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Embodied Rhythm Interventions for Children with Autism Spectrum Disorders (ASDs)

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Embodied Rhythm Interventions for Children with Autism Spectrum Disorders (ASDs)

Sudha Madhav Srinivasan, PhD

University of Connecticut, 2014

Abstract

The current randomized controlled trial compared the effects of novel, embodied, rhythm interventions - music and robotic - with those of a standard-of-care, stationary, academic intervention on the social communication, behavioral, and motor skills of 36 children with Autism Spectrum Disorders (ASDs) between 5 and 12 years of age. Children were matched on age, level of functioning, and services received prior to randomization. The study lasted for 10 weeks with the pretest and posttest sessions conducted during the first and last weeks of the study. Training was provided in the intermediate 8 weeks, with 2 sessions provided each week. Between-group differences and within-group changes in social attention and social verbalization skills, repetitive/problem behaviors, and motor performance were assessed using task-specific tests within the training context and standardized tests outside the training context. The music-based context afforded greater social monitoring and spontaneous initiation of engagement compared to the robotic and academic contexts. The robotic context promoted fixation on robots and greater scripting and self-directed vocalizations, limiting opportunities for interactions with social partners. Due to the novelty of the training activities, the movement groups initially demonstrated greater negative behaviors compared to the academic group. Although the academic group afforded responsive verbalization, children spent a majority of time in non-social object-based engagement. In terms of task-specific training effects, the music group showed an increase in duration of social verbalization and reductions in imitation error scores and frequency of negative behaviors across weeks. Although the robot group demonstrated small improvements in imitation scores, children demonstrated a decrease in engagement with the context across training sessions. The academic group improved their fine motor imitation scores, but did not demonstrate any changes in social attention, social verbalization, and repetitive behaviors across sessions. In terms of generalized changes in skills, the music and academic

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groups demonstrated improvements in responsive joint attention following training. Consistent with training demands, the movement groups improved gross motor skills, whereas the academic group improved fine motor skills, on a standardized test of motor performance. Overall, movement-based music contexts hold promise in remediating the impairments associated with autism and warrant future investigation.

Embodied Rhythm Interventions for Children with Autism Spectrum Disorders (ASDs)

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A Dissertation

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APPROVAL PAGE

Doctor of Philosophy Dissertation

Embodied Rhythm Interventions for Children with Autism Spectrum Disorders (ASDs)

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Chapter 1

Autism Spectrum Disorders: An overview of impairments and current therapy approaches

1.1. Core impairments in Autism Spectrum Disorders

Autism Spectrum Disorders (ASDs) are a group of neurological disorders characterized by impairments in social communication skills as well as the presence of stereotyped and repetitive behaviors and interests (American Psychiatric Association, 2013). Recent prevalence estimates suggest that 1 in every 68 children is diagnosed with ASDs (Baio, 2014). Children with autism demonstrate impairments in social skills such as poor social and emotional reciprocity, reduced eye contact, reduced sharing of interests with social partners, difficulty initiating interactions with others, difficulties in turn taking within social exchanges, and difficulties forming stable long-term relationships (Bryson et al., 2007; Charman et al., 1998; Dawson et al., 2004; Jones & Carr, 2004; Mundy & Crowson, 1997; Yoder, Stone, Walden, & Malesa, 2009). Communication impairments in autism typically involve the lack of or a delay in the acquisition of language, difficulties in initiating and sustaining conversations with social partners, idiosyncratic use of language, and impaired non-verbal communication skills (Gernsbacher, Stevenson, Khandakar, & Goldsmith, 2008; Paul & Sutherland, 2005; Tager-Flusberg, Paul, & Lord, 1997). In addition, the presence of repetitive and stereotypical behaviors is a hallmark of autism; children with ASDs demonstrate repetitive manipulations of objects, stereotypical behaviors such as flapping of hands, twisting of the body, and compulsive behaviors such as insistence on adherence to fixed routines and rituals as well as highly circumscribed interests (Bodfish, Symons, Parker, & Lewis, 2000; Boyd, McDonough, & Bodfish, 2012; Leekam, Uljarevic, & Prior, 2011). In addition to these core impairments, children may demonstrate several behavioral and emotional problems including anxiety, aggression, depression, non-compliance, pica, hyperactivity, temper tantrums, and/or self-injurious behaviors (Bodfish et al., 2000; Didden, Duker, & Korzilius, 1997; Horner, Carr, Strain, Todd, & Reed, 2002; Lecavalier, 2006; Loh et al., 2007; Mazefsky, Pelphrey, & Dahl, 2012).

1.2. Perceptuo-motor impairments in Autism Spectrum Disorders

In recent times, growing evidence has emerged for the presence of additional perceptuo-motor impairments in children with autism (Bhat, Landa, & Galloway, 2011; Downey & Rapport, 2012; Fournier, Hass, Naik, Lodha, & Cauraugh, 2010; Lloyd, MacDonald, & Lord, 2013). Interestingly, the earliest indicators of autism risk in infants under 1 year of age are delays and abnormalities in motor development rather than impairments in the core deficit areas (Esposito & Venuti, 2009; Flanagan, Landa, Bhat, & Bauman, 2012; Teitelbaum, Teitelbaum, Nye, Fryman, & Maurer, 1998). Children with autism demonstrate significant and pervasive impairments in gross and fine motor skills (Ghaziuddin, Butler, Tsai, & Ghaziuddin, 1994; Ghaziuddin & Butler, 1998; Jansiewicz et al., 2006; Sacrey, Germani, Bryson, & Zwaigenbaum, 2014), dual and multi-limb coordination (Fournier et al., 2010; Green et al., 2009; Isenhower et al., 2012; Marsh et al., 2013), imitation and praxis skills (Dewey, Cantell, & Crawford, 2007; Mostofsky et al., 2006; Rogers, Hepburn, Stackhouse, & Wehner, 2003; Rogers, Bennetto, McEvoy, & Pennington, 1996; Smith & Bryson, 2007; Smith & Bryson, 1998), postural control (Minshew, Sung, Jones, & Furman, 2004), gait (Hallett et al., 1993; Rinehart et al., 2006b; Vilensky, Damasio, & Maurer, 1981), and balance (Freitag, Kleser, Schneider, & von Gontard, 2007; Jansiewicz et al., 2006). The presence of motor impairments has cascading effects on the socio-emotional, communication, behavioral, and cognitive development of children with autism (Bhat et al., 2011; Leary & Hill, 1996; Nickel, Thatcher, & Iverson, 2010). Specifically, perceptuo-motor skills provide children with ample opportunities for both environmental exploration and participation in meaningful socio-communicative exchanges with caregivers and peers. Developmentally, early infant-caregiver interactions, within which social communication skills such as joint attention, turn-taking, and language are learnt, necessarily involve movements such as showing, pointing, and reaching (Bhat et al., 2011; Gernsbacher, Sauer, Geye, Schweigert, & Hill Goldsmith, 2008). Given this evidence, it is possible that motor clumsiness, a reduced movement repertoire, as well as difficulties in movement planning, initiation and sustenance may in fact underlie the social awkwardness and communication difficulties encountered

in autism (Bhat et al., 2011; Leary & Hill, 1996; Nickel et al., 2010). Overall, the above evidence suggests that there is a dire need for multisystem interventions that address the perceptuo-motor, social communication, and behavioral impairments of children with ASDs.

1.3. Traditional and contemporary interventions for Autism Spectrum Disorders

Interventions for individuals with ASDs can be broadly grouped into traditional Applied Behavioral Analysis (ABA) approaches, contemporary ABA approaches, developmental/pragmatic approaches, and complementary approaches (Landa, 2007). Traditional ABA approaches, commonly referred to as Discrete Trial Training (DTT), are highly structured, adult-led interventions based on principles of operant conditioning (Granpeesheh, Tarbox, & Dixon, 2009; Howlin, Magiati, & Charman, 2009; Lovaas, 1987; Matson, Benavidez, Stabinsky Compton, Paclawskyj, & Baglio, 1996; Matson et al., 2012). The therapist identifies target behaviors as well as their antecedents (environmental events that precede the behavior) and consequences (events that follow the behavior). By manipulating the antecedent-behavior-consequence chain, the therapist either increases or decreases the chances of the target behavior in the future (Delprato, 2001; Goldstein, 2002). Although DTT is successful in teaching children new behaviors by providing blocks of massed trials, this approach is limited by a lack of generalization of learned behaviors to novel contexts involving novel people, and by difficulties in promoting spontaneous behaviors in children with ASDs (Ingersoll, 2008; Landa, 2007; Vismara & Rogers, 2010). Contemporary ABA interventions have tried to address the limitations in traditional ABA approaches by centering therapeutic activities around the interests of the child, embedding learning opportunities within naturalistic interactions, and promoting spontaneous initiation of behaviors by children with ASDs (Rogers, 2006; Vismara & Rogers, 2010). Some of the common naturalistic interactions based on ABA principles include incidental teaching (Hart & Risley, 1968; McGee, Morrier, & Daly, 1999), Pivotal Response Therapy (Koegel & Koegel, 1995; Schreibman & Pierce, 1993), and milieu teaching (Yoder & Stone, 2006). The third set of treatment approaches, developmental and pragmatic approaches, provide children with developmentally appropriate experiences to mimic the types

of learning opportunities that typically developing (TD) children receive (Rogers, 2006; Yoder & McDuffie, 2008). For this purpose, learning is emphasized during multiple occasions within the daily routine. The onus is on creating a reciprocal relationship between the child and the therapist to promote shared attention and shared affective experiences during play-based activities involving joint action (Landa, 2007; Vismara & Rogers, 2010). Some of the common developmental approaches include Floortime (Greenspan & Wieder, 1997), the Denver model (Rogers & Dawson, 2010), Reciprocal Imitation Training (RIT) (Ingersoll & Schreibman, 2006), and Social Communication, Emotional Regulation and Transactional Support (SCERTS) (Prizant, Wetherby, Rubin, Laurent, & Rydell, 2006).

In addition to mainstream treatments for autism, there are several complementary therapies that have been used for the treatment of children with ASDs including sensory-motor interventions such as sensory integration therapies (Baranek, 2002), Treatment and Education of Autistic and related Communication-handicapped Children (TEACCH) (Mesibov, Shea, & Schopler, 2004), augmentative and alternative communication systems (Paul & Sutherland, 2005, Bondy & Frost, 2003), and social skills interventions (Reichow & Volkmar, 2010; Wang & Spillane, 2009). Picture Exchange Communication System (PECS) (Bondy & Frost, 2003), is a type of augmentative and alternative communication system which is commonly used to promote functional communication in children with autism. The PECS approach is a picture-based system based on ABA principles to teach non-verbal or low-verbal children with ASDs a mode of communication. Children are taught to initiate requests and describe their environment using pictures. The goal is to eventually use pictures to construct sentences and comment on environmental events; it is expected that there will be carry-over to improved verbal communication abilities (Bondy & Frost, 2003; Charlop-Christy, Carpenter, Le, LeBlanc, & Kellet, 2002). Another commonly used complementary approach for children with ASDs is TEACHH (Mesibov et al., 2004). The TEACHH program emphasizes strategies for structuring the environment, including minimizing environmental distractions, having a set schedule for the day, use of visual cues, and ensuring consistency in the environment and the people involved in the training, all of which promote learning of new skills

(Mesibov et al., 2004). Although the treatment approaches outlined above are commonly delivered by teachers or clinicians, there has been an increasing shift towards involving parents and peers in intervention programs to promote easy generalization of learned skills to interactions involving children and their parents/peers (Laushey & Heflin, 2000; Meadan, Ostrosky, Zaghlawan, & Yu, 2009; Rocha, Schreibman, & Stahmer, 2007; Rogers, 2000). To summarize, several approaches exist for remediating the core social communication and behavioral impairments in ASDs.

1.4. Need for diversification of autism interventions

A majority of the interventions discussed above focus primarily on remediating the core social communication impairments in ASDs and promoting preacademic skills in this population. However, given the growing body of literature on perceptuo-motor impairments in ASDs, there is a pressing need for diversifying current autism interventions. Specifically, given the potential cascading effects of motor impairments on social, communication, and cognitive skills discussed previously, it is critical to develop movement-based interventions that focus on the motor issues of children and adolescents with ASDs. We argue that socially-embedded movement interventions have the potential for facilitating not only motor but also social communication development in children with ASDs. In the current study, we evaluated the effects of two novel multisystem rhythm interventions, music and robotic, on the social communication, behavioral, and motor impairments of children with ASDs.

Chapter 2

Novel embodied interventions for children with Autism Spectrum Disorders

2.1. Need for novel interventions for Autism Spectrum Disorders

Recently, there has been a growing interest in exploring the effects of novel therapy tools for children and adolescents with ASDs. As discussed previously, ASDs are lifelong multisystem disorders with impairments in social communication, cognitive, behavioral, and motor domains. The focus of current research efforts is on developing comprehensive yet motivating and engaging interventions that can address the multisystem needs of this population. The emphasis is on harnessing the strengths and predilections of children with autism within therapy programs to ensure adherence to treatment and to maximize learning. Two promising approaches that have attracted considerable research include music and robotic therapies. Research suggests that children with ASDs find music enjoyable and intrinsically motivating, and there is similar evidence suggesting that they find it easier to interact with robots than with human therapists, since robots are simpler and more predictable entities. Briefly outlined below are the rationale and evidence for the use of music and robotic therapies in the treatment of children with ASDs.

2.2. Embodied music interventions for children with ASDs

Music-based therapies form about 12% of all autism interventions and 45% of all alternative treatment strategies used within school settings (Hess, Morrier, Heflin, & Ivey, 2008; Simpson et al., 2005). Music-based interventions are particularly attractive for individuals with ASDs for several reasons. First, children with ASDs find musical activities enjoyable, perhaps due to their enhanced musical understanding (Heaton, 2003). In fact children with autism have enhanced pitch perception abilities compared to typically developing children, for instance, enhanced pitch memory, pitch labeling (Heaton, 2003), and pitch discrimination skills (Bonnell, Mottron, Peretz, Trudel, & Gallun, 2003). Therefore, clinicians and special educators often use music-based activities in school settings to engage children with

ASDs (Hess et al., 2008). Second, music-based activities can be made comfortable and non-intimidating experiences, where a child with ASD is encouraged to spontaneously explore various musical instruments, with the trainer joining in and copying the child's actions as a means of creating reciprocation of interaction. Children with ASDs have difficulties with direct social engagement; hence, socially embedded group musical activities provide excellent opportunities for children with autism to engage in predictable interactions with their social partners (Allgood, 2003; Darrow & Armstrong, 1999). Third, the critical elements of all musical interactions involve singing, listening, music-making, and synchronized movements to music. Hence, group-based musical experiences naturally entail joint action, turn taking, social reciprocity, social monitoring, as well as verbal and nonverbal communication between individuals (Overy & Molnar-Szakacs, 2009; Srinivasan & Bhat, 2013). Since these are the very skills that are impaired in autism, we argue that music and movement activities have the potential to address the various core autism impairments in joint attention, social reciprocity, and nonverbal and verbal communication, as well as remediate the secondary impairments in multisensory perception, motor performance, and behavioral skills seen in this population (Srinivasan & Bhat, 2013).

