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HHS Public Access

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Res Autism Spectr Disord. Author manuscript; available in PMC 2017 July 01.

Published in final edited form as:

Res Autism Spectr Disord. 2016 July ; 27: 73–87. doi:10.1016/j.rasd.2016.04.001.

The effects of embodied rhythm and robotic interventions on the spontaneous and responsive verbal communication skills of children with Autism Spectrum Disorder (ASD): A further outcome of a pilot randomized controlled trial

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Abstract

The current manuscript is the second in a mini-series of manuscripts reporting the effects of alternative, movement-based, rhythm and robotic interventions on the social communication skills of 36 school-age children with ASD. This pilot randomized controlled trial compared the effects of 8-weeks of rhythm and robotic interventions to those of a standard-of-care, comparison intervention. The first manuscript reported intervention effects on the spontaneous and responsive social attention skills of children. In this manuscript, we report intervention effects on the spontaneous and responsive verbal communication skills of children. Communication skills were assessed within a standardized test of responsive communication during the pretest and posttest as well as using training-specific measures of social verbalization during early, mid, and late training sessions. The rhythm and comparison groups improved on the standardized test in the posttest compared to the pretest. The rhythm and robot groups increased levels of social verbalization across training sessions. Movement-based and stationary contexts afforded different types and amounts of communication in children with ASD. Overall, movement-based interventions are a promising tool to enhance verbal and non-verbal communication skills in children with ASD.

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Keywords

rhythm; robots; communication; autism; embodied interventions

1. Introduction

Autism Spectrum Disorder (ASD) is a common pediatric developmental disorder with 1 in every 68 children in the US being diagnosed with ASD (Baio et al., 2014). Given the rising prevalence of ASD, there is growing research on developing novel and engaging interventions for children with ASD to address their core social communication impairments. The current manuscript is the second paper in a mini-series of manuscripts reporting the findings from a pilot randomized controlled trial (RCT) conducted to assess the effects of novel, multisystem, rhythm and robotic therapies compared to a standard-of-care intervention on the non-verbal and verbal communication skills of school-age children with ASD. The first manuscript reported the effects of rhythm and robotic therapies on the spontaneous and responsive attention patterns of children with ASD. In the current manuscript, we will report the effects of rhythm and robotic interventions on the spontaneous and responsive verbal communication skills of children.

Verbal communication impairments in children with ASD include difficulties with initiation of conversations, responding to communicative bids of others, and engaging in reciprocal conversations (Eigsti et al., 2011). In addition, children with ASD have difficulties understanding and integrating non-verbal behaviors such as eye contact, body language, gestures, and facial expressions into their social interactions (Eigsti et al., 2011). In fact, delays in language milestones such as the onset of first words are amongst the earliest causes for parental concern and physician referral in children who eventually develop an ASD diagnosis (Carter, & Tager-Flusberg, 2008; Dahlgren & Gillberg, 1989; De Giacomo & Fombonne, 1998; Lord, Risi, & Pickles, 2004; Luyster, Kadlec, Wetherby et al., 2004; Mitchell et al., 2006). However, there is tremendous variability in the language profiles of children with ASD; around 25% never develop functional speech (Kjelgaard & Tager-Flusberg, 2001; Tager-Flusberg, Paul, & Lord, 2005), whereas other children develop vocabularies comparable to typically developing (TD) children (Luyster et al., 2008; Thurm, Lord, Lee, & Newschaffer, 2007). Nevertheless, even children at severity level 1 according to the latest DSM V criteria (American Psychiatric Association, 2013) demonstrate subtle difficulties in using language appropriately during social interactions (Eales, 1993; Luyster et al., 2008). Early language skills of children with ASD have been associated with long-term outcomes and future prognoses (Gillberg, 1991; Gillberg & Steffenburg, 1987; Howlin, Mawhood, & Rutter, 2000; Kobayashi, Murata, & Yoshinaga, 1992; Lincoln, Courchesne, Kilman, Elmasian, & Allen, 1988; Rutter, 1970; Sigman & Ruskin, 1999; Venter, Lord, & Schopler, 1992). Overall, impaired verbal and non-verbal communication skills negatively affect children's abilities to engage in meaningful interactions, which in turn may lead to missed opportunities to learn skills associated with adaptive functioning, academic competence, and social engagement.

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Children with ASD demonstrate poor receptive and expressive communication skills, with greater impairments in receptive compared to expressive language (Charman, Drew, Baird, & Baird, 2003; Hudry et al., 2010; Kjelgaard & Tager-Flusberg, 2001; Luyster et al., 2008). Poor receptive language could be due to both a core difficulty in understanding linguistic input and an impaired perception of subtle cues that accompany speech, including the speaker's facial expressions, tone of voice, etc. (Landa, 2007; Tager-Flusberg et al., 2005; Tager-Flusberg & Caronna, 2007). In terms of language production, children have impaired responsive and spontaneous speech production, although deficits in spontaneous communication are more severe and persistent (Vismara & Rogers, 2010). For example, children with ASD had difficulty offering relevant information during ongoing conversations initiated by others (Adams, Green, Gilchrist, & Cox, 2002; Chuba, Paul, Miles, Klin, & Volkmar, 2003; Lord et al., 1989; Surian, Baron-Cohen, & Van der Lely, 1996; Ziatas, Durkin, & Pratt, 2003). Children also demonstrate difficulties in spontaneously initiating speech and engage in lower rates and variety of speech compared to TD children (Koegel, Koegel, Harrower, & Carter, 1999; Stone & Caro-Martinez, 1990; Tager-Flusberg et al., 2005). Moreover, instead of using language to communicate with others, children with ASD frequently engage in echolalia (repetition/echoing of words and phrases heard in the past), self-directed speech, and speech monologues (Eigsti, de Marchena, Schuh, & Kelley, 2011; Ramberg, Ehlers, Nydén, Johansson, & Gillberg, 1996; Tager-Flusberg & Calkins, 1990). In addition to these obvious communication impairments, children demonstrate impaired joint attention (JA), motor imitation, and play skills that are foundational for the development of language skills (Amato Jr, Barrow, & Domingo, 1999; Charman et al., 1998; Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998; Mundy, Sigman, & Kasari, 1990; Rogers, 1999; Smith & Bryson, 1994). For example, JA and motor imitation skills were predictive of future language abilities in children with ASD (Bono, Daley, & Sigman, 2004; Charman et al., 2003; Dawson et al., 2004; McDuffie, Yoder, & Stone, 2005; Murray et al., 2008; Stone, Ousley, & Littleford, 1997; Toth, Munson, Meltzoff, & Dawson, 2006). Similarly, functional and symbolic play have been linked to receptive and expressive language abilities in ASD (Mundy, 1987; Sigman & Ruskin, 1999). Given these developmental links, it is imperative that interventions targeting communication skills in ASD also promote precursors of language including JA, play, and motor imitation.

