overall, the non-intimidating yet enjoyable nature of rhythmic synchrony-based activities may have promoted spontaneous social attention in children with ASD.

4. 3. Training-specific changes in attention patterns of the Robot group

The robot group demonstrated greater social attention than the comparison group but lower than the rhythm group. Similar to the rhythm group, the robot group also engaged in dual and multilimb synchrony-based games that could have promoted sustained monitoring of the model.

Moreover, while practicing each movement sequence, the first trial involved the robot, child, and model moving together. In the second trial, we encouraged children to synchronize movements with the model in the absence of robotic movement that may have encouraged social monitoring. Along the same lines, other studies have also used robots to promote social skills such as shared attention, JA, imitation, and turn taking in children with ASD (Kozima et al., 2007; Robins, Dickerson, Stribling, & Dautenhahn, 2004; Robins et al., 2005; Srinivasan, Gifford, Bubela, & Bhat, 2013; Srinivasan & Bhat, 2013; Stanton, Kahn, Severson, Ruckert, & Gill, 2008; Warren et al., 2013; Werry, Dautenhahn, Ogden, & Harwin, 2001).

Interestingly, we found that social attention levels in the robot group were lower than the rhythm group. Given children's intrinsic interest in technology, we expected that they would engage in high levels of robot-directed attention in the early sessions, but across training weeks the robot would act as an effective mediator to promote shared attention between children and their social partners. On the contrary, children continued to devote maximum attention to the robot with no increase in social attention, suggesting that visual fixation on the robot may have restricted their opportunities to engage with social partners. Moreover, trainers and models had to repeatedly bid children to get them to disengage from the robot and monitor adult actions contributing to higher amounts of responsive attention in this group. Our findings do not fit with studies that demonstrated improvements in social interactions following robot-child interactions (Kozima et al., 2007; Robins et al., 2004; Robins et al., 2005; Stanton et al., 2008; Warren et al., 2013; Werry et al., 2001). A majority of these studies assessed changes in children's behaviors following a single session or a short duration of training. Only two studies to date have examined the effects of prolonged duration of robotic interactions in autism (Kozima et al., 2007; Robins et al., 2004). One of these studies used a creature-like robot, Keepon, in a day care center for children with ASD, but unlike our study, children were free to approach and interact with the robot at any time during their routine activities (Kozima et al., 2007). In a more structured protocol, Robins et al., (2004) observed the reactions of 4 children with ASD over 100 sessions of interactions with robots; however, on an average each trial lasted between 3 and 5 minutes and was terminated as soon as the child showed boredom (Robins et al., 2004). In contrast to the short duration low intensity training reported in the robotic therapy literature, we argue that the utility of robots as therapy tools should be evaluated using the intensive standards of current autism interventions (Lovaas, 1987). Along these lines, we systematically assessed the effects of an intense 32-session protocol on children's social attention skills and found that our robotic technology failed to sustain engagement in children following prolonged interventions.

Across training sessions, the robot group demonstrated large effect sizes for reduction in attention towards the robot and concurrent increase in attention towards elsewhere. These

findings may reflect a reduction in engagement and progressive boredom with the context. Our own previous work with TD children using a smaller robot, Isobot, also suggested that the limited capabilities of the robot could not sustain children's engagement across four weeks and children showed an increase in attention to elsewhere in the latter sessions (Srinivasan & Bhat, 2013). Similarly, during an 18-day trial with an interactive humanoid robot, Robovie, that could teach words, TD children demonstrated a sharp reduction in interest towards the robot during the second week (Kanda, Hirano, Eaton, & Ishiguro, 2004). Although, in the current study, we used state-of-the-art Nao robots, the limitations of our robotic technology might have led to a decrease in engagement over time. Specifically, the movement repertoire of the robot was limited, noisier, and slower than that of the child, once triggered the robot had difficulty adapting to the quick movements of children, and the robot's verbiage was unclear and slightly delayed. The lack of contingent responding and dynamic adaptive capacities limited the robot's capacity to promote social engagement. Our data suggest that the robot promoted visual fixation towards itself at the cost of social interactions.