Music-based contexts can promote communication, socio-emotional, behavioral, and motor skills in individuals with ASDs. In terms of communication skills, music and language are structurally similar in that they are both hierarchically arranged with lower level units such as notes/syllables forming higher-level units such as chords/words (Molnar & Overy, 2006). Moreover, both music and language use spatial notation (notes and letters) and recruit memory and attentional processes (Foxton et al., 2003; Patel, Peretz, Tramo, & Labreque, 1998). These similarities between music and language allow for an easy transfer of skills from the former to the latter (Tallal & Gaab, 2006). When children engage in music-making or singing in dyadic, triadic, or group contexts, the shared experience of making music helps foster social connections and leads to a shared affective experience within the group (Kirschner & Tomasello, 2010; Marsh, Richardson, & Schmidt, 2009; Overy & Molnar-Szakacs, 2009). Musical interactions begin by imitating the actions of others, but over time children begin to understand the

affective states and intentions of others (Overy & Molnar-Szakacs, 2009). Hence, these contexts are a good medium to promote skills such as joint attention, imitation, and empathy, which are particularly impaired in children with ASDs (Koelsch, 2009; Overy & Molnar-Szakacs, 2009; Srinivasan & Bhat, 2013). Moreover, the enjoyable and non-intimidating nature of the interaction can help provide structure, improve compliance, and reduce problem behaviors in individuals with ASDs (Boso, Emanuele, Minazzi, Abbamonte, & Politi, 2007). Lastly, music offers a great context to practice rhythmic movements such as marching, clapping, skipping, and galloping, and therefore provides opportunities to promote gross motor skills in children (Derri, Tsapakidou, Zachopoulou, & Kioumourtzoglou, 2001; Zachopoulou, Tsapakidou, & Derri, 2004; Zachopoulou, Bakle, & Deli, 2006). Rhythm underlies all musical experiences as well as human movements. Hence, movements practiced to the beat of music have the potential of improving children's sense of timing and their ability to coordinate their bodies smoothly and flexibly in space (Zachopoulou et al., 2004). Moreover, group-based play activities to the beat of music can enhance children's ability to synchronize their movements in time and space with those of their social partners (Marsh et al., 2009). Similarly, engaging in music-making using instruments such as drums, piano, guitar, etc. provides opportunities to promote fine motor and motor sequencing/praxis skills of children (Costa-Giomi, 2005; Srinivasan & Bhat, 2013). Overall, music is a powerful tool with the potential to promote, within engaging and motivating interactions, the very skills that are lacking in autism.

Current music therapy approaches that have commonly been used in children with autism or children with other developmental disabilities such as dyslexia, apraxia, and intellectual disabilities include auditory motor mapping training (AMMT) (Wan et al., 2011), melodic intonation therapy (MIT) (Norton, Zipse, Marchina, & Schlaug, 2009; Roper, 2003), rhythm training (Overy, 2008), and improvisational music therapy (Kim, Wigram, & Gold, 2008; Kim, Wigram, & Gold, 2009). In both AMMT and MIT, language production is facilitated in non-verbal/low-verbal children by training an association between self-produced sounds (drum hit or finger tap) and articulatory movements, thereby facilitating auditory-motor

mapping (Carroll, 1996; Norton et al., 2009; Roper, 2003; Wan et al., 2011). For example, in AMMT the child progresses from listening to the therapist singing and tapping a pair of tuned drums to unison singing and music-making. The goal is to ultimately encourage the child to articulate words independently (Wan et al., 2011). These approaches have been used to facilitate speech in children with autism (Wan et al., 2011) and apraxia (Norton et al., 2009; Roper, 2003). Rhythm training has been used to address the timing deficits in language, motor control, perception, and cognition encountered in children with dyslexia (Overy, 2008). It has been suggested that multisensory experiences involving singing and rhythmic games might promote auditory and motor timing skills, and subsequently language skills, in children with dyslexia (Overy, 2008). Lastly, improvisational music therapy is an individualized, person-centered approach that has been used to facilitate social engagement and verbal and non-verbal communication skills in children with ASDs (Kim et al., 2008; Kim et al., 2009). In this approach, the therapist uses improvised, shared music-making experiences to tune in to the child's musical and non-musical expressive behaviors. Such moment-to-moment musical attunement of the therapist to the patient helps develop a medium of communication between the two, which in turn facilitates social skills such as turn taking, imitation, and joint attention as well as verbal communication skills (Kim et al., 2008; Kim et al., 2009). Overall, the above evidence suggests that music-based rhythm interventions seem to be a feasible tool to remediate the core social communication and secondary perceptuo-motor impairments associated with ASDs (Srinivasan & Bhat, 2013).

2.3. Embodied robotic interventions for children with ASDs

Assistive robotics is a field that promotes the use of robots as aids for humans, with recent expansion into the area of neurorehabilitation (Feil-Seifer & Mataric, 2005). Specifically, socially assistive robots assist special populations through social interactions that do not involve physical contact (Feil-Seifer & Mataric, 2008). Socially assistive robots have been used as therapeutic tools to develop socially directed behaviors in children with ASDs (Cabibihan, Javed, Ang Jr, & Aljunied, 2013; Diehl, Schmitt, Villano, & Crowell, 2011). Robots could be engaging entities for children with ASDs for several reasons. First, children with

ASDs demonstrate considerable affinity for mechanical objects and are intrinsically more motivated to engage in electronic or robotic technology compared to humans (Robins, Dautenhahn, & Dubowski, 2006). Second, in contrast to interactions with humans, which children find very distressing as a result of having to simultaneously process multiple inputs through speech, gestures, intonation, and facial expressions, interactions with robots are simple and predictable (Billard, Robbins, Nadel, & Dautenhahn, 2007). In fact the complexity of robotic interactions can be systematically controlled and increased as children become accustomed to the context (Dautenhahn et al., 2009; Dautenhahn & Werry, 2004). Third, there is evidence to suggest that even very low-functioning children with ASDs who otherwise do not engage in social interactions with humans, demonstrate more proactive social behaviors during robot-child interactions (Feil-Seifer & Mataric, 2008; Robins, Dautenhahn, Te Boekhorst, & Billard, 2005). Lastly, the robot can be programmed to provide individualized and incremental therapy for children with ASDs (Dautenhahn & Werry, 2004; Scassellati, 2007). Within dyadic interactions involving the robot and the child, the robot is perceived as a novel, semi-social stimulus, and children spontaneously look at the robot, touch the robot, vocalize towards the robot, and also spontaneously copy its actions (Duquette, Michaud, & Mercier, 2008; Robins, Dickerson, Stribling, & Dautenhahn, 2004; Scassellati, Admoni, & Mataric, 2012). Further, when these interactions are expanded to involve another human - an adult clinician or a peer - the robot can be used as a catalyst for verbal and non-verbal interactions involving turn-taking, shared attention, shared affect, and reciprocal conversations between children and their social partners (Feil-Seifer & Mataric, 2009; Robins et al., 2005; Srinivasan & Bhat, 2013). Lastly, robot-child interactions can be used to promote motor skills such as bilateral coordination and imitation in children with ASDs (Kaur, Gifford, Marsh, & Bhat, 2013; Srinivasan, Gifford, Bubela, & Bhat, 2013). Overall, embodied robot-based interactions seem to be promising and motivating contexts to facilitate social communication and motor skills in children with ASDs.

Several research groups have used robots in different roles during their interactions with children with ASDs. Specifically, robots have been used to elicit target behaviors, as tools to model/ teach/ practice

several skills, and to provide feedback and reinforcement for children's behaviors (Diehl et al., 2011). For example, robots have been used to elicit prosocial behaviors including joint attention, verbal responses, and shared enjoyment between children and their social partners (Dautenhahn et al., 2009; Kim et al., 2013; Kozima, Nakagawa, & Yasuda, 2007; Robins et al., 2004; Warren et al., 2013). In their role of eliciting target behaviors, robots can provide a structured hierarchy of prompts involving gaze shift, head turn, pointing, verbalization, and target activation to elicit joint attention, i.e. instances where the child and the robot jointly look at objects in the environment (Warren et al., 2013). Similarly, in triadic interactions involving the robot, the child, and an adult or peer, the robot can become a focus of shared attention between people, and children may spontaneously share their interest regarding the robot with their social partners (Kozima et al., 2007; Robins et al., 2004; Robins et al., 2005). Moreover, children also spontaneously demonstrate empathetic behaviors towards the robot during the course of repeated interactions (Kozima et al., 2007). In its role as a "model social agent", the robot models target behaviors which the child can subsequently imitate (Dautenhahn, 2003). In the same vein, the robot could function as a "social crutch", prompting children to practice social behaviors within the predictable and less demanding environment of robot-child interactions, before generalizing skills to a novel context involving people (Scassellati, 2007; Tapus, Mataric, & Scasselati, 2007). Using this approach, robots have been used to teach children with ASDs imitation of body movements within repeated sessions (Duquette et al., 2008). Lastly, robots have been used to provide feedback or encouragement to children with ASDs (Diehl et al., 2011). For example, within triadic interactions, the robot could be a facilitator/ mediator of interactions between the children and their peers or adult therapists (Dautenhahn, 2003). In this context, the robot encourages the child to interact with the other social partners in the room (Dautenhahn, 2003). Similarly, robots have also been used to provide encouragement to children, thus enhancing their motivation to proceed with the target behavior (Duquette et al., 2008). Overall, there is preliminary encouraging evidence for the use of robots to promote critical social communication skills in children with ASDs.

Although both music and robotic interventions seem to be appealing therapy tools for children with autism, the research to date on these therapies has been largely anecdotal and limited in many respects. A majority of the studies in both fields involved very small sample sizes and used case study designs. Moreover, studies frequently did not use standardized measures for group characterization or for quantifying targeted outcomes. Given the variability in symptoms across the autism spectrum, it is imperative that studies use standardized tests such as the Autism Diagnostic Observation Schedule, 2nd edition (ADOS-2) (Lord, Rutter, DiLavore, Risi, Gotham, & Bishop, 2012) to confirm diagnosis, and measures such as the Stanford Binet Test of Intelligence (SBIT) (Becker, 2003) to assess IQ levels of participants. It is surprising that both bodies of literature lack studies with large sample sizes that examine the effects of music and robotic therapies in comparison to the standard-of-care for autism. Without such studies, it is difficult to make definitive claims about the potential utility and efficacy of music and robotic interventions for children with autism. Moreover, there is great variability in terms of the outcomes assessed following music-based or robotic interactions, and a majority of the studies have not used standardized tests to assess generalization and carry-over of learned skills to novel contexts during follow-up assessments. In spite of the overwhelming evidence on perceptuo-motor impairments in autism, interestingly, there are no studies to date that have systematically assessed the effects of music- and robot-based interactions on overall gross and fine motor performance of children with ASDs. Although studies employing music therapies provided interventions for relatively long periods of time, a majority of the studies that used robot-child interventions assessed treatment effects over only a few sessions. Most of these studies were proof-of-concept studies conducted by robotics groups, and literature examining feasibility of using robots as therapy tools for children with autism within clinical settings or naturalistic environments is lacking. Specifically, there is no definitive evidence on whether integrating robots into routine therapy of children with ASDs has any additional benefits for children. Moreover, it is not clear if repeated robotic interactions delivered at the intensity commensurate with standard-of-care interventions are comparable to human-delivered interventions. To examine this question, there is a need for systematic and controlled studies that compare and contrast the effects of prolonged interventions involving robot

and human mediators in autism. To summarize, as a result of the limitations of the existing literature, it is not possible at present to draw firm conclusions and interpret the evidence on efficacy of music and robotic therapies in autism.

Chapter 3

Aims and hypotheses

3.1. Overview of current study

Our study aimed to address some of the previously discussed gaps identified in the literature on music and robotic therapies in autism. We conducted a randomized controlled trial involving 36 children with ASDs between 5 and 12 years of age, and compared the effects of novel, embodied, rhythm interventions - music and robotic - to those of a standard-of-care, stationary, academic intervention. Children were matched on age, level of functioning, and services received, and subsequently randomly assigned to one of three groups - music, robotic, or academic. Our study lasted for 10 weeks, with the pretest and posttest sessions conducted during the first and last weeks of the study respectively. Our training sessions were conducted in the intermediate 8 weeks, with 2 sessions provided each week. We assessed training-related changes in social communication, behavioral, and motor skills using task-specific measures within the training context, as well as standardized tests conducted during the pretest and posttest sessions. Our study design allowed us to compare the effects of novel, movement-based rhythm interventions with those of a standard-of-care, academic intervention in children with ASDs. In addition, within the rhythm interventions, we compared the differential effects of music and robotic therapies on the core impairments of children with ASDs.

All three groups engaged in training activities within a group setting involving the child, the trainer, and an adult model. In the robot group, the 23-inch humanoid robot, Nao, was an added entity in the interaction. The trainer structured the interaction in all three groups, whereas the adult model served as the child's confederate by engaging in all activities with the child. In the movement groups (music and robotic), children engaged in whole-body, gross motor movements; in contrast, in the academic group, children engaged in table-top academic and fine motor activities. In the music group, the human trainer delivered the sessions, whereas in the group receiving robot-assisted training, the robot delivered the

session, and the human trainer controlled the robot with a laptop system. In the music group, children engaged in singing, joint action, as well as imitation and synchrony-based activities to the beat of music within different conditions during each session. Specifically, children engaged in the following conditions within each session – social interaction phase, action song, beat keeping, music making, moving game, and calming song. In the robot group, children engaged in communicative interactions and whole-body imitation games with the robot during the following conditions – social interaction phase, warm up game, action game, drumming game, and walking game. Lastly, in the academic group, children engaged in activities targeted towards improving children’s academic and fine motor skills during the following conditions – social interaction, reading, building using supplies such as Play-Doh® and Lego® blocks, and art-craft activities. In all three groups, we encouraged social communication skills such as greetings and farewell, eye contact, requesting, helping, commenting, use of gestures such as showing and pointing, responding to questions, and turn-taking. The motor targets for the rhythm groups were whole-body imitation and synchrony with social partners, whereas for the academic group, we encouraged fine motor skills such as coloring, drawing, and different types of grips and pinches. An in-depth discussion of the methods of the study is provided in the following chapters.