Current autism interventions can be classified into two types – communication interventions that primarily facilitate speech or provide children with alternative modes of communication and holistic interventions that facilitate language and related skills such as JA, play, and motor imitation (Delprato, 2001; Paul & Sutherland, 2005). Communication interventions include contemporary behavioral interventions (Hart & Risley, 1968; Lovaas, 1987; Lovaas, 2003; McGee, Krantz, Mason, & McClannahan, 1983) based on principles of applied behavioral analysis (ABA) as well as augmentative and alternative communication strategies such as sign language training (Sundberg & Partington, 1998), pictorial communication systems (Bondy & Frost, 2003), and voice output communication aids (VOCAs) (Paul & Sutherland, 2005). Contemporary ABA interventions use stimuli centered on the child's interests to promote spoken language using repeated practice and reinforcement within naturalistic environments (Delprato, 2001; Goldstein, 2002; Rogers & Vismara, 2008). In contrast, alternative and augmentative interventions such as sign language training and

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Picture Exchange Communication System (PECS) provide children with non-vocal means for communication (Paul, 2008). For example, the PECS approach teaches children to request and comment using pictures (Bondy & Frost, 2003, Charlop-Christy, Carpenter, Le, LeBlanc, & Kellet, 2002). Lastly, VOCAs are high-tech electronic devices that allow the child to type a response or select a picture that triggers a spoken output generated by a device with speech synthesis capacity (Paul & Sutherland, 2005). In contrast to communication-based interventions, holistic interventions including developmental pragmatic approaches such as Floortime (Wieder & Greenspan, 2003), the Denver Model (Rogers, Herbison, Lewis, Pantone, & Reis, 1986), and Social Communication, Emotional Regulation and Transactional Support (Prizant, Wetherby, Rubin, Laurent, & Rydell, 2006) aim to facilitate the full range of developmental skills including eye contact, gestures, imitation, play, shared affect, vocalization, and speech within naturalistic settings, to mimic the typical developmental sequence of language acquisition (Landa, 2007; Paul & Sutherland, 2005; Rogers & Vismara, 2008). Overall, several contemporary treatment approaches have been used to facilitate communication skills in children with ASD.

Recently, there has been growing research on the use of novel interventions such as rhythm and robotic therapies to facilitate communication skills in autism (Diehl, Schmitt, Villano, & Crowell, 2012; Srinivasan & Bhat, 2013). Novel interventions differ from conventional therapies as they tap into children’s inherent strengths and predilections, thereby making sessions enjoyable and motivating for children. Readers may review our first manuscript from this mini-series for a detailed review of research to-date on music-based and robotic therapies in children with ASD. Although ideologically appealing in terms of their potential positive outcomes, the evidence supporting the use of music-based and robotic therapies is preliminary in nature. In the current study, we tried to systematically address these limitations in the literature by comparing the effects of novel, whole-body, rhythm and robotic therapies to a standard-of-care intervention in 36 children with ASD between 5 and 12 years. The rhythm therapy group engaged in imitation- based music and movement activities based on several musical elements including rhythm, melody, and phrasing. The robot therapy group engaged in whole-body imitation games with multiple robots. The comparison group engaged in sedentary tabletop activities focused on academic and communication skills, to mimic the types of activities children with ASD typically receive in school-based therapy sessions. Given the lack of previous RCTs on this topic, we were unsure of the treatment outcomes; at the very least, we aimed to demonstrate non-inferiority of the rhythm and robotic interventions compared to the standard-of-care intervention. We had three main research aims: (1) to identify *group differences* in verbalization patterns; we hypothesized that the rhythm and robotic contexts would elicit similar or greater levels of social verbalization compared to the comparison group, (2) to examine *intervention-related changes* in communication skills; we expected all groups to improve social verbalization skills on the standardized and training-specific measures following training, and (3) to assess *activity-related differences* in verbalization patterns. In each group, children practiced imitation-based games within different activities. We hypothesized that activities that facilitated social interactions and/or singing without additional motor demands would elicit greater social verbalization than activities that required children to imitate gross and fine motor actions of their social partners.

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2. Method

2. 1. Participants

Thirty-six children with ASD (32 Males and 4 Females, 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)) were recruited for the study. **Readers may refer to our first manuscript in this mini-series for details on recruitment procedures, enrollment criteria, and eligibility assessment**. Following enrollment in the study, children were matched on age bands (4–5, 6–7, 8–9, 10–12 years), level of functioning, and amount of prior services, and then randomly allocated to the rhythm, robotic, or comparison group with twelve children per group (see Figure 1). Children participated in the study following written parental consent as approved by the Institutional Review Board at xxxx.

2. 2. Study Procedure

Our study was conducted over 10 weeks, with the pretest and the posttest sessions conducted during the first and the last weeks of the study, respectively. The training was provided over the intermediate 8 weeks, with 4 sessions conducted each week (2 expert trainer sessions and 2 parent sessions) for a total of 32 sessions. Each expert training session involved a triadic context consisting of the trainer, an adult model, and the child. Details of the expert and parent training sessions have been reported in our first manuscript.

2. 3. Testing Protocol

The testing protocol consisted of a standardized test of communication skills administered by a novel examiner in the pretest and posttest as well as training-specific measures of verbal communication skills.

2. 3. 1. Standardized test of Joint Attention (JTAT) (Bean & Eigsti, 2012)—The standardized test of joint attention (JTAT) assesses responsive verbal and non-verbal communication skills of children and has been used as an outcome measure in both manuscripts in this mini-series. Readers should refer to our first manuscript for details on the various items, administration, and scoring procedures of the JTAT measure. Three children (i.e.; one per group) did not cooperate during the JTAT measure so data are being reported for 11 children per group (see Figure 1).

2. 3. 2. Training-specific measure of response to social bids—In terms of training-specific measures, we coded children's responses to a set of custom-developed structured social bids and the overall duration of vocalization/verbalization that children engaged in during an early, mid, and late training session. Specifically, we coded children's responses to three standard questions per session i.e. social bids, asked by the adult model in all groups during an early (session 2), mid (session 7), and late (session 15) session. In each session, we examined children's response to three bids - one pertaining to their daily routine, one pertaining to their favorite item, and one testing their factual knowledge (see Table 1). In case children did not respond to the bid, the adult prompted them by providing two choices for each question and using pictures to assist them. We coded for the total number of words that the children used to respond to each social bid. We calculated a total word count by

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summing the number of words children used to respond to all three bids within each session. Social bids were not administered to two children due to their lack of cooperation on the given day (see Figure 1). A single coder coded the data after establishing intra-rater and inter-rater reliability of > 90% using 20% of the data.

2. 3. 3. Training-specific measure of vocalization/verbalization patterns—We coded for the total duration of children's vocalization/verbalization during an early (session 1), mid (session 8), and late (session 16) training session in each group using custom video coding software called OpenSHAPA (GitHub Inc.). We coded for the duration of vocalization/verbalization in two rounds. First, we coded the percent duration of time within each session that children spent vocalizing/verbalizing *to their social partners* (to the trainer, model), *to themselves* (bouts not directed towards social partners including instances of squealing, giggling, whining, echolalia, and unclear word approximations), and *to the robot* (applicable only in the robot group). Next, we further coded each bout of social verbalization as being either *spontaneous* (initiated by the child without external prompting or bidding) or *responsive* (initiated by the child in response to bids, questions, or comments by adult partners) in nature. A single coder coded all videos after establishing intra- and inter-rater reliability of greater than 90% using 20% of the dataset.