4. 4. Training-specific changes in attention patterns of the Comparison group

The comparison group was designed to mimic the standard-of-care therapy settings that children with ASD typically receive at school. Children engaged in activities that promoted academic, social communication, and fine motor skills during reading, building, and art-craft activities. We hypothesized that the sedentary context in the comparison group would promote high levels of social attention. On the contrary, compared to the other groups, the comparison group engaged in the lowest levels of social attention. Instead, children spent maximum time attending to objects/supplies. The very nature of the context and the type of activities practiced could have contributed to the distinct attentional patterns. Children engaged in familiar activities that were designed to promote shared attention, as children took turns to read a book or built theme-based creations with adult partners. However, the context allowed easy access to objects – books, building supplies, and art-craft materials. Secondly, social partners demonstrated the sequence of steps involved in making the building or art-craft creations and depicted them using picture schedules. Many children chose to focus on the picture schedules versus attending to the demonstration of their social partners. Previous research also suggests that children with ASD prefer to attend to non-social compared to social stimuli (Annaz, Campbell, Coleman, Milne, & Swettenham, 2012; Chawarska, Macari, & Shic, 2012; Klin et al., 2002; Ozonoff et al., 2010; Sasson et al., 2008; Swettenham et al., 1998). Salient objects may be a “visual trap” limiting children's opportunities to explore their social world (Landry & Bryson, 2004; Sasson et al., 2008). For example, 20-month old toddlers interacting with caregivers during free play spent greater time attending to objects than people and showed fewer attention shifts between people and objects compared to typically developing infants and infants with developmental delays (Swettenham et al., 1998). Overall, the nature of the context and the type of supplies provided may have elicited greater non-social visual fixation at the cost of social attention.

Similar to the robot group, the comparison group also engaged in greater responsive compared to spontaneous social attention. Given children's visual fixation on objects, trainers and models had to use multiple verbal bids to redirect children's attention towards

them, possibly leading to higher levels of responsive social attention. Moreover, as mentioned earlier, contemporary behavioral interventions that involve activities similar to our comparison group are more effective in promoting responsive compared to spontaneous communication (Vismara & Rogers, 2010; Whalen & Schreibman, 2003). Overall, our findings of higher levels of social attention in the rhythm group compared to the comparison and robot groups emphasize the importance of naturalistic, object-free play to facilitate spontaneous engagement and social initiations (Kasari, Freeman, & Paparella, 2006; Rogers & Dawson, 2010; Schreibman & Pierce, 1993; Chawarska et al., 2012).

4. 5. Generalized changes in the JTAT: Rhythm, Robot, & Comparison Groups

The rhythm and comparison groups demonstrated large effect sizes for improvements on the JTAT from the pretest to the posttest. The robot group did not demonstrate improvements on the JTAT. All groups practiced gross motor or fine motor/academic activities within a group setting. Children were provided plenty of opportunities to engage in shared attention bids with their adult partners. For example, in the rhythm group, adults prompted children to attend to picture schedules as well as pass props and instruments during the setup and cleanup phases of each activity. Similarly, in the comparison group, adults engaged in shared attention activities such as asking children to pass supplies, label specific objects, and cleanup supplies. The rhythm and comparison groups may have improved their ability to respond to JA bids within the training context and also generalized learned skills to the JTAT. In contrast, lack of engagement and boredom with the training context may have reduced opportunities for internalization of JA behaviors in the robot group leading to limited generalization to the JTAT. Alternatively, the lack of improvement could be due to a ceiling effect, since the robot group demonstrated relatively higher scores on the JTAT even in the pretest session.

It was surprising that children in the rhythm and comparison groups showed generalized improvements in JA without accompanying changes on the training-specific test of social attention. Our current coding scheme may not be sensitive enough to capture changes in social attention. For example, the video coding may not have captured instances when children used peripheral vision to attend to social partners. Future studies could use eye tracking to accurately assess changes in social attention patterns following behavioral interventions. Alternatively, differences in the nature of the variables measured in the training-specific (duration of social attention) and generalized tests (frequency of responses to JA bids) may have contributed to these findings. Moreover, improvements in social attention may be evident in the frequency (not duration) of shared attention episodes, which may be a more sensitive variable to detect change in attention patterns following short-term behavioral interventions. Consistent with our findings, recent work suggests that sustained social monitoring within dyadic contexts might be a greater deficit in toddlers with ASD compared to brief attentional bids within JA contexts (Chawarska et al., 2012). Our training could have led to improvement in JA, but the intensity and duration may be inadequate to lead to robust improvements in sustained social monitoring skills of children. Future long-duration RCTs on behavioral interventions should test this hypothesis.