We assessed the training-related effects of rhythm and academic interventions on the following variables – (1) social attention patterns, (2) verbalization patterns, (3) repetitive and problem behaviors, (4) motor performance and imitation skills. To assess training-related task-specific changes in social attention patterns, we coded the duration of attention children directed towards their social partners during the entire duration of an early (session 1), a mid (session 8), and a late (session 16) session. Along the same lines, to assess task-specific changes in verbalization patterns following training, we coded the duration of social verbalization during the entire length of the early, mid, and late training sessions. To assess generalized changes in social communication skills, we used a modified version of a standardized test, the Joint Attention Test (JTAT) (Bean & Eigsti, 2012) during the pretest and posttest sessions. The JTAT is a valid and reliable measure for assessing joint attention in children with ASDs between 7 and 17 years of

age (Bean & Eigsti, 2012). The JTAT assesses the child's ability to respond to the verbal and gestural cues initiated by the novel tester to direct the child's attention to objects/events in the environment. In terms of repetitive and problem behaviors, we assessed the frequencies of negative/self-injurious, sensory, and stereotyped behaviors during the entire length of the early, mid, and late training sessions. Lastly, for assessing changes in motor skills with training, we examined children's imitation skills using task-specific activities in each group during an early and a late session. In addition, we also assessed changes in motor performance on the gross and fine motor sub-scales of the standardized Bruniniks Oseretsky Test of Motor Proficiency (BOT-2) (Bruininks & Bruininks, 2005), which is a valid and reliable test of motor performance in children and youth between 4 and 21 years of age (Dietz, Kartin, & Kopp, 2007).

3.2. Broad aims and hypotheses of the current study

The broad aims of the study are listed below. The specific aims related to each variable are listed in the following chapters which provide in-depth discussion on each dependent variable.

Aim 1: Between-group context-related differences - To compare differential effects of music, robotic, and standard-of-care academic training on social attention, social verbalization, and repetitive/problem behaviors of children with ASDs.

Hypothesis 1: We expected that the standard-of-care academic training context would afford maximum social attention and social verbalization in children with ASDs. However, the movement groups, music and robotic, would also engage in levels of social attention and socially-directed verbalization that would be comparable to those seen in the academic group. In terms of repetitive/problem behaviors, we expected that children in the academic group would engage in the lowest frequencies of negative/self-injurious behaviors as a result of their familiarity with the context and the constrained nature of the context; instead, we expected these children to engage in greater sensory behaviors with objects due to their proximity to building and art-craft supplies. In contrast, given the novelty of the rhythm interventions and

the unconstrained nature of the context, we expected children in the music and robotic groups to engage in greater negative behaviors in the early training session.

Aim 2: Within-group training-related changes - To assess training-related changes in the music, robotic, and academic groups in social attention and social verbalization skills, repetitive/problem behaviors, imitation skills, and motor performance following 8 weeks of training.

Hypothesis 2: We expected all three groups to demonstrate improvements on the task-specific and generalized measures of social attention, social verbalization, repetitive/problem behaviors, imitation skills, and motor performance.

Aim 3: Within-group condition-related differences - To compare differential effects of the various movement and non-movement-based conditions on social attention skills, social verbalization patterns, and repetitive/problem behaviors within each of the three groups.

Hypothesis 3: In the music group, we expected the movement-based conditions to afford greater social attention and to lead to greater repetitive behaviors. We expected greater social verbalization during conditions that encouraged singing and social interactions without additional motor demands. In the robot group, we expected greater social monitoring and repetitive behaviors during the movement-based conditions that facilitated rhythmic synchrony. In contrast, we expected greater socially-directed verbalization during the non-movement-based social interaction phase. Lastly, in the academic group, we expected greater social attention during the social interaction phase and greater social verbalization during the social interaction and reading conditions. We expected children to engage in greater object-related sensory behaviors during the building and art-craft conditions that encouraged fine motor activities.

3.3. Organization of dissertation

Chapters 1, 2, & 3 provide a general introduction to the dissertation. Specifically, chapter 1 provides an overview of Autism Spectrum Disorders and the current interventions used for children with ASDs.

Chapter 2 discusses the need for novel therapy approaches, with an emphasis on music- and robot-based therapies, for children with autism. Chapter 3 outlines the aims and hypotheses of the current study. Chapters 4, 5, 6, & 7 are written as four separate manuscripts examining the effects of the music, robotic, and academic interventions on our dependent variables of social communication, behavioral, and motor skills. In chapter 4, the effects of music, robotic, and academic interventions on the social attention patterns of children with ASDs are discussed. Chapter 5 discusses the effects of the three interventions on spontaneous and responsive verbalization/vocalization patterns of children. In chapter 6, the effects of the interventions on the repetitive and problem behaviors of children are discussed. In chapter 7, the effects of music, robotic, and academic training on children's imitation skills and overall gross and fine motor performance are discussed. Each of the chapters 4-7 are organized in the form of introduction, methods, results, discussion, clinical implications, limitations, and future directions. Chapter 8 summarizes our work in the form of conclusions and also discusses clinical implications of the current project. Chapter 9 highlights the limitations of the current study and suggests potential future directions for this work.

Chapter 4

The effects of embodied rhythm interventions on the social attention patterns of children with Autism Spectrum Disorders (ASDs)

4. 1. Introduction

4.1.1. Overview of Autism Spectrum Disorders and implications of social attention in autism

According to the recent guidelines published in the Diagnostic and Statistical Manual of Mental Disorders (DSM-V) (American Psychiatric Association, 2013), Autism Spectrum Disorders (ASDs) are characterized by persistent deficits in social communication skills across a variety of contexts and the presence of restricted and repetitive patterns of interests (American Psychiatric Association, 2013). Amongst the social impairments in ASDs, atypical social attention has been identified as one of the key core impairments (Dawson, Bernier, & Ring, 2012). Attentional impairments are manifested in different ways from very early in life in children with autism. Impaired eye contact is a robust impairment that emerges within the first year of life (Adrien et al., 1993; Gillberg et al., 1990; Rogers & DiLalla, 1990; Werner, Dawson, Osterling, & Dinno, 2000; Zwaigenbaum et al., 2005). In addition, other attentional impairments in infancy and early childhood include lack of response to name (Baranek, 1999; Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998; Osterling, Dawson, & Munson, 2002; Zwaigenbaum et al., 2005), lack of interest in social stimuli including faces (Maestro et al., 2002; Ozonoff et al., 2010), poor social initiation skills (Bryson et al., 2007), reduced sharing of interests with caregivers using joint attention bids (Charman et al., 1998; Mundy, Sigman, Ungerer, & Sherman, 1986; Rozga et al., 2011; Yoder et al., 2009), and poor social imitation skills (Bryson et al., 2007; Zwaigenbaum et al., 2005). Early emerging deficits in social orienting and social attention have far reaching cascading effects on the multisystem social, cognitive, and language development of children (Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992; Leppänen & Nelson, 2008; Pascalis et al., 2005; Thiessen & Saffran, 2007). For example, during dyadic interactions with their caregivers, typically developing (TD) infants learn to

attend to and interpret multiple inputs conveyed by caregivers through speech, gestures, facial expressions, and eye gaze (Dawson et al., 2004). Moreover, critical skills such as imitation, turn taking, and social reciprocity, which are integral to all communicative exchanges, are learnt within these early dyadic interactions and have implications for children's abilities to form and sustain future relationships with their social partners (Jones & Carr, 2004; Mundy & Hogan, 1994; Travis, Sigman, & Ruskin, 2001). Lastly, towards the end of the first year, infants broaden their communicative exchanges with caregivers (CGs) to include interesting events and objects within the environment. During episodes of shared attention within such triadic contexts, TD infants typically learn object labels and object affordances (Baldwin, 1995; Baldwin, 1991; Baron-Cohen, 1997; Jones & Carr, 2004; Tomasello & Farrar, 1986; Tomasello, 1992). Thus, the ability to attend to their social partners and shift attention between their CGs and objects in the environment influences infants' social, cognitive, and linguistic development. Given the pervasive nature of the attentional impairments in ASDs and their potential cascading effects, considerable research efforts have been devoted towards understanding the nature of attentional impairments in ASDs and developing early interventions to remediate these impairments.

4.1.2. Social attention impairments in ASDs

Children with ASDs have difficulties in spontaneously orienting to social stimuli (Baranek, 1999; Charman et al., 1998; Dawson et al., 1998; Leekam, Lopez, & Moore, 2000; Osterling et al., 2002; Werner et al., 2000). For example, compared to TD children and children with Down's syndrome, children with ASDs had greater difficulty in visually orienting to social stimuli (name calling and hand clapping) compared to non-social stimuli (rattle and jack-in-the-box) (Dawson et al., 1998). These social orienting impairments are further compounded by children's preference for visual fixation on objects that typically do not afford social interaction. Several studies involving either observation of children within naturalistic settings or laboratory tests of children's reactions to static and dynamic displays of social scenes have suggested that children with ASDs preferentially attend to non-social background stimuli over social stimuli (Ben-Sasson et al., 2007; Bird, Catmur, Silani, Frith, & Frith, 2006; Hutman, Chela, Gillespie-

Lynch, & Sigman, 2012; Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Leekam et al., 2000; Maestro et al., 2005; Shic, Bradshaw, Klin, Scassellati, & Chawarska, 2011; Wilson, Brock, & Palermo, 2010).

Twenty-month-old toddlers with ASDs who watched a video of a play interaction between an adult and a child demonstrated lower attention towards the activities of the people involved and instead devoted greater attention to the background non-social objects such as toys compared to control TD and developmentally delayed (DD) infants (Shic et al., 2011). This fundamental impairment in social orienting and a preference for non-social exploration can alter the developmental trajectory of children with ASDs by depriving them of critical social input that leads to incidental learning (Mundy & Rebecca Neal, 2000). Moreover, other lines of research have suggested that children with ASDs also have problems in disengaging attention in the presence of multiple competing stimuli (Courchesne et al., 1994; Landry & Bryson, 2004). For example, during a visual orienting task where children with ASDs were presented with competing stimuli simultaneously, they had difficulty disengaging attention. In fact, in 20% of the trials, children fixated their attention on one of the competing stimuli for the entire duration of the trial (Landry & Bryson, 2004). Such attentional disengagement impairments may lead to children visually perseverating on salient objects, and this significantly reduces their opportunities to explore their environments (Ben-Sasson et al., 2007). Impaired social orienting and a preferential bias for non-social stimuli on one hand, and difficulties in attentional disengagement on the other, have negative implications for the development of joint attention in children with ASDs (Courchesne, Chisum, & Townsend, 1994; Dawson et al., 1998; Dawson et al., 2004; Leekam & Ramsden, 2006). Joint attention (JA) is the ability to coordinate attention with social partners using eye gaze and gestures, in relation to an interesting object or event in the environment (Bakeman & Adamson, 1984; Mundy et al., 2003). Joint attention involves both the ability to respond to attentional bids initiated by others, often referred to as responding to joint attention (RJA), as well as the ability to direct others' attention towards salient objects by using eye contact and gestures, referred to as initiating joint attention (IJA) (Mundy & Newell, 2007). To engage in shared attention episodes, infants need to orient towards their social partners and subsequently shift attention rapidly between social and non-social stimuli in the environment (Courchesne et al., 1994;

Dawson et al., 1998). Given the nature of the social attentional impairments in ASDs discussed above, children have impaired IJA and RJA skills, which in turn hampers their ability to engage in communicative exchanges with their caregivers and has downstream negative effects on their overall social communication, cognitive, and affective development. In fact, as a consequence of the far-reaching effects of social attention impairments in autism, it has been argued that social attention should be considered an early indicator of efficacy of treatments for autism. Specifically, interventions that can facilitate social attention in children can increase children's opportunities to learn from their social environment, and thus can potentially change the developmental trajectory in children with autism (Dawson et al., 2012).

4.1.3. Traditional interventions for social impairments in ASDs

Traditional interventions that aim at facilitating social skills can broadly be classified into contemporary behavioral interventions, developmental approaches, and social skill interventions. While contemporary behavioral and developmental interventions focus on addressing several impairments in the social, communication and behavioral domains using a comprehensive framework (Vismara & Rogers, 2010), social skill interventions focus on facilitating specific social skills such as turn taking, social initiations, and response to questions (Rao, Beidel, & Murray, 2008; Reichow & Volkmar, 2010). Contemporary behavioral interventions are based on principles of Applied Behavioral Analysis (ABA) which suggest that the consequences of any behavior determine whether the behavior is repeated in the future (Granpeesheh et al., 2009; Lovaas, 1987). Behaviors that are followed by desirable consequences are more likely to be repeated. Contemporary behavioral interventions such as Pivotal Response Therapy (PRT) (Koegel & Koegel, 2006; Schreibman & Koegel, 1996), incidental teaching (McGee et al., 1999), and milieu teaching (Yoder & Stone, 2006) use child-led activities within naturalistic environments to maximize the child's learning. Therapists modify the environment and use natural reinforcers to increase or decrease the frequency of target behaviors (Vismara & Rogers, 2010). For example, peer-mediated PRT was effective in increasing peer interactions, joint attention, play, social initiations, and language

skills demonstrated by two children with ASDs (Pierce & Schreibman, 1995). In contrast to contemporary behavioral interventions where therapy goals are derived based on children's behavioral skills, developmental approaches rely on assessment of children's developmental skills to decide on therapy goals (Vismara & Rogers, 2010). The idea is to provide children with developmentally appropriate experiences during multiple occasions within the daily routine including meal times, family activities, bathing, playtime, etc. (Landa, 2007; Vismara & Rogers, 2010). A few examples of treatment approaches that are considered developmental include the Early Start Denver Model (ESDM) (Rogers & Dawson, 2010), Developmental Individual-Difference, Relationship-Based model (DIR) (Greenspan & Wieder, 1997), and Responsive Teaching (RT) (Mahoney & Perales, 2003; Mahoney & Perales, 2005). For example, a case review involving 200 children with ASDs who received DIR therapy for 2 to 8 years suggested an overall positive response to intervention, with children showing improvements in peer interactions, affective reciprocity, and cognitive skills (Greenspan & Wieder, 1997). Lastly, social skill interventions that focus exclusively on facilitating specific social skills in children and adolescents with ASDs include social skill groups (Krasny, Williams, Provencal, & Ozonoff, 2003; Kroeger, Schultz, & Newsom, 2007), social stories (Gray, 1994; Karkhanavich et al., 2010), Socio-Dramatic Affective-Relational Intervention (SDARI) (Lerner, Mikami, & Levine, 2011), and social skill training (Gresham, 1986; Rao et al., 2008; Rogers, 2000). For example, a social story is a short story that describes a specific situation in terms of relevant social cues and perspectives and also discusses the expected behavioral response in that situation (Gray, 1994). A review based on 6 studies that assessed the effects of social stories on school-aged children with ASDs suggested that 5 out of the 6 studies found greater improvements in social interaction skills of children, including game playing, story comprehension, emotion recognition and labelling, social skills, communication skills, and aggressive behaviors in the social story group compared to the control group (Karkhanavich et al., 2010). Conventionally, all the interventions discussed above are delivered by trained therapists, but there has been a shift towards parent- and peer-mediated interventions in an effort to capitalize on incidental learning opportunities and to enhance generalization of learned skills to naturalistic interactions of children with their caregivers and peers (Rocha et al., 2007; Rogers,

2000; Schreibman & Koegel, 1996). Several empirical studies have suggested positive effects of parent- and peer-mediated interventions on children's social interaction skills (Kamps et al., 2002; Laushey & Heflin, 2000; Meadan et al., 2009; Odom et al., 1999; Rocha et al., 2007; Rogers, 2000; Schertz & Odom, 2007).