2. 4. Training Protocol

Children were randomly assigned to the rhythm, robot, or comparison groups. Our first aim was to compare movement-based interventions with the standard-of-care treatment provided to children with ASD. Therefore, the rhythm and robot groups engaged in whole-body synchrony and imitation-based games, whereas the comparison group engaged in sedentary activities focused on academic and communication skills that are typically used in ABA-based treatment sessions. Moreover, to compare human-delivered versus robot-delivered interventions, we developed similar activities in the rhythm and robot groups, with the important distinction that the rhythm therapy was delivered by a human trainer and the robotic therapy was delivered by the robot trainer, while keeping treatment contact time similar across groups. Although we refer to our music and movement-based activity group as the rhythm group, we acknowledge that this group uses multiple elements of music such as rhythm, melody, and phrasing (see details of training elements in the first manuscript). We would also like to clarify that rhythm therapy used in this study was delivered by physical therapists and not by certified music therapists. Further details of the training protocol can be found in our first manuscript of this mini-series.

2. 5. Statistical Analysis

We checked our data for assumptions of parametric statistics including normal distribution and homogeneity of variances. As discussed in the first manuscript, data from the standardized JTAT test satisfied all assumptions of parametric statistics and we used dependent *t*-tests to assess within-group changes in these data. The training – specific measure of total word count on the social bids also satisfied all assumptions of parametric statistics. Hence, repeated measures ANOVA with Session (early, mid, and late) as the within-subjects factor and Group as a between-subjects factor was conducted. For the training-specific measure of percent duration of vocalization/verbalization, the analysis

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revealed that the data were not normally distributed. Hence, a square root transformation was applied to the dependent variable and two analyses were conducted on the transformed data. First, to assess group differences in types of verbalization, repeated measures ANCOVA was conducted with Verbalization target (social partners, self, robot) and Session (early, mid, late) as the within-subjects factors and Group as the between-subjects factor. Duration of children's verbalization to social partners in the early session was added as a covariate in this analysis to control for baseline differences in social verbalization across groups. Next, to assess the nature of social verbalization and training-related changes in verbalization, repeated measures ANCOVA was conducted with Social partner target (trainer, model), Verbalization type (spontaneous, responsive), Session (early, mid, late), and Activity type (all activities within each 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) as the within-subjects factors, Group as the between-subjects factor, and level of social verbalization in the early session as the covariate. In case of violations of the Mauchly's test of sphericity, Greenhouse Geisser corrections were applied. If there was a significant main effect and an interaction involving the same factor, post-hoc *t*-tests were conducted to evaluate the significant interactions only. In case of significant 2-way and 3-way interactions involving the same factors, the 3-way interactions were analyzed further using post-hoc *t*-tests. Effect sizes are reported using the partial eta-squared (η_p^2) and standardized mean difference (SMD) values (calculated 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 $p \leq 0.05$.

3. Results

3. 1. Generalized changes in the JTAT

There were no between-group differences in terms of JTAT performance. However, both, the rhythm and the comparison group increased their total response scores from the pretest to the posttest. Specifically, nine out of eleven children in the two groups improved their scores. In the robot group, there were no significant improvements on the total response scores between the pretest and the posttest. Readers should refer to the first manuscript in this series for statistical details on our JTAT findings.

3. 2. Training-specific changes in response to social bids

The repeated measures ANOVA indicated a significant effect of session ($F(2, 62) = 4.76$, $p = 0.012$, $\eta_p^2 = 0.13$) and a significant session x group interaction ($F(4, 62) = 3.11$, $p = 0.021$, $\eta_p^2 = 0.17$). Post-hoc analysis of the session x group interaction indicated that the rhythm group showed an increase in total word count from the early to late and mid to late sessions (see Table 2, p values < 0.03, SMD (Early to late) = 1.18, CI (SMD) = 0.19 to 2.16; SMD (Mid to late) = 1.67, CI (SMD) = 0.46 to 2.87). Individual data suggest that 7 out of 10 children followed the group trends. The other two groups did not demonstrate training-related improvements (Table 2).

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3. 3. Training-specific changes in vocalization/verbalization patterns

3. 3. 1. Group differences in vocalization/verbalization patterns—The first repeated measures ANCOVA indicated a significant effect of verbalization target (F(1.27, 40.71) = 48.53, p< 0.001, η_p^2= 0.60) and a verbalization target x group interaction (F(4, 64) = 4.35, p = 0.004, η_p^2= 0.21). Post-hoc analysis of the verbalization target x group interaction is reported below as between-group differences and within-group changes.

Between-group differences: Irrespective of session, the robot group engaged in greater self-directed vocalization compared to the rhythm and comparison groups (see Figure 2A, p values < 0.002, range of SMD values = 0.75 to 0.76). The comparison group engaged in greater social verbalization compared to the robot group (see Figure 2A, p = 0.001, SMD = 0.78). There were no significant differences between social verbalization in the rhythm and comparison groups.

Within-group changes: Irrespective of session, children in the rhythm and comparison groups engaged in greater social compared to self-directed vocalization/verbalization (see Figure 2A, p values < 0.001, range of SMD values = 0.67 to 1.07). Children in the robot group spent least time talking to the robot compared to other targets (see Figure 2A, p values < 0.001, range of SMD values = 1.10 to 1.14).

3. 3. 2. Group differences in verbalization to social partners—The second repeated measures ANCOVA indicated a significant main effect of session (F(2, 66) = 15.98, p< 0.001, η_p^2= 0.33), activity type (F(3.03, 96.90) = 6.62, p< 0.001, η_p^2= 0.17), and verbalization type (F(1, 32) = 11.09, p = 0.002, η_p^2= 0.26), as well as significant interaction effects of activity type x group (F(8, 128) = 12.45, p< 0.001, η_p^2= 0.46), social partner target x group (F(2, 32) = 8.75, p< 0.001, η_p^2= 0.35), verbalization type x group (F(2, 32) = 12.44, p< 0.001, η_p^2= 0.44), social partner target x verbalization type (F(1, 32) = 5.05, p = 0.032, η_p^2= 0.14), session x social partner target x group (F(4, 64) = 3.47, p = 0.013, η_p^2= 0.18), activity type x social partner target x group (F(8, 128) = 8.86, p< 0.001, η_p^2= 0.36), and activity type x verbalization type x group (F(8, 128) = 2.71, p = 0.009, η_p^2= 0.15). We analyzed the three meaningful interactions of: i) verbalization type x group, ii) session x social partner target x group, and iii) activity type x social partner target x group using post-hoc t tests. We report results as between-group differences and within-group changes.