4. 6. Clinical Implications

To the best of our knowledge, this is the first study that assessed the effect of novel rhythm and robotic interventions compared to a standard-of-care comparison intervention in children with ASD. This pilot study was meant to test the feasibility of recruitment, assessment, and implementation procedures in preparation for the design of a larger efficacy trial in the future. Given the small sample size of this study, we acknowledge that the effect sizes calculated in this study are imprecise with large confidence intervals. Consistent with the current guidelines for interpretation of pilot studies, we therefore recommend that our findings be validated using larger efficacy trials meant to calculate accurate between-group effect sizes (Leon, Davis, & Kraemer, 2014). Nevertheless, the findings of this study suggest that rhythmic contexts that focused on whole-body imitation and interpersonal synchrony-based activities were motivating and promoted social attention in children with ASD. In contrast, in the robot and comparison groups, children spent maximum time attending to the robot and objects respectively, which restricted their opportunities for social engagement. Overall, the rhythm intervention was superior to the comparison intervention in terms of affording social attention. Although the robotic intervention also afforded levels of social attention higher than the comparison group, across sessions there was a reduction in engagement with the context thereby limiting the long-term utility of this context in promoting shared engagement in children with ASD. Our second manuscript in this two-part series further describes positive effects on social verbalization and confirms that movement-based activities provide an enjoyable and motivating context for children to spontaneously communicate and share interests with their social partners.

Our findings underscore the importance of promoting group play between children and their social partners in “object-free” contexts that facilitate sustained engagement with people in the absence of environmental distractors. Shared engagement in turn has implications for the development of triadic joint attention, verbal communication, empathy, and affective skills (Dawson et al., 2004; Kirschner & Tomasello, 2010; Overly & Molnar-Szakacs, 2009). Contemporary autism interventions should include activities that encourage shared engagement with social partners in environments free of object distractors. Moreover, training contexts must shift from being predominantly sedentary play focused on academic activities to inclusion of more engaging, socially embedded, movement interventions including rhythm, dance, sport, and other active play therapies to facilitate a variety of social communication, motor, and behavioral skills. Our findings are an urgent call for educators, clinicians, and caregivers to incorporate group-based creative movement experiences within the treatment plan of children with ASD.

Although the robotic intervention was initially engaging for children, across sessions, the novelty of the robot was lost and children were bored with the context. Given the state of the current robotic technologies, clinicians could consider using robots as adjunct therapies for short-term training to ensure sustained engagement. We recommend future efforts to be directed towards the development of semiautonomous robots that can effectively adapt their behaviors to the needs of the child. Specifically, there is a need to enhance the motor and verbal repertoire of the Nao robot to effectively engage children during long-term interventions. Lastly, robotic therapies should be carefully designed to include functionally

relevant activities and to facilitate sustained engagement between children and their social partners.

4. 7. Limitations

Our study was limited by a small sample size, relatively short training duration, heterogeneity in the levels of functioning of participants, and lack of follow up sessions to evaluate carryover of training. Moreover, in terms of behavioral coding of training sessions, the coders were not blinded to the grouping of the child. In addition, our current evaluation was restricted to the assessment of visual joint attention. Although highly relevant especially in the rhythm group, we did not assess auditory joint attention in this study. In the current paper, we restricted our discussion to the duration of social attention episodes; we are currently in the process of analyzing frequency data for social attention. The present study was a pilot study meant to provide proof of concept and evaluate the feasibility of rhythm and robotic activities in promoting social attention skills in children with ASD. Therefore, in the current study, we did not tightly control and manipulate the effects of individual musical (pitch, melody, rhythm, etc.) or robotic (animate, inanimate, mobile, humanoid) elements on social attention skills. We hope that this study will serve as a foundation for future work that can systematically manipulate and evaluate the effects of individual musical or robotic elements on social communication skills of children with ASD. Moreover, although we investigated the effect of rhythm therapies on social attention skills of children, given the dearth of evidence on rhythm therapies in ASD, we have drawn upon the broader music therapy literature to provide support for the results observed in this study. We therefore strongly recommend that future studies replicate the results of this pilot RCT using larger homogenous samples and longer training durations. In terms of the robotics literature, we found significant differences in the results observed in our study and previous studies. Several factors such as the prolonged duration of the current study, the limited capabilities of the robot used in the study, etc. may have contributed to these differences. Given the state of this literature, we recommend further meta-analysis be conducted to assess the overall effects of robotic interventions in children with ASD with a focus on mediator variables.