4.1.4. Novel interventions for social impairments in ASDs

In addition to the above-mentioned traditional interventions for facilitating social skills in ASDs, in recent times, there has been considerable research on novel interventions, namely music and robotic therapies, for children with ASDs. Previous research has suggested that motivating contexts which promote joint focus of attention between children and their social partners are effective in promoting social engagement and JA (Kasari, Paparella, Freeman, & Jahromi, 2008; Landa, Holman, O'Neill, & Stuart, 2011).

Likewise, by using activities that are engaging and preferable for this population, there is an increased likelihood that within such motivating contexts children will initiate interactions with their social partners and share their enjoyment with them. Both music-based and robotic contexts harness children's strengths and predilections and can be potentially used to remediate the core impairments associated with ASDs.

For example, music appears to be a non-intimidating, predictable, and enjoyable medium for children with autism to interact with their surrounding world (Allgood, 2003; Darrow & Armstrong, 1999). In fact, music-based interventions form up to 12% of all autism interventions and approximately 45% of all alternative treatments for children from pre-kindergarten to 12th grade (Hess et al., 2008). Children with autism have relatively unimpaired music processing skills (Blackstock, 1978; Heaton, 2003). Hence, socially embedded music-making contexts provide great opportunities to promote eye contact, smiling, shared affect, and prosocial behaviors (Overy & Molnar-Szakacs, 2009). Moreover, musical exchanges are similar to social interactions in that they are reciprocal in nature and involve imitation, turn-taking, and shared attention (Overy & Molnar-Szakacs, 2009; Srinivasan & Bhat, 2013). Several studies have therefore used music-based contexts to promote social attention and engagement in children with ASDs (Kern & Aldridge, 2006; Kern, Wolery, & Aldridge, 2007; Kim et al., 2009; Reitman, 2005; Stephens,

2008; Wimpory & Others, 1995). For example, Kim et al., compared the effects of improvisational music therapy with those of toy play using a single subject comparison design and found that the music therapy sessions led to greater initiation of interactions and greater compliant responses compared to toy play sessions (Kim et al., 2009). Similarly, a music-based outdoor play intervention implemented by teachers and peers of 4 children with ASDs, involving individually composed songs, play activities with musical instruments, and singing, led to an increase in peer interactions and meaningful play with peers (Kern & Aldridge, 2006).

Along the same lines, given children's intrinsic interest in technology, robots have been used anecdotally as innovative technology-based treatment tools in autism (Diehl et al., 2011; Robins et al., 2006). It has been proposed that within interactions involving the robot, the child, and a social partner i.e. an adult or peer, the robot could be used as a catalyst to facilitate prosocial behaviors in children with ASDs (Dautenhahn, 2003; Feil-Seifer & Mataric, 2009). Moreover, the robot can direct children's attention to salient events or objects in the environment and can therefore be used to train JA in children with ASDs (Warren et al., 2013). The idea is that children with ASDs find it easy to interact with a robot, an engaging yet predictable entity; hence, robot-child contexts can be used by children to learn and practice social skills with the robot, which can then be transferred to interactions with people (Dautenhahn, 2003; Scassellati, 2007; Tapus et al., 2007). Several groups have provided anecdotal evidence for the use of robots to facilitate social skills such as eye contact and JA in children with ASDs (Costa, Santos, Soares, Ferreira, & Moreira, 2010; DeSilva, Matsumoto, Saito, Lambacher, & Higashi, 2009; Feil-Seifer & Mataric, 2009; François, Powell, & Dautenhahn, 2009; Ismail, Shamsudin, Yussof, Hanapiah, & Zahari, 2012a; Kozima et al., 2007; Pop et al., 2013; Robins et al., 2004; Robins et al., 2005; Stanton, Kahn, Severson, Ruckert, & Gill, 2008; Wainer, Ferrari, Dautenhahn, & Robins, 2010; Warren et al., 2013; Werry, Dautenhahn, Ogden, & Harwin, 2001). For example, a qualitative observation of pairs of children with ASDs interacting with a mobile robot suggested that the robot was a successful mediator of interactions between the two children and between children and the adult therapist (Werry et al., 2001). In

another study, a robot-delivered graded prompting system to elicit JA in 6 children with ASDs for a total of 4 sessions led to an improvement in children's ability to orient to bids delivered by the robot (Warren et al., 2013). Similarly, a comparison of efficacy of social stories delivered via a robot versus a computer display suggested that robotic technology was more effective in promoting social skills compared to the computer-delivered intervention (Pop et al., 2013). Overall, the above evidence suggests that both music and robotic contexts are compelling and promising treatment tools that capitalize on predilections of children with ASDs and can be used to promote social skills in autism.

4.1.5. Rationale for current study and specific aims and hypothesis for social attention

In spite of the promising nature of music and robotic interventions, the current state of the literature in both fields can at best be considered preliminary. Studies assessing the efficacy of music and robotic therapies are limited by their small sample sizes and their study designs. A majority of the studies are case studies and there is a dire need for systematic randomized controlled trials (RCTs) using well-matched control groups and standardized tools to assess treatment efficacy. In this study, we aimed to address these limitations in the literature by conducting an RCT comparing the effects of music and robotic interventions on social communication, behavioral, and motor skills of children with ASDs. Moreover, in an attempt to compare the effects of the two novel interventions with the current standard-of-care treatment for autism, we included an additional academic group in our study. Thirty-six children with ASDs between 5 and 12 years of age were randomly assigned to one of three groups, music, robotic, or academic. Our interventions were provided for 16 sessions delivered over 8 weeks. In the current paper, we restrict our discussion to the effects of the three interventions on the social attention skills of children. The effects of the three interventions on other social communication, behavioral, and motor skills are reported elsewhere. We assessed changes in social attention during a standardized test of RJA and within a task-specific measure of attention patterns during an early, a mid, and a late training session. In the task-specific test, we used behavioral coding to examine changes in the duration of time children spent attending to their social partners (trainer and model/CG), to objects, to elsewhere in the room, and lastly

to the robot (applicable only in the robot group) across training sessions. Given the evidence that children with ASDs have greater impairments in spontaneous initiations compared to responding to the bids initiated by others, we also coded each attention bout that children directed towards their social partners as being either spontaneous (initiated by the child without external prompting) or responsive (produced in response to external prompting) in nature. We were interested in 3 main research aims: (1) identifying context-related differences in attention patterns between groups, (2) assessing for training-related changes in attention patterns within each group, and (3) examining condition-related differences in attention patterns within each group. Typically, ABA-based contexts have been used to promote social skills in children with ASDs (Matson et al., 1996). Specifically, children benefit from the organization and scaffolding afforded by such structured contexts, leading to greater improvements in social attention compared to unstructured contexts (Dawson & Galpert, 1990; Dekylen & Odom, 1989; Kasari, Sigman, & Yirmiya, 1993). Hence, we hypothesized that social attention levels would be highest in the academic group; however, in light of the previously discussed literature on the positive effects of music and robotic therapies on social skills, we expected the movement groups also to have social attention levels comparable to those in the academic group. All three groups promoted social monitoring, turn-taking, imitation, and reciprocal interactions involving verbal and non-verbal communication between children and their social partners. Hence, in terms of training-related changes, we expected that children in all 3 groups would improve their social attention skills within the standardized test as well as the task-specific test of attention. Within each group, children practiced social communication and motor skills during different conditions, and we were interested in examining specific conditions in each group that afforded greater social attention. We expected that conditions which focused on social interactions and promoted rhythmic synchrony and social monitoring would lead to greater social attention, whereas conditions that involved use of objects would lead to greater object-directed attention episodes.

4.2. Methods

4.2.1. Study Procedure

Our study was conducted over 10 weeks. We conducted the pretest and posttest sessions during the first and the last weeks of the study respectively, and the training was provided during the intermediate 8 weeks. We provided training at an intensity of 2 sessions/ week for a total of 16 sessions. Each session lasted for approximately 45 minutes. During each session, an expert trainer and an adult model interacted with the child within a triadic context (see Figures 4-1A, 4-1B, and 4-1C). In the robot group, the robot was an added entity in the interaction. The triadic context provided multiple opportunities for promoting social interactions and communication between children and their social partners. The target social behaviors in all three groups included eye contact, greeting/farewell, turn taking, ready response, and gestural use including showing and pointing. Communication targets included commenting, requesting for help, responding to questions, and word/sentence/song repetition. In the music and robot groups, in addition to the above mentioned social communication targets, we also promoted specific motor skills including balance, coordination, gross and fine motor discrete imitation and praxis, as well as rhythmic synchrony during joint action activities. In the academic group, we promoted fine motor skills such as different types of symmetrical and asymmetrical grips and pinches, coloring, drawing, gluing, and cutting. In addition to the expert training sessions, we encouraged parents in all groups to provide two additional home sessions per week to practice activities that children learnt during the expert sessions. We provided parents with detailed instruction manuals and necessary supplies for the home sessions. In addition, we also conducted in-person training sessions with parents each week to review the supplies and activities for home sessions in that week. We asked parents and expert trainers to maintain a training diary to document details of training sessions including, number of sessions completed, the duration of each session, a list of activities completed, the child's affect during the session, as well as details of activities and skills that children found difficult during each session. All expert sessions were videotaped for behavioral coding of several variables. We encouraged parents to videotape one early and one late home-training session. Out of the 36 children, 15 children missed one expert training session each, due to scheduling conflicts.

We recruited 36 children with ASDs (32 Males and 4 Females) between 5 and 12 years of age ($M (SD) = 7.63(2.24)$) in our study. Children were enrolled in the study following written parental consent as approved by the Institutional Review Board at the University of Connecticut. Children were recruited through online announcements on local websites and fliers distributed to autism schools and early intervention centers. Parents were asked to fill out the Social Communication Questionnaire (SCQ) (Rutter, Bailey, & Lord, 2003) as part of a screening procedure prior to enrollment in the study. The eligibility of children was confirmed using the Autism Diagnostic Observation Schedule, 2nd edition (ADOS-2) (Lord et al., 2012), which is a gold standard assessment for autism diagnosis. We excluded children with additional visual, hearing, cardiovascular, neurological, or orthopedic abnormalities. Participating families fell within the upper-middle to upper socioeconomic classification as described by the Hollingshead scale of socioeconomic status ($M (SD) = 49.18 (10.03)$) (Hollingshead, 1975). Out of the thirty-six families, twenty were Caucasian, six were African American, four were Asian, three were Hispanic, and three were of mixed ethnicity. Following enrollment in the study, children were matched on age, level of functioning, and amount of services received, and then randomly assigned to one of the following three groups – music, robot, or academic. Specifically, we matched children on age bands (4-5, 6-7, 8-9, and 10-12 years) prior to randomization. To estimate children's level of functioning we calculated a composite score based on subjective ratings of children's social communication and motor skills during the pretest session. Specifically, expert testers rated children's pretest performance on a scale of 1 to 4 (1 – extremely low, 2 – low, 3 – moderate, 4 – high) for target social, communication, and motor skills. In addition to ensuring baseline similarity across groups prior to randomization, we also assessed for post-hoc differences between groups on age, gender, and socialization. There were no differences between groups on age (Music: $M (SD) = 7.88(2.56)$; Robot: $M (SD) = 7.52 (2.22)$; Academic: $M (SD) = 7.36(2.02)$, p values > 0.05) and gender (Music: 10 Males, 2 Females; Robot: 11 Males, 1 Female; Academic: 11 Males, 1 Female, $\chi^2 p > 0.05$). Socialization was quantified using the Vineland Adaptive Behavior Scales, 2nd edition (VABS) (Sparrow, Cicchetti, & Balla, 2005), a standardized measure to assess the adaptive functioning level of children (Sparrow et al., 2005). The socialization domain of the

VABS includes 3 sub-domains of interpersonal relationships, play and leisure time skills, and coping skills. Parents were asked to score all items of the socialization domain on a scale of 0 to 2 (0 – never, 1 – sometimes or partially, and 2 – usually) based on the child’s abilities. Out of the 36 families, 33 families filled out the VABS questionnaire (2 families in the music group and 1 family from the robot group did not have VABS data). The three groups did not differ significantly on the socialization domain standard scores of the VABS (Music: $M (SD) = 69.1 (14.72)$; Robot: $M (SD) = 64.18 (16.74)$; Academic: $M (SD) = 74.92 (22.41)$, p values > 0.05).

4.2.2. Testing protocol

We assessed for changes in social attention skills of children within a standardized test for responsive joint attention (RJA) and a task-specific measure for social attention abilities within the training context. Specifically, we assessed children’s abilities to respond to bids for joint attention initiated by a novel tester during the pretest and posttest sessions. We used a modified version of the Joint Attention Test (JTAT) (Bean & Eigsti, 2012), in which the tester initiated 9 naturalistic verbal and gestural prompts to elicit the child’s attention and verbal responses (original JTAT is composed of 6 prompts). The test was modified to suit the needs of our study with permission from Dr Eigsti, who was a collaborator on this project. The revised JTAT included 4 verbal and 5 gestural bids to elicit the child’s attention. The tester was seated in front of the child across a table, and specific objects were arranged at specific locations in the environment. The tester initiated a bid to elicit the child’s attention and the child’s response was scored. If the child did not respond at the first level of prompting, the tester provided additional gestural and/or verbal prompts to elicit a response from the child. For example, for a bid to elicit “high-five” from a child, the tester initially gestured the child for a high-five. If the child did not respond to this, the tester provided an additional verbal prompt by saying, “Hey, Joey” while still holding their hand out for a high-five. If the child still did not respond, the tester explicitly stated, “Hey Joey, can you give me a high-five?” while gesturing for a high-five. Children were given points on a scale of 0 to 5 based on their responses. A point was awarded for each of the following responses to tester-initiated bids – (1) Correct

action, which was based on the bid type, for example, a correct action for the gestural bid of “waving hi” was the child raising their arm to greet the tester (see Table 4-1 for details), (2) eye contact, which was when the child made eye contact with the tester while responding to the bid, (3) look at face/ appropriate direction, included instances where the child did not make eye contact but instead looked at the tester’s face or in instances where the child looked in the general direction of the tester’s attentional focus without directly looking at the specific object that the tester was attending to , (4) smile, which was directed towards the tester, and (5) verbal response, which was verbiage initiated by the child that was relevant to the tester-initiated bid. For example, if the tester asked the child about a personal object such as a wrist-watch, explanation offered by the child about where he/she got the watch was considered a relevant verbal response. Testers interspersed the JTAT bids during other standardized fine motor activities that were conducted during the pretest and the posttest sessions. The first and the third author coded the entire dataset after establishing inter-rater reliability of greater than 85% using 20% of the dataset.