Between-group differences: Irrespective of session and activity type, the rhythm and comparison groups engaged in greater spontaneous social verbalization compared to the robot group (see Figure 2B, p values < 0.03, range of SMD values = 0.51 to 0.61). The comparison group also engaged in greater duration of responsive social verbalization compared to the other two groups (see Figure 2B, p values < 0.001, range of SMD values = 0.99 to 1.07). In terms of social partner targets, the robot group spent greater time talking to the model compared to the rhythm group in the mid and late sessions (see Table 3, p values < 0.04, range of SMD values = 0.87 to 0.90). In contrast, the comparison group spent greater time talking to the trainer during the early, mid, and late sessions compared to the robot group (see Table 3, p values < 0.02, range of SMD values = 1.03 to 1.17).

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Within-group changes: The **rhythm** group verbalized more with the trainer compared to the model across all 3 sessions (see Figure 3A, p values < 0.02, range of SMD values = 0.65 to 0.78). In terms of training-related changes, children showed an increase in verbalization to the trainer in the late compared to the early session (see Table 3, $p = 0.02$, SMD = 1.43, CI (SMD) = 0.47 to 2.38). Specifically, 11 out of 12 children followed this group trend. In terms of activity type-related differences, the social interaction phase and the action song afforded the highest levels of social verbalization compared to the other activities (see Figure 3A, p values range from 0.006 to < 0.001).

In the **robot** group, in all 3 sessions, children showed no significant differences in the amount of verbalization to the trainer and the model (see Figure 3B). In terms of changes with training, children showed an increase in verbalization to the model from the early to the mid session and from the early to the late session (see Table 3, p values ≤ 0.009, SMD for early to mid session = 1.18, CI (SMD) = 0.32 to 2.05; SMD for early to late session = 2.86, CI (SMD) = 1.28 to 4.43). Overall, 11 out of 12 children showed improvements from the early to the mid-session and 12 out of 12 children improved from the early to the late session. In terms of activity type-related differences, the social interaction phase afforded highest levels of verbalization compared to the other activities (see Figure 3B, p values range from 0.03 to < 0.001).

In the **comparison** group, in all 3 sessions, children verbalized more with the trainer compared to the model (see Figure 3C, p values < 0.002, range of SMD values = 1.01 to 1.28). There were no training-related improvements in verbalization to the trainer or the model (see Table 3). In terms of activity type-related differences, the social interaction phase, reading, and cleanup activities afforded the highest levels of social verbalization (see Figure 3C, p values range from 0.03 to < 0.001).

4. Discussion

4. 1. Summary of results

In this second manuscript from a two-part series on attention and verbalization outcomes, we report the effects of 8-weeks of rhythm, robotic, and standard-of-care interventions on the spontaneous and responsive verbal communication skills of children with ASD. In terms of *group differences*, the robot group engaged in greater self-directed vocalization compared to the other groups, whereas the comparison group engaged in greater social verbalization compared to the robot group. While the rhythm and comparison groups spent greater time engaged in social compared to self-directed vocalization, in the robot group, there were no such differences seen. Moreover, children spent least time talking to the robot during training sessions. *In terms of verbalization type*, the rhythm and comparison groups spontaneously initiated conversations for longer durations compared to the robot group. The comparison group also had higher levels of responsive social verbalization compared to the other groups. In terms of *training-related changes*, the rhythm and comparison groups improved on the standardized test of communication skills from the pretest to the posttest. Within the training context, only the rhythm group improved responses to standardized social bids from the early to the late session. Moreover, after controlling for baseline levels of social verbalization, the rhythm and robot groups increased social verbalization levels

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across sessions. In terms of *activity type-related differences*, activities that focused on social interactions and/or singing without concurrent motor demands afforded greater verbalization in all groups.

4. 2. Group differences in vocalization/verbalization patterns

The comparison group showed greater social verbalization compared to the robot group but not the rhythm group. We hypothesized that social verbalization in the movement groups would at the very least be comparable to that seen in the comparison group. Conventionally, tabletop activities have been used in school settings to facilitate verbal communication skills in children with ASD (Goldstein, 2002; Paul & Sutherland, 2005). Therefore to mimic these settings, the comparison group was confined to the table, which provided adults with multiple opportunities to engage in reciprocal conversations with children, possibly contributing to high levels of social verbalization. In contrast, the rhythm and robot groups engaged in whole-body movement-based games. The unconstrained nature of the contexts, the novelty of the training activities, and the presence of background music, may have made it harder to engage in frequent conversations. However, since the training activities were enjoyable and capitalized on children’s intrinsic strengths, we expected these contexts to afford high levels of shared engagement and spontaneous communication between children and their social partners. The rhythm group followed our expectations and engaged in levels of social verbalization comparable to the comparison group. Our findings fit with evidence from a comprehensive review that suggests that child-led activities within unconfined play-based settings are more effective in promoting language skills compared to adult-selected activities within highly structured and confined table-top settings (Delprato, 2001). Moreover, interventions promoting developmental skills such as motor imitation, play, and JA led to collateral increases in language skills in children with ASD (Ingersoll & Schreibman, 2006; Jones, Carr, & Feeley, 2006; Kasari, Freeman, & Paparella, 2006; Kasari, Paparella, Freeman, & Jahromi, 2008). When children engaged in co-constructed and synchronous activities with their social partners, a state of joint engagement was created, which in turn promoted verbal communication skills over sessions (Ingersoll & Schreibman, 2006; Kasari et al., 2008). Along these lines, the movement groups were designed to promote joint engagement through imitation and interpersonal synchrony-based games, and across training sessions, the rhythm group may have progressively increased spontaneous verbal communication and shared their enjoyment with social partners.

The significantly lower levels of social verbalization in the robot group compared to the comparison group could be due to the limitations of the robotic technology including limited preprogrammed verbiage, time lag associated with online speech capacities, and unclear, synthetic speech quality of the robot. The ability of the robot to foster verbal communication relies heavily on the contingent nature of the robot’s interactions (Feil-Seifer & Mataric, 2008); limitations in this regard may have restricted the robot’s ability to effectively mediate reciprocal social interactions in our study. A few other studies have also compared the effects of a human versus robot mediator on the communication skills of children with ASD (Anzalone et al., 2014; Duquette, Michaud, & Mercier, 2008; Huskens, Verschuur, Gillesen, Didden, & Barakova, 2013; Kim et al., 2013; Wainer et al., 2014). For example, children engaged in greater utterances towards an adult confederate during a single session with a

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robot partner compared to a human partner within a triadic context involving the child, the adult confederate, and the interaction partner (Kim et al., 2013). More in lines with our findings, Duquette et al. (2008) demonstrated that children showed better verbal imitation abilities with a human mediator compared to a robot mediator. Similarly, children with ASD demonstrated greater collaborative and cooperative behaviors with a human compared to a robot (Wainer et al., 2014). While a majority of the previous studies reported positive effects following a single session of robot-child interactions (Anzalone et al., 2014; Huskens et al., 2013; Kim et al., 2013), we found that repeated interactions with robots failed to sustain children's engagement, thereby possibly limiting the social verbalization afforded by this context.