4. 8. Conclusions

Social attention has been proposed to be a marker for evaluating treatment efficacy in autism. In this pilot RCT, we compared the effects of rhythm, robotic, and comparison interventions on the social attention skills of children with ASD between 5 and 12 years of age. We found that it is difficult to change levels of sustained social attention in children through short-term behavioral interventions. However, certain contexts involving rhythmic and whole-body interpersonal synchrony games elicit high levels of social attention compared to sedentary contexts. Therefore, in addition to the emphasis on promoting JA skills within triadic contexts, contemporary autism interventions should focus on facilitating sustained social attention skills using engaging group-based active play activities that emphasize social monitoring, joint action, imitation, and interpersonal synchrony. Although robotic technologies are an appealing tool for children with ASD, their applications are currently restricted due to technological limitations. Further technological advances such as greater autonomy and contingent responding will be needed to make robots feasible and effective treatment tools for children with autism.

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Appendix 1: Checklist to assess fidelity of training sessions

Checklist criteria	Exemplar behaviors assessed
Eye contact	Trainer and model elicit eye contact from child during social interactions
Ready response	Trainer asks child if he/she is ready before each activity
Use of PECS board	Trainer takes child through the activities of the day using the PECS board
Session theme	Trainer explains the theme of the session to the child. Example: "Today's theme is turn taking. When I move you watch, and when I stop it is your turn to move"
Activity introduction using PECS	Trainer introduces activity using picture boards. Example: "Let's get ready for music making" while pointing at the picture for "Music making"
Help with setup	Trainer and model ask child to help with setup for each activity. Example: "Can you pass that blue lego block to me"
Presentation of activity	At the beginning of each activity, trainer gives simple instructions for the activity. Example: "Now, we will copy the robot"
Activity-specific bids	Appropriate bids to promote motor and social communication skills during each activity were provided. Example: For building activity, "Let's roll the play-doh into a ball. Roll with me."
Trials	Trainer asks child to repeat each activity twice
Spontaneous exploration	Trainer and model provide children with opportunities for free play and spontaneous exploration. Example: "It is free music time. You can play the drums in any way you want."
Social praise	Trainer and model provide verbal and gestural praise to child as required.
Help with cleanup	Trainer and model ask child to help with cleanup of supplies after completion of each activity.
Activity completion	After each activity, trainer asks child to move down the picture for the activity on the PECS board.
General characteristics in the session	The overall session is evaluated for the following characteristics – # of activities completed, environmental arrangement (supplies in close proximity but out of the sight of the child to avoid distractions), and incremental prompts (visual, verbal, gestural, and lastly manual prompts/assistance provided if child is unable to perform the activity)
Trainer and model behaviors	The trainer's and model's behaviors are evaluated for the following criteria on a scale of 1 to 5 – <ul style="list-style-type: none"> • Appropriateness of instructions, prompts, and reinforcement • Voice and affect modulation • Appropriateness of movements
Child interest	Child's interest and compliance during session assessed on a scale of 1 to 5.

Abbreviations

ASD	Autism Spectrum Disorder
JA	Joint Attention
JTAT	Joint Attention Test
RJA	Responsive Joint Attention
IJA	Initiating Joint Attention
PRT	Pivotal Response Therapy
ABA	Applied Behavioral Analysis
TEACCH	Treatment and Education of Autistic and related-Communication Handicapped Children
PECS	Picture Exchange Communication System
VABS	Vineland Adaptive Behavior Scales
SCQ	Social Communication Questionnaire
SMD	Standardized Mean Difference
CONSORT	Consolidated Standards of Reporting Trials
CI	Confidence Intervals

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Highlights

- Effects of rhythm and robotic interventions on attention patterns in autism were assessed
- Rhythm and comparison groups showed improvements in responsive joint attention
- Social attention was greatest in the rhythm group
- Robot group showed progressive boredom with the activities across weeks
- Comparison group directed greatest attention towards objects/training supplies

Figure 1.
Flow diagram describing participant enrollment and treatment allocation using Consolidated Standards of Reporting Trials (CONSORT) guidelines

Figure 2A.
Experimental set-up for a rhythm group training session

Figure 2B.
Experimental set-up for a robot group training session

Figure 2C.
Experimental set-up for a comparison group training session

Figure 3.
Intervention-related changes in total response scores of the JTAT
* $p < 0.05$

Figure 4A.
Intervention-related changes in attention patterns in the Rhythm group

Figure 4B.

Intervention-related changes in attention patterns in the Robot group

Figure 4C.

Intervention-related changes in attention patterns in the Comparison group

* $p < 0.05$

Figure 5A.
Activity-related differences in attention patterns in the Rhythm group

Figure 5B.
Activity-related differences in attention patterns in the Robot group

Figure 5C.
Activity-related differences in attention patterns in the Comparison group

Figure 6.