Prompts	Correct responses
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, wristwatch etc.)	Looks at the tester/appropriate direction and the object
Gestural prompts	
Wave “hi”/shake hand	Waves “hi” or shakes hand
Hand pen	Takes pen
High-five	Gives high-five
Low-five	Gives low-five
Wave “bye”	Waves “bye”

Table 4-1: Verbal and gestural prompts of the JTAT

In addition to a standardized test of joint attention with a novel tester, we also examined changes in children’s attentional patterns within the training context. Specifically, an expert coder coded an early (session 1), a mid (session 8), and a late (session 16) training session using video coding software, OpenShapa (Github Inc.) to assess for changes in children’s attentional patterns with training. We ensured

intra- and inter-rater reliability of > 85% using 20% of the dataset. We coded the duration of attention to each of the following targets within the entire duration of each session –

1. Attention to Objects: This category included bouts where children directed attention to objects including the picture board, props, musical instruments, as well as building supplies and art-craft materials used in the training session.
2. Attention to Social Partners: This included bouts when children attended to their social partners including the trainer, the adult model, and the caregiver (if present). We further classified episodes of social attention as being spontaneous or responsive. Spontaneous bouts of social attention were instances when children spontaneously initiated ‘looking’ behaviors towards their social partners without any external prompting. Responsive social attention was defined as bouts when children looked at their social partners in response to a comment/question/prompt initiated by their social partners.
3. Attention to Robot: This included bouts when children in the robot group attended to the Nao and Rovio robots used for training.
4. Attention to Elsewhere: This included bouts when the children looked away or at any unrelated objects in the room including furniture, walls etc.

4.2.3. Dependent Variables

For the standardized measure of social attention skills, the JTAT, we calculated a total response score (maximum possible score – 38) which was the sum of the raw response scores on the 9 individual items of the JTAT. In addition, we were interested in assessing the summed response scores for the 4 verbal (maximum possible verbal response score – 16) and 5 gestural items (maximum possible response score – 22) separately. A higher score on the JTAT indicates better performance. In terms of the task specific measure of attention patterns, we calculated the percent duration of attention to objects, social partners,

robot, and elsewhere in the room for each session. We also calculated the percent duration of spontaneous and responsive social attention episodes to the trainer and the model/ CG in each session.

4.2.4. Training Protocol

As mentioned previously, children were randomly assigned to one of three groups – music, robotic, or academic. We used training principles derived from contemporary autism interventions including ABA (Lovaas, 1987), Picture Exchange Communication System (PECS) (Bondy & Frost, 2003), and Treatment and Education of Autistic and related Communication-Handicapped Children (TEACHH) (Mesibov et al., 2004) in the training of children in all three groups. For example, in line with ABA principles, we used graded prompting (starting with visual and verbal prompts and then progressing to manual prompts if needed) to teach children new activities. We also encouraged repetition of activities across training sessions to promote learning. In addition, we used verbal and gestural reinforcement upon successful completion of activities. In accordance with TEACHH principles, we structured the environment to ensure consistency of materials used, people involved, and conditions practiced. Lastly, consistent with PECS principles, we used picture boards to facilitate transitions between conditions in all groups. We provided children in all groups with ample opportunities for free play and spontaneous exploration of their bodies and the supplies provided.

All expert trainers involved in the study were pediatric physical therapists or physical therapy/kinesiology graduate students. All trainers underwent significant training from the last author. The adult models involved in the study were undergraduate students who received 6-hour in-person, written, and video training prior to participation in the project. Moreover, we developed detailed instruction manuals for trainers and adult models for each group. To assess training fidelity, we asked an unbiased undergraduate student to randomly pick and code any 3 sessions for each child using a comprehensive checklist developed to assess trainer and the model behaviors during the session.

Commonalities existed within the session structure across groups: initial greeting, group-specific activity, and farewell. While the session structure remained consistent throughout the entirety of the training, activities were varied to stimulate the child's interest with general progression from simple to more complex tasks.

In the music group, children engaged in singing as well as group-based synchronous whole body imitation-based games to the beat of music (see Figure 4-1A). Specifically, children engaged in the following conditions – hello song to greet the trainer and the model, action song that involved finger play, beat keeping that involved whole body activities to music, improvisational music making that involved playing with different musical instruments, moving game involving walking-based synchronous activities to music, calming song that promoted relaxation, and farewell song where children bid farewell to the trainer and the model (see Table 4-2). Each session was based on themes such as start and stop, moving on a steady beat, turn-taking, slow and fast, and soft and loud.

Music Group	Robot Group	Academic Group
Hello Song	Hello	Hello
Action Song	Warm up Game	Condition Introduction
Beat Keeping	Action Game	Reading
Music Making	Drumming Game	Building
Moving Game	Walking Game	Arts & Crafts
Farewell Song	Farewell	Farewell

Table 4-2: Training conditions in the music, robot, and academic groups

In the robot group, children engaged in whole-body imitation and synchrony games with a 23 inch humanoid Nao robot and a mobile Rovio robot within a group setting (see Figure 4-1B). Children practiced the following conditions – hello condition where children greeted the robot, the trainer, and the adult model, warm up game during which children practiced whole body stretching movements, action game where children engaged in rhythmic upper and lower body imitation games based on several themes, drumming game where children practiced simple and complex drumming sequences, walking game where children traced letters and shapes while following the Rovio robot, and farewell condition

where children bid goodbye to the robot, the trainer, and the adult model (see Table 4-2). The themes practiced in the robot group were similar to those discussed above for the music group.

In the standard-of-care academic group, children engaged in sedentary table-top activities promoting academic and fine motor skills within a group setting (see Figure 4-1C). Specifically, children engaged in the following conditions – hello condition where children greeted the trainer and the model, reading condition where children took turns with the trainer and the model to read a book which was appropriate to their developmental level, building condition where children made creations using building supplies including Play-Doh®, Duplos®, Zoob (InfiniToy®), and building blocks, arts & crafts condition where children made theme-based creations by drawing, coloring, cutting, and pasting, and farewell condition where children said goodbye to the trainer and the model (see Table 4-2). For all building and arts & crafts creations, we provided children with a visual model of the final creation and a visual instruction sheet outlining all the steps involved to make the creation. Some of the exemplar themes in the academic group included solar system, vegetables and fruits, weather and seasons, water bodies, and basic shapes.



Figure 4-1: Experimental set-up for training sessions - (A) Music group, (B) Robot group, (C) Academic group

4.2.5. Statistical Analysis

We used SPSS Version 16 (SPSS, Inc., Chicago, IL) for statistical analysis of our data. We checked our data for assumptions of parametric statistics including normality and homogeneity of variances. Data from the standardized test of RJA satisfied all assumptions. Hence, we conducted dependent *t*-tests comparing the raw total response scores, verbal response scores, and the gestural response scores between the pretest and posttest sessions within each group. Our task specific measure of percent duration of attention was not normally distributed and had a moderate number of outliers. Hence, we applied a square transformation on these data. We used transformed data to conduct 2 repeated measures ANOVAs on the percent duration of attention. In the first ANOVA, we used attention target (to objects, to social partners, to robot, and to elsewhere), condition (5 conditions per group – see Table 4-2 for details), and session (early, mid, and late) as within-subjects factors and group as the between-subjects factor. In the second ANOVA, we were interested in further examining the social attention patterns of children in all groups. For this analysis, we included social partner target (trainer, model/caregiver (CG)), condition (5 conditions per group), attention type (spontaneous and responsive), and session (early, mid, and late) as within-subjects factors and group as a between-subjects factor. To further investigate the significant main and interaction effects, we conducted post-hoc *t*-tests. In case of a significant main and interaction effect involving the same factor, we have reported on the interaction effect only. In case of violations of the Mauchly's test of sphericity, we applied Greenhouse Geisser corrections. We report data in the form of means and standard deviations (M (SD)). For the standardized JTAT test, we will report data in terms of raw scores, whereas for the task-specific measure of attention, we will report data in terms of percent duration of time. We report effect sizes using the partial eta-squared (η_p^2) and standardized mean difference (SMD) values (calculated using Hedge's *g*) (Hedges, 1981). For all analyses, significance was set at $p \leq 0.05$.

4.3. Results

4.3.1. Generalized changes in the standardized test of RJA

We report on the generalized changes in social attention from the pretest to the posttest session using the standardized JTAT test. Three children out of the total thirty-six children were excluded from the analysis of the standardized test since they were very low-functioning and could not remain seated and attend to the tester's instruction, both in the pretest and the posttest sessions. The final analysis for the standardized JTAT test was based on 11 children in each group.

On the JTAT, there were no significant between-group differences in the pretest total response scores ($p > 0.05$). Our within-group analyses of total response, verbal response, and gestural response scores of the JTAT suggested that there were significant improvements in performance from the pretest to the posttest session in the music and academic groups (see Figures 4-2A & 4-2C). No significant training-related improvements were observed in the robot group (see Figure 4-2B).

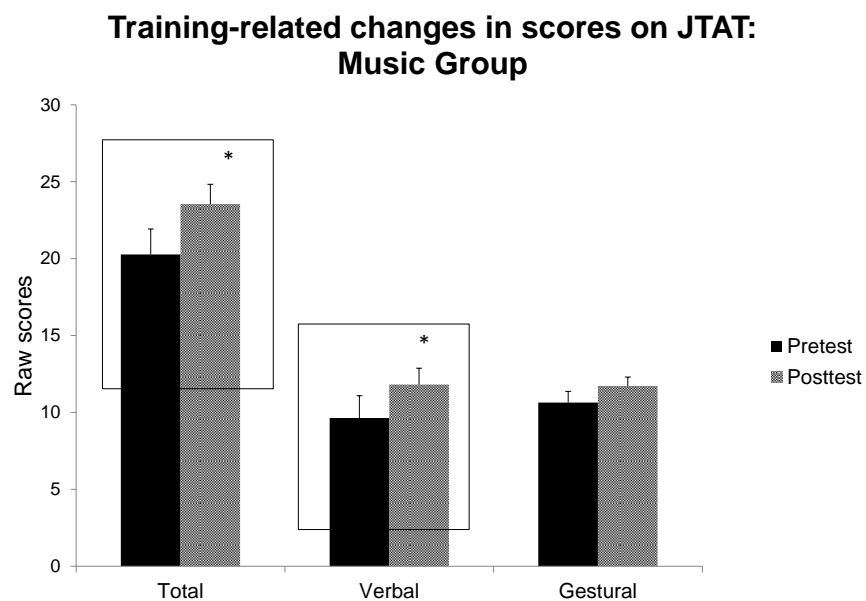


Figure 4-2A: Training-related changes in total, verbal, and gestural response scores of the JTAT in the Music group. Error bars represent standard errors. $*p \leq 0.05$

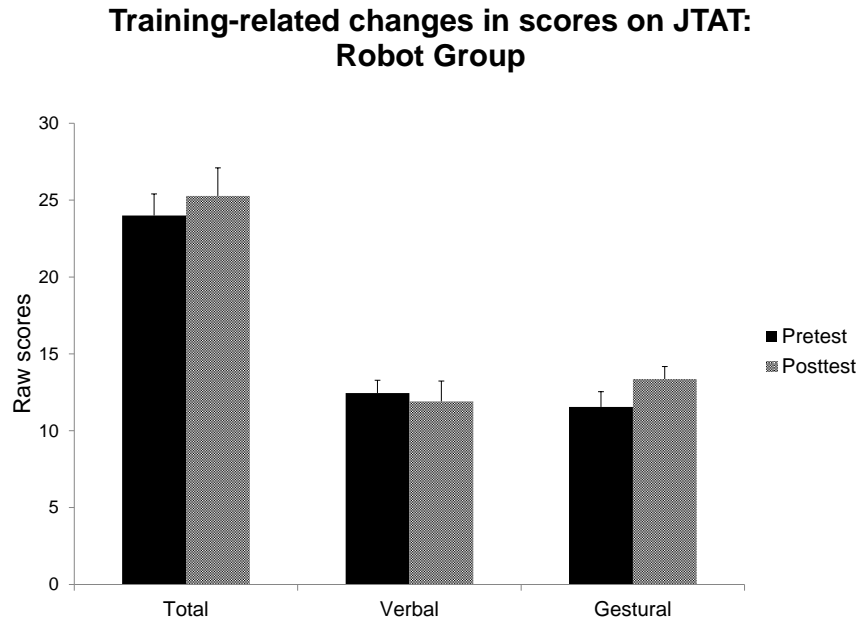


Figure 4-2B: Training-related changes in total, verbal, and gestural response scores of the JTAT in the Robot group. Error bars represent standard errors.

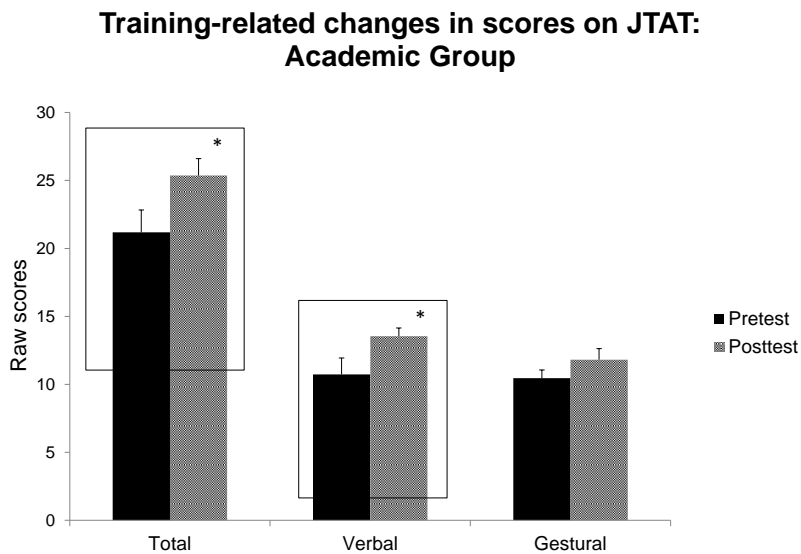


Figure 4-2C: Training-related changes in total, verbal, and gestural response scores of the JTAT in the Academic group. Error bars represent standard errors. $*p \leq 0.05$

In the music group, children improved their total response scores from the pretest ($M (SD) = 20.27(5.50)$) to the posttest ($M (SD) = 23.55(4.27)$, $p = 0.005$, $SMD = 0.55$) session. We found that these improvements were a result of an increase in verbal response scores from the pretest ($M (SD) = 9.64(4.80)$) to the posttest ($M (SD) = 11.82(3.52)$, $p = 0.02$) (see Figure 4-2A). Individual data suggested that 9 out of the 11 children in the group followed this trend. Along the same lines, children in the academic group had significantly greater total response scores in the posttest ($M (SD) = 25.36(4.11)$) compared to the pretest ($M (SD) = 21.18(5.47)$, $p = 0.004$, $SMD = 0.71$). Similar to the music group, these improvements were seen as a result of increases in the verbal response scores from the pretest ($M (SD) = 10.73(4.03)$) to the posttest ($M (SD) = 13.55(2.02)$, $p = 0.008$) session (see Figure 4-2C). Individual data indicated that 9 out of 11 children in this group followed this trend.