The robot group also engaged in greater self-directed, non-functional vocalization compared to the other groups including stereotypic speech, scripting, echolalia, squealing, and whining during several activities perhaps due to the progressive boredom with the training context. Along these lines, stereotypic behaviors were noticed during robot-child interactions in a different study, probably due to the limited and repetitive nature of the robot's movements that were less varied than biological movements (Robins, Dautenhahn, & Dubowski, 2005). Our findings also fit with attention data reported in our first manuscript in this series, where children demonstrated an increase in attention towards elsewhere in the room and progressively decreasing attention towards the robot. Overall, both attention and verbalization data from this study call for the development of adaptive and dynamically contingent robots that can provide a variety of diverse naturalistic interactions to sustain children's engagement across multiple sessions.

The comparison group engaged in significantly greater levels of responsive verbalization compared to the other groups. Trainers had greater opportunities to engage verbally with children, for example, questioning them about the book they were reading, asking them to make choices about supplies, etc. thereby eliciting responsive verbalization. **Sedentary contents have shown to increase responsive compared to spontaneous communication in children with ASD as reported in our first paper as well as in work done by others** (Kasari et al., 2006; Schreibman, 1997; Vismara & Rogers, 2010; Whalen & Schreibman, 2003). In contrast, in the movement groups, children continuously engaged in imitation games to the beat of music, thereby limiting trainer-initiated verbalization and affording greater spontaneous child-initiated conversation. We are currently in the process of coding trainer and model behaviors to systematically assess the impact of trainer/model verbalization on the verbalization patterns of children with ASD

4. 3. Training-related changes in verbalization patterns of the rhythm group

The rhythm group demonstrated significant improvements on the standardized and training-specific measures of communication skills. Given the dearth of literature on the effects of rhythm therapies in children with ASD, we have drawn upon evidence on the positive effects of music therapies delivered by certified music therapists in children with ASD, to provide support to our findings. Our findings fit with several previous musical intervention studies that were conducted to facilitate communication skills in children with ASD (Buday, 1995; Edgerton, 1994; Farmer, 2003; Gattino, dos Santos Riesgo, Longob, Leite, & Faccini, 2011;

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Lim & Draper, 2011; Lim, 2010; Simpson & Keen, 2011; Tindell, 2010; Wan et al., 2011; Whipple, 2004; Wimpory & Nash, 1999). For example, following improvisational music therapy for 10 weeks, children with ASD demonstrated improvements in both musical and non-musical communicative behaviors including speech production (Edgerton, 1994). In fact, a Cochrane meta-analysis suggested that short-term **music therapy** interventions led to small to moderate size improvements in verbal and non-verbal communication skills in children with ASD (Geretsegger, Elefant, Mössler, & Gold, 2014). Music-based activities within socially embedded contexts have the potential to produce collateral improvements in speech in children with and without disabilities possibly due to the shared neural substrates underlying speech and music as well as commonalities in the structure and processing of linguistic and musical inputs (Besson, Schön, Moreno, Santos, & Magne, 2007; Butzlaff, 2000; Chan, Ho, & Cheung, 1998; Forgeard, Winner, Norton, & Schlaug, 2008; Ho, Cheung, & Chan, 2003; Meyer, Alter, Friederici, Lohmann, & Von Cramon, 2002; Srinivasan & Bhat, 2013; Wan & Schlaug, 2010). We observed that across sessions, children learned and spontaneously sang the songs practiced in the sessions. They also increased their rapport with their adult partners and initiated conversations with them. In addition to capitalizing on the links between musical training and language production, our intervention may have also promoted pre-linguistic correlates of speech such as JA, motor imitation, and play (Ingersoll & Schreibman, 2006; Kasari et al., 2008). As children engaged in play-based music and movement games, they may have learned skills such as turn taking, shared attention, and imitation that are integral to all communicative exchanges. Overall, the rhythm training led to improvements in children's spontaneous and responsive communication skills both within the training context and on a standardized test with a novel tester outside the training context.

4. 4. Training-related changes in verbalization patterns of the robot group

The robot group demonstrated a training-related improvement of large effect size in the amount of social verbalization towards the adult model. In this group, children had greater opportunities to interact with the model compared to the trainer, who was primarily responsible for controlling the robot. We were able to replicate and extend findings from our pilot study that suggested improved spontaneous social verbalization in two children with ASD following a 4-week training protocol with a 7-inch humanoid robot (Srinivasan & Bhat, 2013). Our results also fit with other studies that used humanoid and non-humanoid robots to facilitate verbal communication in children with ASD (Duquette et al., 2008; Hanson et al., 2012; Huskens et al., 2013, Kim et al., 2013; Kozima, Nakagawa, & Yasuda, 2007; Malik, Shamsuddin, Yussof, Miskam, & Hamid, 2013; Shamsuddin et al., 2012; Tanaka & Matsuzoe, 2012;). However, interestingly, only two of these studies provided robot-based training for a prolonged duration (Kozima et al., 2007; Tanaka & Matsuzoe, 2012). For example, in a "care-receiving role," where children with ASD were prompted to teach Nao specific actions and their word labels, children successfully learned new verbs over 6 sessions (Tanaka & Matsuzoe, 2012). Similarly, following 15 play-based interactions with a creature-like robot, Keepon, children with ASD spontaneously approached the robot and initiated conversations with it (Kozima et al., 2007). In spite of improvements on the training-specific measure of social verbalization, the robot group was not able to generalize learned skills to a standardized test outside the training context. Children with ASD typically

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have difficulty generalizing skills to novel situations (Delprato, 2001; Hwang & Hughes, 2000; Kasari, 2002; Vismara & Rogers, 2010). Our own work suggested that imitation training provided during robot-child interactions led to improvements in imitation of robot actions within the training context but did not carry-over to a standardized motor test with a human tester (Srinivasan, Gifford, Bubela, & Bhat, 2013). Similarly, in the current study, children may have faced difficulties in generalizing skills learned during robot-adult-child interactions to contexts devoid of robots. Our comparison of robot-delivered versus human-delivered interventions suggested that human-delivered contexts were superior in promoting social verbalization both within and outside the training context. Therefore, although results in the robot group are promising, we recommend that they be interpreted with caution until future studies can replicate our findings using large sample sizes, rigorous study designs, and well-matched comparison groups.

4. 5. Training-related changes in verbalization patterns for the comparison group

Children in the comparison group did not show improvements on the training-specific measures of verbalization; however, they improved their responsive communication skills on the standardized test from pretest to posttest. Compared to the other groups, the comparison group engaged in higher levels of social verbalization to begin with and maintained these levels across sessions, possibly contributing to a ceiling effect on the training-specific measures. However, since the training was provided within children's naturalistic environments (home/school), it may have facilitated easy carryover of communication skills outside the training context to a standardized test with a novel examiner. Other studies in children with ASD suggest that children can learn social skills within the training context and also generalize learned skills to novel contexts. For example, children with ASD who received a play-based or a JA intervention improved the diversity of their play and their ability to initiate and respond to JA bids respectively, within the training context and also generalized skills to naturalistic interactions with caregivers (Kasari et al., 2006).