Group differences in spontaneous and responsive social attention

* $p < 0.05$

Demographic characteristics of children in the rhythm, robot, and comparison groups

Table 1

Participant Characteristics	Rhythm Group M(SD)	Robot Group M(SD)	Comparison Group M(SD)	F or χ^2 value	p-value
Age	7.88(2.56)	7.52(2.22)	7.36(2.02)	0.44	0.65
Gender	10M, 2F	11M, 1F	11M, 1F	0.56	0.76
Socioeconomic status	47.33(10.86)	47.75(8.75)	52.46(10.37)	0.97	0.39
Adaptive behavior composite on the VABS	71.45(11.75)	67.91(15.01)	75.92(18.43)	0.80	0.46

Table 2

Verbal and gestural prompts of the Joint Attention Test

Examiner Prompt	Correct response
Verbal prompts	
Look at poster on the side	Looks at the tester/appropriate direction and the poster
Look at poster at the back	Looks at the tester/appropriate direction and the poster
Look at novel object on the floor	Looks at the tester/appropriate direction and the object
Look at personal object (for example, shirt, pants, or wristwatch)	Looks at the tester/appropriate direction and the object
Gestural prompts	
Wave "hi"/shake hand	Waves "hi" or shakes hand
Hand pen	Takes pen
Hi-five	Gives hi-five
Low-five	Gives low-five
Wave "bye"	Waves "bye"

Table 3

An exemplar rhythm, robot, and comparison group training session

Activity	Rhythm Group	Robot Group	Comparison Group
1.	Hello Song - Child asked to sing to trainer and model Song: Hello everybody yes indeed	Introduction - Child asked to greet the trainer, model, and robot	Introduction - Child asked to greet the trainer, and model
2.	Action Song - Child asked to sing and engage in finger play - Song: Open shut them	Warm up Game - Child asked to copy whole-body stretching moves of the Nao robot	Book Reading - Child reads age-appropriate book while taking turns with trainer and model
3.	Beat Keeping - Child asked to copy trainer during rhythmic arm and leg actions - Song: Stop, go, go, go	Action Game - Child asked to engage in upper and lower body synchrony games with Nao robot and model - Theme: Start and stop game	Building - Child builds creations using Play-doh®, Lego®, etc. - Theme: Make a Lego car
4.	Music Making - Child asked to play instruments like drums, xylophones, cymbals, tambourines, etc. - Song: Jingle jingle jingle jive	Drumming Game - Child asked to practice simple and complex drum patterns with Nao robot and model - Theme: Start and stop game	Arts & Crafts - Child makes creations by drawing, coloring, cutting etc. - Theme: Make a Vegetable basket
5.	Moving Game - Child asked to copy trainer during gross motor actions like skipping, hopping, jumping etc. - Song: On the bridge of Newtown	Walking Game - Child asked to follow Rovio robot with the model to trace letters and shapes on the floor - Theme: Tracing letter "L"	Cleanup - Child asked to clean up all supplies used for the session
6.	Farewell Song - Child asked to sing to trainer and model - Song: It was good to see you	Farewell - Child asked to bid goodbye to the trainer, model, and robot	Farewell - Child asked to bid goodbye to trainer and model

Duration of spontaneous and responsive social attention in the rhythm, robot, and comparison groups

Table 4

Group	Spontaneous Social Attention Percent Duration M(SD)					Responsive Social Attention Percent Duration M(SD)				
	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5
Rhythm	35.5 (13.2)	31.2 (13.6)	38.6 (19.5)	6.4 (5.7)	32.9 (14.6)	24.8 (11.2)	27.6 (11.0)	24.4 (16.7)	12.1 (8.9)	17.9 (10.0)
Robot	7.2 (5.8)	4.4 (4.3)	5.4 (4.0)	7.5 (5.4)	3.1 (3.5)	18.4 (8.7)	13.1 (11.3)	24.0 (13.3)	19.4 (10.1)	6.4 (3.8)
Comparison	2.6 (4.6)	1.3 (2.4)	0.8 (1.0)	1.0 (1.6)	1.3 (2.4)	20.1 (15.5)	9.6 (11.4)	4.8 (7.3)	4.0 (5.6)	9.6 (11.4)

Note: C = training activities in each group; Rhythm Group – C1 = Social interaction, C2 = Action song, C3 = Beat keeping, C4 = Music making, C5 = Moving game; Robot – C1 = Social interaction, C2 = Warm up game, C3 = Action game, C4 = Drumming game, C5 = Walking game; Comparison Group – C1 = Social interaction, C2 = Reading, C3 = Building, C4 = Art & crafts, C5 = Cleanup.