4.3.2. Task-specific changes in attention patterns-

A. Changes in attention patterns to different targets –

The repeated measures ANOVA indicated a main effect of condition ($F (4, 132) = 23.06$, $p < 0.001$, $\eta_p^2 = 0.41$), a main effect of attention target ($F (3, 99) = 113.06$, $p < 0.001$, $\eta_p^2 = 0.77$), a main effect of group ($F (2, 33) = 95.46$, $p < 0.001$, $\eta_p^2 = 0.85$), a condition x group interaction ($F (8, 132) = 10.57$, $p < 0.001$, $\eta_p^2 = 0.39$), an attention target x group interaction ($F (6, 99) = 178.36$, $p < 0.001$, $\eta_p^2 = 0.92$), a session x attention target interaction ($F (3.68, 121.58) = 4.32$, $p = 0.003$, $\eta_p^2 = 0.12$), a session x attention target x group interaction ($F (12, 198) = 2.57$, $p = 0.003$, $\eta_p^2 = 0.14$), a condition x attention target interaction ($F (6.93, 228.70) = 62.03$, $p < 0.001$, $\eta_p^2 = 0.65$), a condition x attention target x group interaction ($F (24, 396) = 33.34$, $p < 0.001$, $\eta_p^2 = 0.67$), and a session x condition x attention target interaction ($F (10.70, 353.23) = 1.87$, $p = 0.04$, $\eta_p^2 = 0.05$).

We further analyzed the two meaningful interactions of session x attention target x group and condition x attention target x group using post-hoc *t*-tests. We will report the results as within-group

changes and between-group differences in attention patterns. All values reported below are in terms of percent duration of time.

a. *Within-group changes:*

1. Music group: In the early session, children spent greater percent duration of time attending to social partners (M (SD) = 45.14(10.00)) followed by to objects (M (SD) = 31.74(7.77)) with least percent duration of attention directed to elsewhere (M (SD) = 23.12(7.95), p values < 0.03) (see Figure 4-3A). In the mid and late sessions, children demonstrated greater attention to their social partners (Mid: M (SD) = 44.81(9.09), Late: M (SD) = 46.74(13.75)) compared to objects (Mid: M (SD) = 29.56(8.62), Late: M (SD) = 29.06(10.48), p values < 0.02) and elsewhere (Mid: M (SD) = 25.63(7.26), Late: M (SD) = 24.20(8.43), p values < 0.003) (see Figure 4-3A). However, there were no training-related changes in attention patterns of children across sessions.

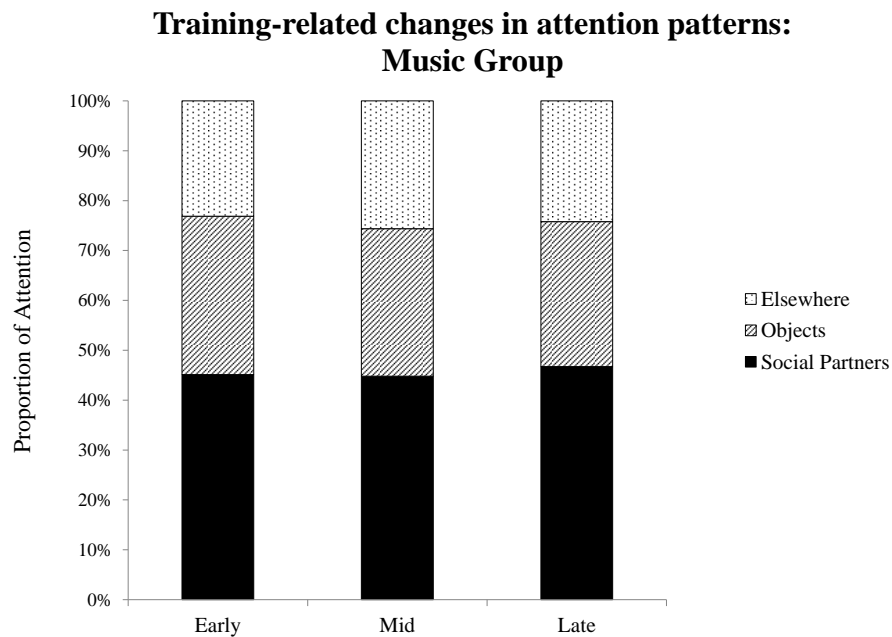


Figure 4-3A: Training-related changes in attention patterns in the Music group.

In terms of condition-related differences, our results suggested that in all conditions except music making, children directed maximum attention to their social partners followed by to elsewhere and directed least attention towards objects (p values between < 0.001 to 0.02) (see Figure 4-4A). In contrast, during the music-making condition, children spent maximum time attending to objects followed by attention to social partners with least attention to elsewhere (p values between < 0.001 to 0.02) (see Figure 4-4A). In terms of attention to social partners, the social interaction phase, the action song, and beat keeping conditions afforded greater social attention compared to the music-making and moving game conditions (p values < 0.001) (see Figure 4-4A). In terms of attention to objects, the music-making condition afforded greatest attention to objects followed by the social interaction and action song conditions compared to the other conditions (p values between 0.008 and 0.01) (see Figure 4-4A). In terms of attention directed to elsewhere in the room, children looked away the most during the moving game condition followed by the beat keeping condition, and then the action song and social interaction conditions. Children spent minimum time attending to elsewhere during the music making condition (p values < 0.001) (see Figure 4-4A).

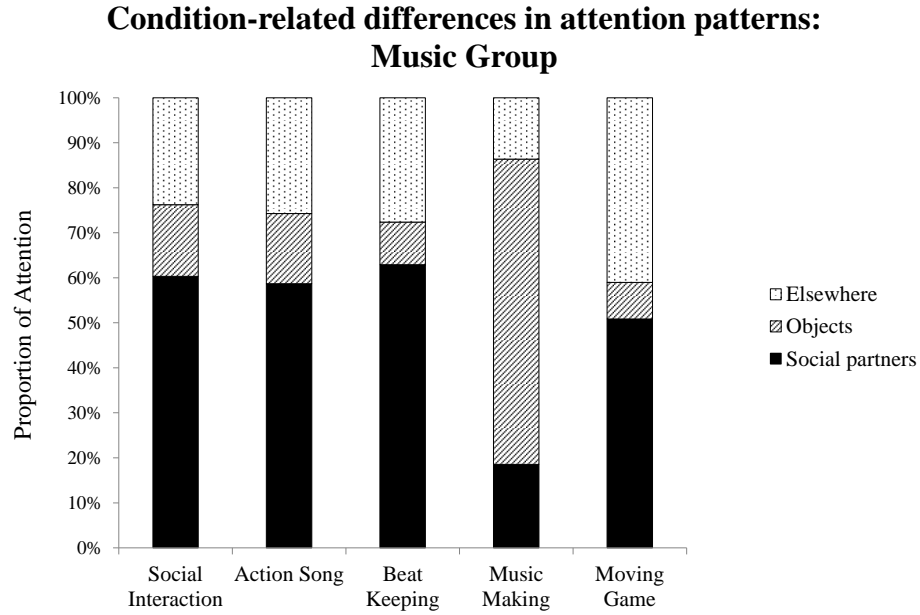


Figure 4-4A: Condition-related differences in attention patterns in the Music group.

2. **Robot group:** Children in the robot group directed maximum attention to the robot (Early: $M (SD) = 47.51(12.87)$, Mid: $M (SD) = 37.37(11.11)$) followed by attention towards their social partners (Early: $M (SD) = 22.69(7.12)$, Mid: $M (SD) = 26.18(6.82)$) and elsewhere (Early: $M (SD) = 18.99(9.69)$, Mid: $M (SD) = 23.07(6.67)$) in the room with least time spent attending to objects (Early: $M (SD) = 10.81(3.52)$, Mid: $M (SD) = 13.38(4.82)$, p values between < 0.001 and 0.04) in the early and mid-sessions (see Figure 4-3B). In the late session, children spent greater time attending to the robot ($M (SD) = 34.28(12.02)$), to their social partners ($M (SD) = 24.04(11.38)$) and to elsewhere ($M (SD) = 30.52(9.88)$) compared to objects ($M (SD) = 11.16(4.48)$, p values < 0.003) (see Figure 4-3B). In terms of training-related changes, children demonstrated an increase in attention to elsewhere from the mid ($M (SD) = 23.07(6.67)$) to the late session ($M (SD) = 30.52(9.88)$, $p = 0.02$, $SMD = 1.04$) as well as from the early ($M (SD) = 18.99(9.69)$) to the late ($M (SD) = 30.52(9.88)$, $p = 0.01$, $SMD = 1.11$) session (see Figure 4-3B).

Individual data suggested that 9-10 out of 12 children followed the group trends. Children

also showed a concurrent reduction in attention to the robot from the early ($M (SD) = 47.51(12.87)$) to the mid-session ($M (SD) = 37.37(11.11)$, $p < 0.001$, $SMD = -0.73$), from the mid ($M (SD) = 37.37(11.11)$) to the late ($M (SD) = 34.28(12.02)$, $p = 0.05$, $SMD = -0.26$) session, and from the early ($M (SD) = 47.51(12.87)$) to the late ($M (SD) = 34.28(12.02)$, $p < 0.001$, $SMD = -0.96$) session (see Figure 4-3B). Specifically, 10-12 out of 12 children followed this trend of decrease in attention to the robot across sessions. Further, children showed some increase in attention to objects from the early ($M (SD) = 10.81(3.35)$) to the mid-session ($M (SD) = 13.38(4.82)$, $p = 0.04$) (see Figure 4-3B). Nine out of the 12 children followed this group trend.

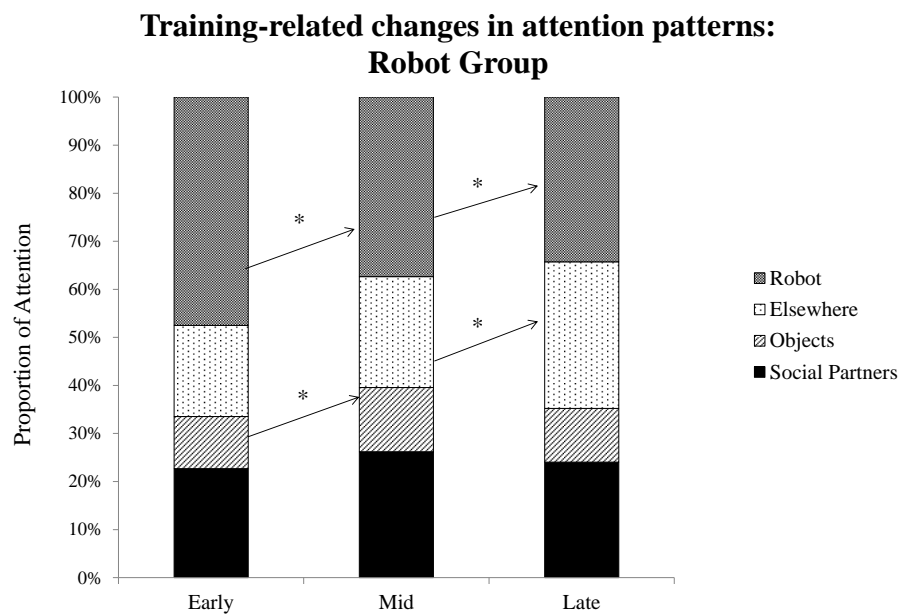


Figure 4-3B: Training-related changes in attention patterns in the Robot group.

In terms of condition-related differences, during the warm up and action games, children spent greater time attending to the robot followed by to elsewhere and to social partners, with least attention to objects (p values between < 0.001 and 0.007) (see Figure 4-4B). During the drumming game, children directed maximum attention to the robot and least attention to elsewhere and to objects (p values between 0.004 and 0.02) (see Figure 4-

4B). In terms of attention to the robot, children spent maximum time looking at the robot during the warm up game compared to all other conditions (p values between < 0.001 and 0.007) (see Figure 4-4B). Similarly, children attended most to their social partners during the action game followed by the drumming game and social interaction phase, and least attention during the walking game (p values range from < 0.001 to 0.04) (see Figure 4-4B). Children looked away the most during the walking game and social interaction phase compared to the other conditions (p values between < 0.001 and 0.009). Lastly, children attended to objects for a longer duration during the drumming game compared to all other conditions (p values range from < 0.001 to 0.01) (see Figure 4-4B).

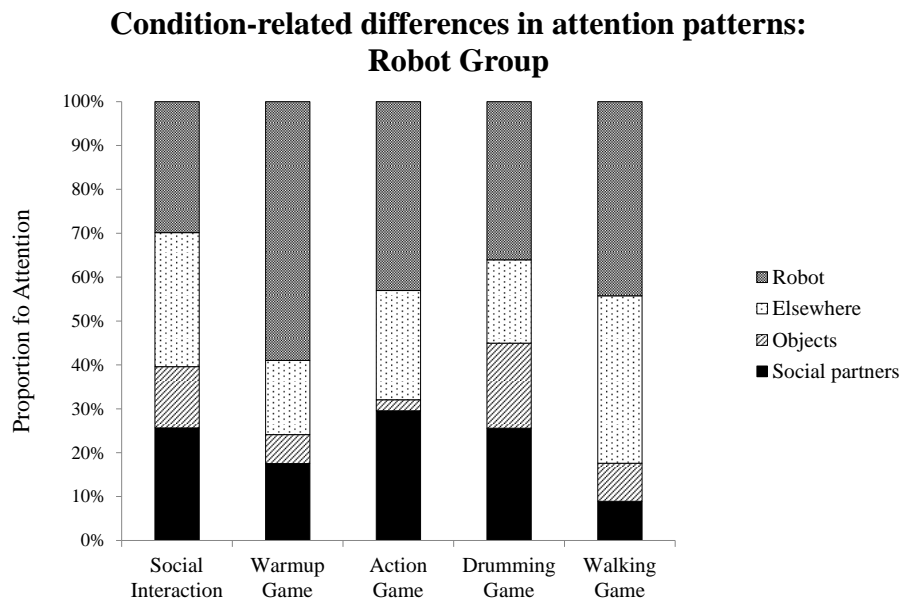


Figure 4-4B: Condition-related differences in attention patterns in the Robot group.