4. 6. Activity type-related differences in verbalization patterns for each group

Within each group, we were interested in identifying activities that afforded greatest social verbalization. We hypothesized that children would verbalize more during activities promoting social interactions without added motor demands compared to activities that focused primarily on promoting motor skills. Our hypothesis was based on evidence of deficits in executive functioning and motor performance commonly seen in children with ASD. Children with ASD have impairments in executive functioning including attention shifting and working memory (Hill, 2004; Ozonoff & Jensen, 1999; Ozonoff, Pennington, & Rogers, 2006); therefore, we expected that activities requiring dual tasking, i.e. singing/talking while playing movement games would elicit lower verbalization than activities focused solely on promoting social interactions. Moreover, we expected that children's impairments in executive functioning would be compounded by their gross and fine motor impairments in bilateral coordination, balance, imitation/praxis, visuomotor coordination, and manual dexterity (Bhat, Landa, & Galloway, 2011; Dewey, Cantell, & Crawford, 2007; Fournier, Hass, Naik, Lodha, & Cauraugh, 2010; Ghaziuddin, Butler, Tsai, & Ghaziuddin, 1994; Ghaziuddin & Butler, 1998; Green et al., 2009; Minshew, Sung, Jones, & Furman, 2004; Mostofsky et al., 2006; Provost, Lopez, & Heimerl, 2007). In line with our hypothesis,

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all groups demonstrated greater verbalization during activities that promoted social interactions with minimal concurrent motor demands. For example, children in all groups engaged in conversations with their social partners during the social interaction phase. Furthermore, in the rhythm group, the action song activity involving practice of common nursery rhymes, and in the comparison group, the reading and cleanup activities afforded maximum reciprocal conversations between children and their social partners. During tasks focused on complex gross and fine motor skills, children in all groups seemed to focus on the motor demands of the task at the cost of verbal communication, leading to lower levels of social verbalization.

Clinical implications based on findings from attention and verbalization data —Several interesting insights can be obtained by integrating findings across the two manuscripts reporting attention and verbalization outcomes. Typically, sedentary tabletop activities have been widely used and promoted as ideal contexts to facilitate verbal and non-verbal communication skills in children with ASD. However, our pilot RCT suggests that socially embedded movement games that capitalize on children's predilections also provide excellent opportunities to promote sustained social attention and spontaneous verbal communication in children with ASD. Given their inherent focus on imitation and interpersonal synchrony, movement-based activities afford high levels of social attention. Although to begin with such contexts may afford low levels of verbalization probably due to the novelty and dual task demands associated with the training activities, over time, these enjoyable and child-preferred activities afford increased shared attention and verbal communication with social partners. Specifically, music and movement-based activities provide multiple opportunities for children to spontaneously initiate verbal and non-verbal communicative bids with adult partners. On the other hand, sedentary standard-of-care activities are a favorable context for adults to engage in conversations with children, thereby affording high levels of verbal communication from the outset. However, given the easy access to objects in this context, such activities afford greater object-based engagement. In order to redirect the children's focus to their social partners, the adult trainers had to frequently prompt the children; hence, such contexts primarily afford responsive forms of social attention and verbalization. Since children with ASD have more profound impairments in spontaneous compared to responsive communication, our study calls for the inclusion of more creative and enjoyable movement-based interventions in the standard-of-care for autism.

Our social attention and verbalization data both suggest that the robotic technology used in this study had several drawbacks thereby limiting the improvements in social communication skills afforded by robot-delivered contexts compared to human-delivered contexts. The slower and relatively restricted motor repertoire, limited preprogrammed verbiage, synthetic voice quality that made the verbiage difficult to comprehend, and control systems that allowed only partial autonomy of the robot may have contributed to the limited sustenance of engagement with this context. There is a clear need for development and testing of more sophisticated, autonomous robot control technologies in large samples of children with ASD. Recently, virtual robots have been used to assess and systematically manipulate critical characteristics that will influence the future design of real-world robots

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(Welsh, Lahiri, Warren, & Sarkar, 2010). However, until the development of long-term, engaging, and functionally relevant robot-child interaction paradigms, we recommend that robots be used as adjunctive tools for short-term training in ASD. Our study also highlights the differences in trainability of social attention and verbalization skills following an 8-week behavioral intervention in children with ASD. Although we found improvements in the duration of social verbalization during sessions across weeks, there were no improvements in the training-specific measure of social attention. This suggests that although short-term behavioral interventions may be able to facilitate verbal communication skills in children with ASD, more intense and prolonged interventions are required to produce robust improvements in social attention skills of children. Our study also suggests that clinicians will need to employ different types of activities to facilitate social attention versus verbal communication in children with ASD. Imitation and interpersonal synchrony-based movement games can facilitate social attention, as children frequently check-back with social partners whilst attempting to synchronize actions with them. In contrast, activities that solely focus on social interactions without competing motor demands seem to primarily enhance verbal communication with partners. Therefore, we strongly recommend clinicians to include training activities involving singing, action songs, and focused face-to-face interactions as well as activities involving imitation and synchrony-based movement games within their therapy sessions. An optimal combination of such activities would be important to promote verbal and non-verbal communication skills in children with ASD.

4. 6. Limitations

Our pilot RCT involving 36 subjects was meant to serve as a feasibility test for a larger efficacy trial in the future. Therefore, we acknowledge that the effect sizes reported in this study are imprecise with large confidence intervals (Leon, Davis, & Kraemer, 2014). Moreover, this proof-of-concept was meant to provide foundational evidence for the potential benefits of rhythm and robotic interventions in ASD; we acknowledge that we did not tightly control and systematically manipulate individual elements of music (pitch, melody, etc.) and robotic (animate, inanimate, humanoid, mobile) therapies. This could be the focus of future work in these areas. In this study, we included children with autism severity levels ranging from 1–3 within a broad age range of 5 to 12 years, which might have been a source of variability in the study. Moreover, some children (at severity level 1) did not cooperate; therefore we do not have data from the entire sample for some of the outcome measures reported in this study. In terms of study design, we assessed the effects of a relatively short, 8-week period of training on children's communication skills. We did not conduct follow-up testing to evaluate carry-over effects of training. Although we used the state-of-the-art Nao robot, we employed the commonly used Wizard-of-Oz paradigm to control robot behaviors. Currently, there is growing evidence that closed loop systems that afford autonomous robot behaviors can promote naturalistic, real-time, contingent robot-child interactions that may be more engaging for children with ASD (Bekele et al., 2014; Liu, Conn, Sarkar, & Stone, 2008; Wainer et al., 2014). In terms of data coding, coders of the training-specific measures were not blind to the grouping of the children. Moreover, in this paper, we only reported data on the duration of verbalization; currently, we are in the process of evaluating changes in rates of verbalization within groups. We are also currently coding trainer and model behaviors to understand the effects of trainer/model verbalization on children's social verbalization skills. Although we investigated the effects of rhythm therapy on verbal and non-verbal communication skills in ASD, given the limited literature in this field, we have drawn upon evidence from music therapy studies to support our findings. Therefore, we strongly recommend that future studies should replicate the results of this pilot study with larger and more homogeneous samples, longer training durations, and follow-up testing measures.