3. Academic group: Overall, in all three sessions, children spent maximum time attending to objects (Early: $M (SD) = 83.46(13.12)$, Mid: $M (SD) = 83.30(8.65)$, Late: $M (SD) = 82.87(10.76)$) compared to time spent attending to their social partners (Early: $M (SD) = 7.62(6.84)$, Mid: $M (SD) = 6.86(5.34)$, Late: $M (SD) = 6.95(7.70)$) and to elsewhere (Early: $M (SD) = 7.62(6.84)$, Mid: $M (SD) = 6.86(5.34)$, Late: $M (SD) = 6.95(7.70)$), p

values < 0.001) (see Figure 4-3C). There were no training-related changes in attention patterns of children across weeks.

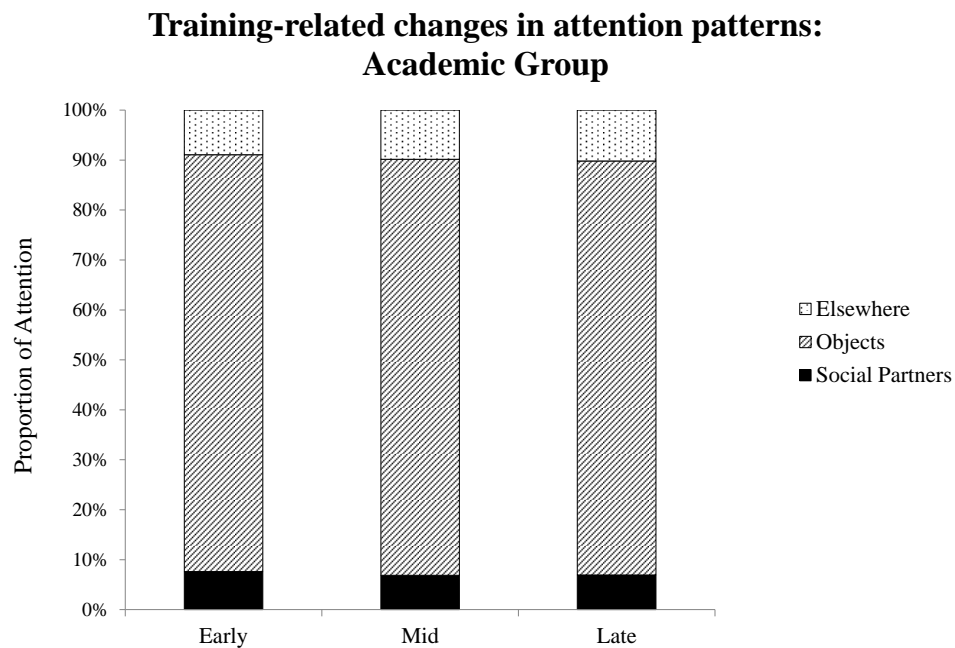


Figure 4-3C: Training-related changes in attention patterns in the Academic group.

In terms of condition-related changes, children directed greater attention to objects compared to elsewhere and to social partners in the reading, building, and art-craft conditions (p values < 0.001) (see Figure 4-4C). Along the same lines, children directed greater attention to objects and to elsewhere than to their social partners during the social interaction phase (p values < 0.01) (see Figure 4-4C). In terms of attention to social partners, the social interaction and reading conditions afforded greater social attention compared to other conditions (p values range from < 0.001 to 0.009) (see Figure 4-4C). In terms of attention to objects, children looked at objects for longer durations during the building and art-craft conditions compared to the other conditions (p values < 0.001). Lastly, children looked away more during the social interaction phase compared to the other conditions (p values < 0.001 to 0.01) (see Figure 4-4C).

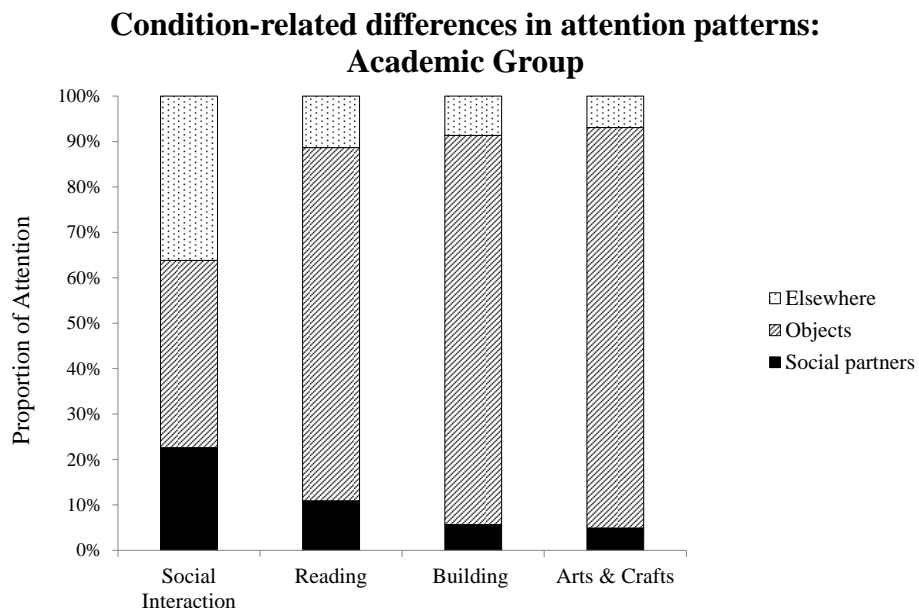


Figure 4-4C: Condition-related differences in attention patterns in the Academic group.

- b. *Between-group differences:* Both the music and the robot groups demonstrated greater duration of attention to social partners and to elsewhere compared to the academic group in the early, mid, and late sessions (see Table 4-3 for details). In contrast, the academic group attended more to objects compared to both music and robot groups in the early, mid, and late training sessions (see Table 4-3 for details). Lastly, children in the music group directed greater attention to their social partners and towards objects compared to the robot group in the early, mid, and late training sessions (see Table 4-3 for details).

Attention Target	Music Group Percent Duration M(SD)			Robot Group Percent Duration M(SD)			Academic Group Percent Duration M(SD)		
	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late
Objects	31.7 (7.8)	29.6 (8.6)	29.1 (10.5)	10.8 (3.4)	13.4 (4.8)	11.2 (4.5)	83.5 (13.1)	83.3 (8.7)	82.9 (10.8)
Elsewhere	23.1 (8.0)	25.6 (7.3)	24.2 (8.4)	19.0 (9.7)	23.1 (6.7)	30.5 (9.9)	8.9 (8.1)	9.8 (5.9)	10.2 (8.4)
Social Partners	45.1 (10.0)	44.8 (9.1)	46.7 (13.8)	22.7 (7.1)	26.2 (6.8)	24.0 (11.4)	7.6 (6.8)	6.9 (5.3)	7.0 (7.7)
Robot	-	-	-	47.5 (12.9)	37.4 (11.1)	34.3 (12.0)	-	-	-

Table 4-3: Group differences in percent duration of attention to objects, to elsewhere, to social partners, and to the robot during the early, mid, and late sessions

B. Changes in attention patterns to social partners -

A repeated measures ANOVA indicated a main effect of session ($F(2, 66) = 3.07, p = 0.05, \eta_p^2 = 0.09$), a main effect of condition ($F(4, 132) = 59.64, p < 0.001, \eta_p^2 = 0.64$), a main effect of social partner ($F(1, 33) = 46.88, p < 0.001, \eta_p^2 = 0.59$), a main effect of attention type ($F(1, 33) = 15.85, p < 0.001, \eta_p^2 = 0.33$), a condition x group interaction ($F(8, 132) = 40.31, p < 0.001, \eta_p^2 = 0.71$), a social partner x group interaction ($F(2, 33) = 24.35, p < 0.001, \eta_p^2 = 0.60$), an attention type x group interaction ($F(2, 33) = 14.98, p < 0.001, \eta_p^2 = 0.48$), a condition x attention type interaction ($F(3, 11, 102.76) = 11.33, p < 0.001, \eta_p^2 = 0.26$), a social partner x attention type interaction ($F(1, 33) = 42.26, p < 0.001, \eta_p^2 = 0.56$), a condition x social partner interaction ($F(4, 132) = 4.76, p = 0.001, \eta_p^2 = 0.13$), a condition x attention type x group interaction ($F(8, 132) = 11.69, p < 0.001, \eta_p^2 = 0.42$), a condition x social partner x group interaction ($F(8, 132) = 15.41, p < 0.001, \eta_p^2 = 0.48$), a condition x social partner x attention type interaction ($F(4, 132) = 6.09, p < 0.001, \eta_p^2 = 0.16$), and a condition x social partner x attention type x group interaction ($F(8, 132) = 2.79, p = 0.007, \eta_p^2 = 0.15$).

We evaluated the social partner x group, attention type x group, condition x social partner x group, and condition x attention type x group interactions further. We have reported results from these analyses as within-group changes and between-group differences in percent duration of social attention.

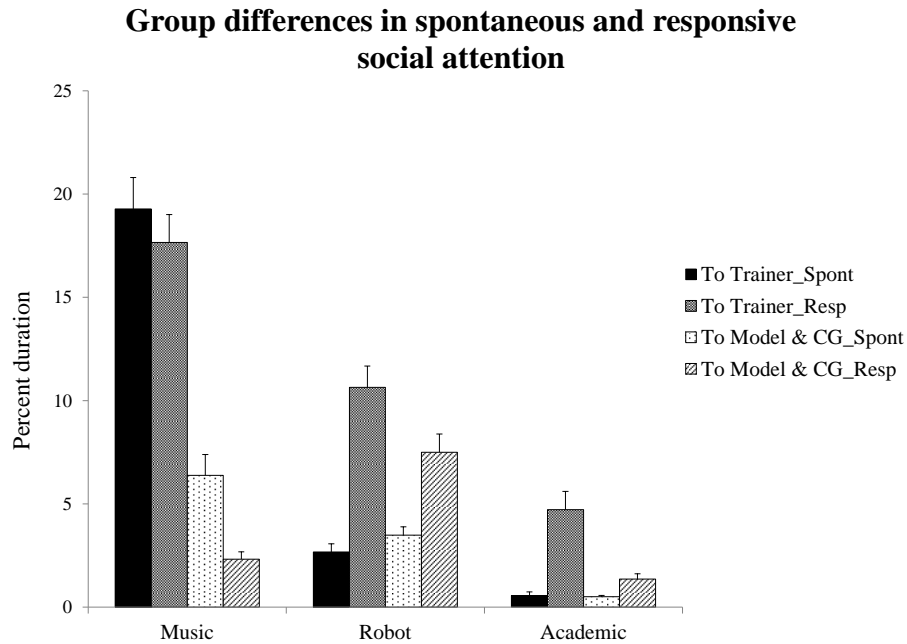


Figure 4-5: Group differences in the duration of spontaneous and responsive attention episodes to the trainer and the model/CG. Error bars represent standard errors.

a. Within-group changes:

- a. Music group: Overall, irrespective of session, children paid greater attention to the trainer ($M (SD) = 36.93(12.15)$) compared to the model/CG ($M (SD) = 8.71(6.90)$, $p < 0.001$) (see Figure 4-5). This trend was seen across all training conditions i.e. social interaction, action song, beat keeping, music making, and moving game (p values < 0.001) (see Table 4-4). In terms of attention type, overall, children engaged in greater duration of spontaneous ($M (SD) = 25.66(10.83)$) versus responsive social attention ($M (SD) = 19.98(8.08)$, $p = 0.04$) episodes with their social partners (see Figure 4-5). This trend was observed during the social interaction, beat keeping, and moving game conditions (p values between < 0.001 and 0.01) (see Table 4-5). During the action song condition, there were no differences in the duration of spontaneous and responsive social attention episodes ($p > 0.05$) (see Table 4-5). In contrast, during the music-making condition,

children engaged in longer duration of responsive compared to spontaneous attention episodes with their social partners ($p = 0.004$) (see Table 4-5).

Group	To Trainer Percent Duration M(SD)					To Model/CG Percent Duration M(SD)				
	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5
M	45.4 (16.6)	48.9 (14.0)	52.8 (18.6)	14.5 (9.8)	41.2 (13.5)	14.9 (9.8)	9.8 (8.4)	10.2 (10.4)	4.1 (5.4)	9.6 (9.0)
R	16.2 (9.7)	10.1 (10.4)	12.2 (7.9)	16.2 (7.9)	4.8 (3.8)	9.5 (7.4)	7.4 (6.8)	17.4 (13.0)	9.4 (6.0)	4.2 (3.4)
A	14.1 (11.6)	8.9 (10.3)	4.2 (5.9)	3.5 (5.0)	-	8.5 (6.9)	2.0 (2.6)	1.5 (2.3)	1.5 (2.6)	-

Table 4-4: Condition-related differences in percent duration of attention to the trainer and the model/CG in the music, robot, and academic groups, C –Condition, M-Music, R- Robot, A- Academic. In the music group, C1 = social interaction, C2 = action song, C3 = beat keeping, C4 = music making, and C5 = moving game. In the robot group, C1 = social interaction, C2 = warm up, C3 = action game, C4 = drumming game, and C5 = walking game. In the academic group, C1 = social interaction, C2 = reading, C3 = building, and C4 = arts & crafts.

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
M	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)
R	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)
A	2.6 (4.6)	1.3 (2.4)	0.9 (1.0)	1.0 (1.6)	-	20.1 (15.5)	9.6 (11.4)	4.8 (7.3)	4.0 (5.6)	-

Table 4-5: Condition-related differences in percent duration of spontaneous and responsive social attention in the music, robot, and academic groups, C –Condition, M-Music, R- Robot, A- Academic.

Conditions are as listed above in the legend for Table 4-4.

- b. Robot group: Overall, irrespective of session, there were no significant differences in the amount of attention directed by children towards the trainer (M (SD) = 13.31(6.03)) and the model/CG (M (SD) = 10.99(7.00), $p > 0.05$) (see Figure 4-5). This trend was

observed in all conditions except the social interaction and drumming conditions (see Table 4-4). In these two conditions, children attended more towards the trainer compared to the model/CG (p values < 0.05) (see Table 4-4). In terms of attention type, children engaged in predominantly responsive (M (SD) = 18.14(7.79)) versus spontaneous (M (SD) = 6.16(3.49), $p < 0.001$) attention episodes with their social partners (see Figure 4-5). This trend was consistently seen across all training conditions in this group (p values < 0.005) (see Table 4-5).