4. 7. Conclusions

We compared the effects of novel rhythm and robotic interventions with those of a standard-of-care comparison intervention on the verbal communication skills of children with ASD. We found that the comparison context afforded higher levels of social verbalization to begin with. However, children in the rhythm and robot groups increased levels of social verbalization over training sessions. In fact the rhythm group also generalized learned skills to a standardized test conducted outside the training context with a novel examiner. To summarize, our work reported in this 2-part manuscript series suggests that movement-based interventions, especially rhythm therapy, is engaging for children with ASD, and can serve as a promising tool to promote sustained social monitoring and spontaneous verbal communication in this population. Clinicians should consider adding music and movement-based active play activities to the standard-of-care treatment of children with ASD.

Acknowledgments

We would like to thank all the children and families who participated in the study. We thank Dr. Deborah Fein and her students Lauren Haisley and Dasal Jashar for their support of this research through completion of the ADOS for the participating children. We thank Linda Neelly for her help and expertise in developing the rhythm intervention. We thank Christian Wanamaker for help with programming the robots used in this study. We thank Dr. Kerry Marsh for her contributions during the early stages of this project. We would also like to thank graduate students Maninderjit Kaur and Isabel Park as well as undergraduate students, Chaitali Korgaonkar, Caitlyn Sousa, Emily Passera, Christina O'Hara, Margaret Reiss, Lyly Tran, Kathleen Lynch, Carolyn Susca, Sean Walsh, Debbie Lee, Cassondra Hunter, Tracy Sooklall, Caitlyn Metsack, Jenna Shaw, and Joanna Sajdlowska for help with data collections, data coding, and data analyses. This manuscript was prepared as a part of the doctoral dissertation of the first author. Lastly, AB thanks the National Institutes of Mental Health (NIMH) for support of this research through awards 5R21MH089441-02, 4R33MH089441-03, and the Autism Speaks foundation for grant support through a pilot treatment award # 8137.

Glossary

ASD	Autism Spectrum Disorder
TD	Typically developing
JA	Joint Attention
RCT	Randomized Controlled Trial
JTAT	Joint Attention Test
ABA	Applied Behavioral Analysis
TEACCH	Treatment and Education of Autistic and related Communication-Handicapped Children

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VOCAs	Voice Communication Aids
PECS	Picture Exchange Communication System
VABS	Vineland Adaptive Behavior Scales
ADOS-2	Autism Diagnostic Observation Schedule, 2nd edition
SMD	Standardized Mean Difference
CI	Confidence Intervals
CONSORT	Consolidated Standards of Reporting Trials

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Highlights

- Assessment of effects of movement interventions on communication skills in autism
- Rhythm and robot groups improved social verbalization with training
- Standard-of-care contexts afford responsive communication skills
- Whole body rhythmic activities promote spontaneous initiation of communication
- Movement interventions can promote verbal and non-verbal communication in children with autism

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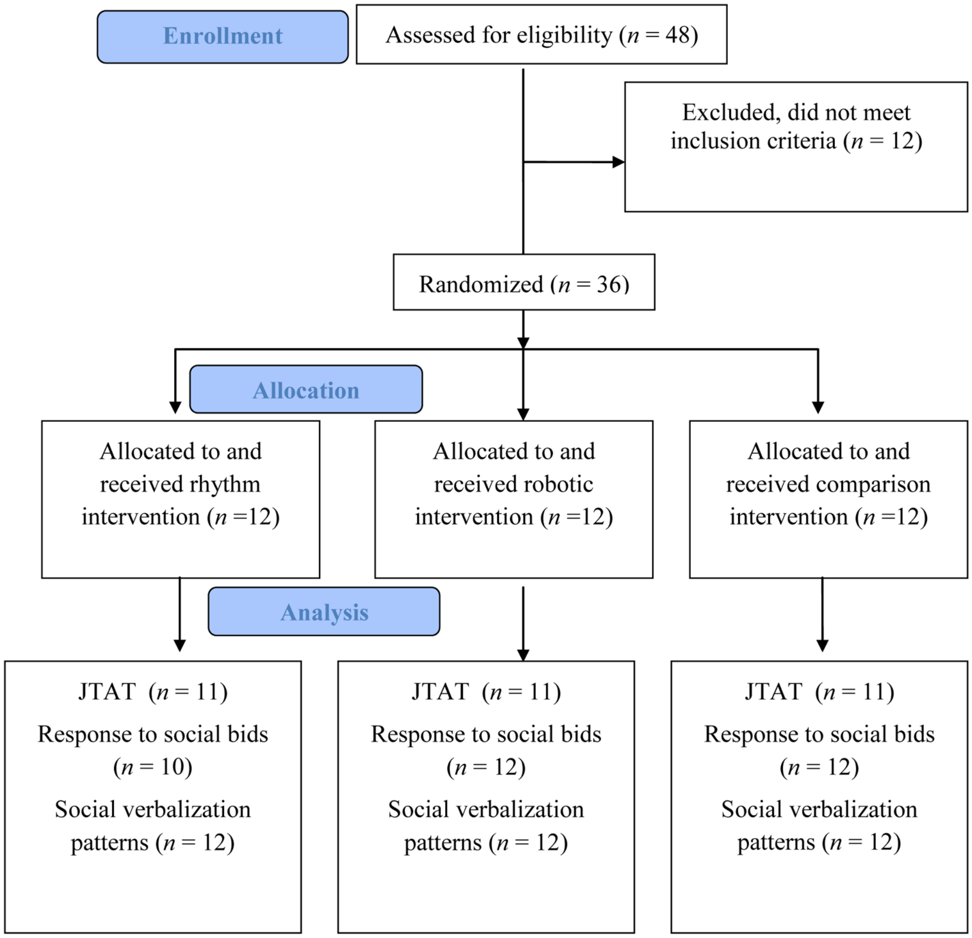

Figure 1.
Flow diagram describing participant enrollment and treatment allocation using Consolidated Standards of Reporting Trials (CONSORT) guidelines

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Figure 2A

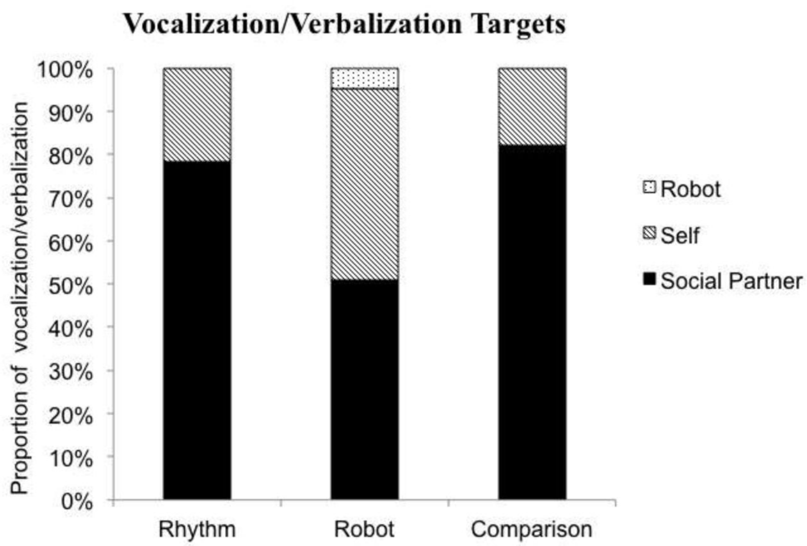
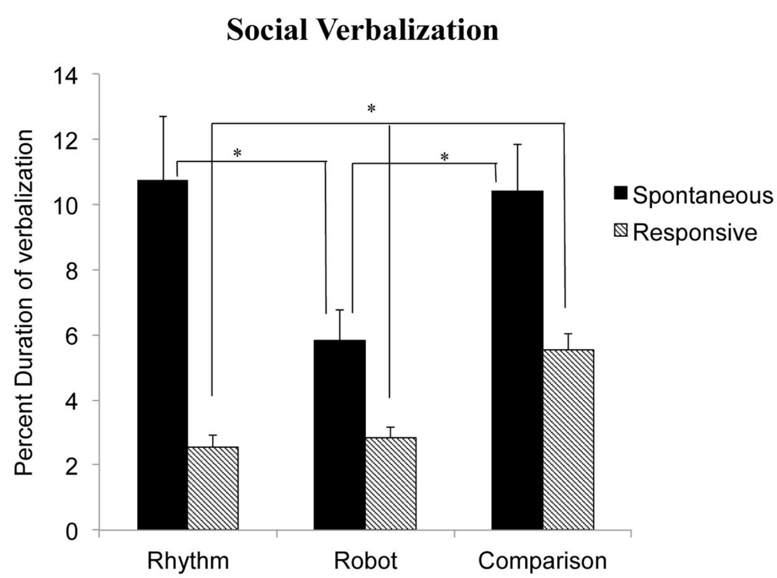


Figure 2B



*$p \leq 0.05$

Figure 2.

Figure 2A: Group differences in vocalization/verbalization to social partners, self, and robot

Figure 2B: Group differences in spontaneous and responsive social verbalization

Figure 3A

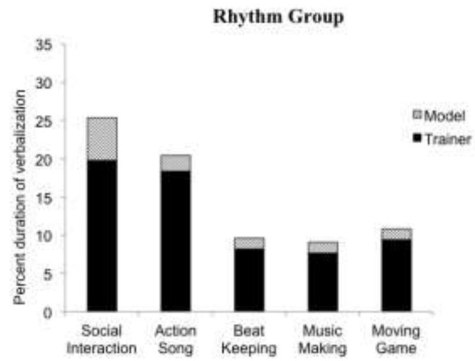


Figure 3B

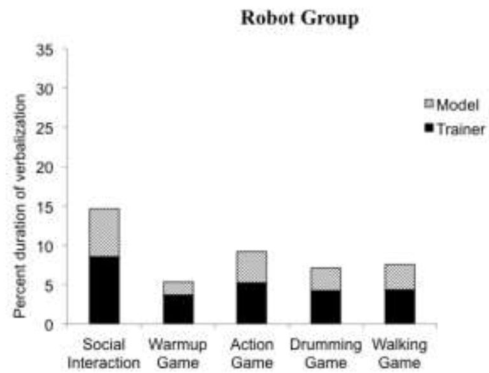


Figure 3Cp

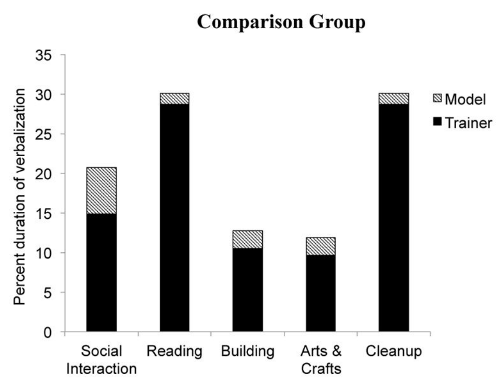


Figure 3.

Figure 3A: Activity-related differences in social verbalization in the Rhythm group

Figure 3B: Activity-related differences in social verbalization in the Robot group

Figure 3C: Activity-related differences in social verbalization in the Comparison group

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Table 1

Social bids administered in training sessions

Session	Early	Mid	Late
Social Bid 1 (Daily routine)	What did you eat for breakfast?	What did you eat for lunch?	What did you eat for dinner?
Social Bid 2 (Favorite item)	What is your favorite food?	What is your favorite vegetable?	What is your favorite snack?
Social Bid 3 (Factual knowledge)	Can you show me a circle? What looks like a circle?	Can you show me your hands? What do you use your hands for?	Where do people go swimming? To the beach or to the pool?

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Table 2

Total word count of responses to standard social bids

Group	Early (M(SD))	Mid (M(SD))	Late (M(SD))
Rhythm	4.4(4.19) * (E vs. L)	3.8(3.29) * (M vs. L)	9.8(8.53)
Robot	5.92(7.04)	7.25(6.74)	7.67(7.60)
Comparison	4.5(3.90)	7.33(8.81)	5.67(4.16)

* $p < 0.05$, E vs. L = early versus late session, M vs. L = mid versus late session

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Table 3

Duration of social verbalization to the trainer and model across sessions

Session	Rhythm Group Percent Duration M(SD)		Robot Group Percent Duration M(SD)		Comparison Group Percent Duration M(SD)	
	Trainer	***Model***	***Trainer***	***Model***	***Trainer***	***Model***
Early	6.1 (5.7)	2.1 (2.3)	3.9 (4.2)	1.9 (1.1)	12.1 (8.6)[a] (C vs. R)	2.0 (1.6)
Mid	12.8 (14.5)	1.8 (1.9)	5.1 (5.3)	3.4 (1.7)[b, b a](R vs. Rh) [b](E vs. M)	14.5 (11.3)[a] (C vs. R)	2.2 (1.9)
Late	14.8 (15.0)[b] (E vs. L)	2.2 (2.3)	6.3 (6.1)	5.4 (4.2)[a, b a](R vs. Rh) [b](E vs. L)	14.4 (8.6)[a] (C vs. R)	2.6 (2.4)

E = early, M = mid, L = late; R = robot group, Rh = rhythm group, C = comparison group;

[a]Between-group differences significant at $p < 0.05$;

[b]Within-group differences significant at $p < 0.05$.