- c. Academic group: Children directed greater attention to the trainer (M (SD) = 5.27(5.52)) compared to the model/CG (M (SD) = 1.87(1.71), $p < 0.001$) across all sessions (see Figure 4-5). This trend was observed during all conditions within the academic group (p values < 0.05) (see Table 4-4). In terms of attention type, children engaged in longer responsive (M (SD) = 6.08(6.22)) versus spontaneous (M (SD) = 1.06(1.26), $p < 0.001$) social attention episodes across training sessions (see Figure 4-5). This trend was also consistent across all conditions of the academic training (p values between < 0.001 and 0.003) (see Table 4-5).
- b. *Between-group differences*: Overall, irrespective of session, attention towards social partners was greatest in the music group and least in the academic group. Specifically, between groups, children in the music group (M (SD) = 36.93(12.15)) directed maximum attention to the trainer followed by children in the robot group (M (SD) = 13.31(6.03)), with least amount of trainer-directed attention demonstrated by the academic group (M (SD) = 5.27(5.52), p values < 0.001) (see Figure 4-5). Along the same lines, children in the music (M (SD) = 8.71(6.90)) and robot (M (SD) = 10.99(7.00)) groups spent greater time attending to the model/CG compared to the children in the academic group (M (SD) = 1.87(1.71), p values < 0.001) (see Figure 4-5). In terms of group differences in attention type, the duration of spontaneous social attention was greatest in the music group (M (SD) = 25.66(10.83)), followed by the robot group (M (SD) = 6.16(3.49)), with least spontaneous social attention seen in the academic group (M (SD) = 1.06(1.26), p values

< 0.001) (see Figure 4-5). Similarly, children spent greater time engaged in responsive social attention episodes in the music ($M (SD) = 19.98(8.08)$) and robot ($M (SD) = 18.14(7.79)$) groups compared to the academic group ($M (SD) = 6.08(6.22)$), p values < 0.001) (see Figure 4-5).

4.4. Discussion

4.4.1. Summary of results

Our RCT compared the effects of two novel movement-based interventions, music and robotic, with those of a standard-of-care academic intervention on the social attention patterns of 36 children with ASDs. Specifically, we were interested in examining social attention patterns with respect to context-related differences between groups, training-related changes within each group, and condition-related differences within each group. In the music group, children engaged in greater duration of social attention compared to the other two groups across all sessions (see Figures 4-3A-C and Table 4-3). Specifically, children directed maximum attention towards their social partners compared to all other attention targets during all conditions, except music making, during which children directed maximum attention to objects appropriate with the task demands (see Figure 4-4A and Table 4-3). Moreover, within this group, children engaged in greater spontaneous compared to responsive social attention episodes in a majority of conditions (see Figure 4-5 and Table 4-5). In terms of training-related changes, children did not show any improvements on the task-specific measure of social attention (see Figure 4-3A). However, children improved their performance on the standardized test of RJA, i.e. the JTAT, in the posttest compared to the pretest (see Figure 4-2A). In the robot group, children directed maximum attention to the robot compared to all other attention targets (see Figure 4-3B and Table 4-3). This finding was seen during a majority of the conditions in the robot group (see Figure 4-4B). Although the amount of social attention in this group was lower than that seen in the music group, it was still higher than that seen in the standard-of-care academic group across all sessions (see Figures 4-3A-C and Table 4-3). Moreover, we found that children in the robot group engaged in greater responsive compared to spontaneous social attention episodes (see

Figure 4-5 and Table 4-5). In terms of training–related changes, children showed a reduction in attention to the robot with a concurrent increase in attention towards elsewhere in the room and towards objects across training sessions (see Figure 4-3B). Those children receiving robot-assisted training did not demonstrate any significant improvements on the standardized test of RJA (see Figure 4-2B). In the academic group, children directed maximum attention to objects, which was evident during all the conditions within the training context (see Figures 4-3C & 4-4C). In addition, the amount of social attention afforded by the academic context was the least of the three training contexts (see Figures 4-3A-C and Table 4-3). In terms of attention type, children engaged in greater responsive compared to spontaneous social attention episodes within sessions (see Figure 4-5 and Table 4-5). In terms of training-related changes, children did not demonstrate any significant changes on the task-specific measure of social attention (see Figure 4-3C); however, children improved their performance on the standardized test of RJA in the posttest compared to the pretest (see Figure 4-2C).

4.4.2. Task-specific changes in attention patterns: Music group

The music group demonstrated greater social attention compared to the robot and academic groups (see Figures 4-3A-C and Table 4-3). Children directed maximum attention towards their social partners compared to all other attentional targets during all conditions except music-making (see Figure 4-4A). We think that the very nature of the context afforded sustained social monitoring. Children were encouraged to practice novel dual and multilimb rhythmic synchrony- and imitation-based games with their social partners during the training sessions. When typically developing children learn complex motor skills, they do so by observing the demonstrations of a skilled model (Ferrari, 1996; Weeks & Anderson, 2000). We encouraged children to learn novel motor sequences to the beat of music and further asked them to synchronize their movements with their social partners. In order to accurately synchronize their movements spatially and temporally with their social partners, children had to continuously monitor their social partners to detect changes in their movement patterns and adapt their own movements to those of their adult partners. Hence, children might have engaged in greater social monitoring given the task

demands of the context. Previous research also suggests that engagement in imitation and synchrony-based activities within dyadic and triadic contexts promotes sustained social attention in children with ASDs (Escalona, Field, Nadel, & Lundy, 2002; Landa et al., 2011). Further, our findings also fit with the existing literature on the positive effects of music on social engagement of children with ASDs (Finnigan & Starr, 2010; Kim et al., 2008; Wimpory & Others, 1995). For example, 7 months of musical interaction therapy, which involved interactive play to the beat of music within dyadic exchanges between a 3.5 year old girl with autism and her mother led to an increase in eye contact and interactive involvement of the child with her mother. Moreover, these improvements were sustained over a 20 month follow-up period (Wimpory et al., 1995). Similarly, in another case study, 12 sessions of music therapy led to greater improvements in eye contact, imitation, and turn taking skills in a pre-school child with autism compared to a non-musical play-based intervention (Finnigan & Starr, 2010). Our results can be explained by findings from music education research on typically developing individuals, which suggest that music is in fact a kind of social glue that improves cooperation and social bonding between people (Overy & Molnar-Szakacs, 2009). It has been proposed that joint actions involving music-making, singing, and dancing lead to a shared affective experience, which in turn evokes prosocial behaviors and a sense of affiliation in the group (Kirschner & Tomasello, 2010; Overy & Molnar-Szakacs, 2009; Wiltermuth & Heath, 2009). For example, following engagement in a joint music-making activity (versus a story-telling game), 4-year old children spontaneously showed cooperative and empathetic behavior towards their peer (Kirschner & Tomasello, 2010). Overall, as children in the music group engaged in enjoyable, socially synchronous activities with their social partners, the task demands and the nature of the context might have promoted shared engagement between children and their interaction partners, and children might have shared their attentional states and interests with their adult partners.

As discussed above, children spent maximum time engaged in social attention episodes during all conditions, except music-making, during which children directed maximum attention towards non-social objects (see Figure 4-4C). The music-making condition involved children engaging in different musical

instruments such as drums and xylophones. We think that given the easy access to objects, children engaged in greater non-social fixation on objects in this condition. Moreover, our activities required them to practice simple and complex drum and xylophone patterns which needed them to attend to the musical instruments. These findings validate the results obtained in the academic group, which suggest that engaging in predominantly object-based activities led to preferential attention to objects (see Figure 4-3C). Further, this fits with existing literature which suggests that in the presence of competing social and non-social stimuli, children with autism prioritize non-social stimuli at the cost of attending to social stimuli (Ben-Sasson et al., 2007; Klin et al., 2002). This could be attributed to their social orienting deficits (Dawson et al., 2004) as well as their impairments in attention disengagement (Courchesne et al., 1994; Courchesne et al., 1994; Landry & Bryson, 2004) which are discussed in greater detail in the following sections.

Lastly, in terms of social attention type, children engaged in greater duration of spontaneous compared to responsive social attention episodes in a majority of conditions (see Figure 4-5 and Table 4-5). Also, consistent with the nature and setup of our training context, children directed greater attention to the trainer compared to the model during all conditions (see Figure 4-5 and Table 4-4). Considering the documented evidence on the persistent nature of impairments in spontaneous initiations in ASDs (Mundy, Card, & Fox, 2000), it was very encouraging to see that the music-based context afforded greater spontaneous compared to responsive engagement in children. Although children with ASDs demonstrate impairments in both RJA and IJA, difficulties in responding to attentional bids initiated by others remit to a great extent over development (Leekam et al., 2000; Mundy & Hogan, 1994; Mundy, 2003). However, impairments in IJA are more severe and persist even in older children with ASDs (Mundy & Hogan, 1994; Mundy, 2000; Sigman & Ruskin, 1999). Moreover, future outcomes such as the ability to establish peer relationships in adolescence are related to IJA and not RJA abilities (Mundy, 2000). Results from behavioral intervention studies targeting attention skills suggest that children demonstrate greater improvements in their ability to respond to bids of others compared to their spontaneous initiation skills,

possibly since IJA is difficult to promote in children with ASDs (Kasari, 2002; Whalen & Schreibman, 2003). Our study suggests that socially-embedded, music-based whole body activities have great potential in promoting spontaneous attention and engagement between children and their social partners. Other studies have also reported improvements in child-initiated social engagement following music-based therapies (Bunt & Stige, 1994; 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 joint attention in 10 children with ASDs compared to toy play sessions (Kim et al., 2008). Along the same lines, we think that the predictable, non-intimidating yet enjoyable nature of the activities in the music group might have elicited spontaneous initiation of social engagement in the current study.

4.4.3. Task-specific changes in attention patterns: Robot group

Children in the robot group spent the greatest amount of time attending to the robots used in the study (see Figures 4-3B and 4-4B). This trend was seen during a majority of the conditions within the training session (see Figure 4-4B). We had hypothesized that children would engage in higher levels of attention directed towards the robot during the early training sessions given their intrinsic interest in robots and technology (Diehl et al., 2011; Robins et al., 2006). However, we expected that across training weeks the robot would act as an effective mediator for interactions between children and their social partners, and children would increase the length of attentional episodes directed towards their interaction partners. In contrast to our hypotheses, children continued to devote maximum attention towards the robot across training sessions, which might have severely restricted children's opportunities to engage with their social partners. To the best of our knowledge, ours is the first study to systematically compare the effects of prolonged 8-week human vs. robot-mediated therapies on the social communication skills of children with ASDs. Our findings suggest that the music group demonstrated greater social attention levels compared to the robot group. Our findings do not fit with the current literature on effects of robotic therapies in autism. Several studies that compared the effects of a single session of interaction with a

human vs. robot mediator suggested that children with ASDs found robots engaging, and directed greater attention to the robot compared to the human mediator (Bekele, Crittendon, Swanson, Sarkar, & Warren, 2013; Duquette et al., 2008; Ismail, Shamsudin, Yussof, Hanapiah, & Zahari, 2012a). We also observed that children directed greater attention towards the robot at the cost of attention to their social partners. However, it is important to note that the ultimate goal of all robot-child interactions is not to enhance children's interactions with the robot, but rather to use the robot as a mediator to engage in interactions with social partners (Ricks & Colton, 2010). In line with this motivation, several anecdotal studies have reported improvements in shared attention, imitation, turn taking, and joint attention skills in children with ASDs following interactions with a robot in a triadic context (Kozima et al., 2007; Robins et al., 2004; Robins et al., 2005; Stanton et al., 2008; Warren et al., 2013; Werry et al., 2001). However, only two of these studies assessed the effects of repeated sessions of robot-child interactions over a prolonged period of time (Kozima et al., 2007; Robins, Dautenhahn, Te Boekhorst, & Billard, 2004). Kozima and colleagues introduced their creature-like robot, Keepon, within the playroom of a day care center for children with ASDs, but unlike our study, children were free to approach and interact with the robot at any time during their routine activities based on their will (Kozima et al., 2007). In a more structured interaction protocol, Robins and colleagues observed the reactions of 4 children with ASDs 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 with the context (Robins et al., 2004). We argue that a reasonable test of the potential utility of robots as therapy tools in autism should be based on the current standards for autism interventions. Current autism interventions are very intensive and are provided for around 30-40 hours per week (Landa, 2007; Vismara & Rogers, 2010). Hence, we evaluated the effects of an intense 16-session protocol of robot-child interactions provided over 8 weeks on children's social communication skills which suggested that the robot in fact limited children's opportunities for social interactions.

Although social attention levels in the robot group were significantly lower than those seen in the music group, they were nevertheless higher than the levels seen in the standard-of-care academic group (see Figures 4-3A-C and Table 4-3). Similar to the design of the music group, children in the robot group also engaged in dual and multilimb synchrony-based games. The joint action-based activities might have promoted social monitoring of the adult model (see Figure 4-5). Moreover, while practicing each movement sequence, the first trial involved the robot, the child, and the model all moving together, but following this, we encouraged children to focus on synchronizing with the adult model in the absence of robotic movement. This phase might have encouraged children to monitor the actions of the adult model. We also noticed that unlike the music group, the robot group engaged in greater responsive compared to spontaneous social attention episodes with their social partners (see Figure 4-5 and Table 4-5). We observed that given children's visual fixation on the robot, it was very hard to get them to disengage from the robot and attend to their social partners. The trainers and models had to repeatedly bid children to attend to them and monitor their actions which might have led to the higher amounts of responsive attention in this group.

In terms of training-related changes in attention patterns, the robot group demonstrated a reduction in attention towards the robot across training sessions with a concurrent increase in attention towards elsewhere and non-social objects (see Figure 4-3B). We think that these findings reflect a reduction in engagement and progressive boredom with the context. Similar findings were found in an 18-day field trial that used an interactive humanoid robot, Robovie, in first and sixth grade TD children to teach them words. The authors found a sharp reduction in interest towards the robot during the second week of interaction in some of the children (Kanda, Hirano, Eaton, & Ishiguro, 2004). Our own previous work with TD children using a smaller humanoid robot, I-sobot, also suggested that over time the limited capabilities of the robot could not sustain children's engagement across training sessions (Srinivasan et al., 2013). In the current study, though we used state-of-the-art Nao robots, we think that the limitations of our current robotic technology might have led to decrease in engagement over time. The Nao robot has 25

degrees of freedom, but the movement repertoire of the robot is still limited compared to that of a child. Moreover, the robot's movements are noisy and much slower than those of a human. Once triggered, the robot cannot adapt its movements to those of the child during an ongoing movement sequence. In terms of social interaction capacities, the robot's verbiage was unclear and children had difficulty understanding the robot's speech. Moreover, even though we used the online speech capabilities of the robot, there was some time lag between the child's verbiage and the robot's response since the adult trainer had to manually type in the responses of the robot. Hence, the lack of contingent responding and dynamic adaptive capacities severely limited the robot's ability to become an effective mediator between the child and their social partners. Instead, the robot promoted visual fixation towards itself and non-social attention towards objects at the cost of interactions between children and their social partners.

4.4.4. Task-specific changes in attention patterns: Academic group

The academic group was designed to mimic the standard-of-care ABA therapy settings that children with autism typically receive during school-based therapy sessions. Children engaged in activities that promoted academic and fine motor skills including reading, building, and art-crafts. We hypothesized that such a context, which is typically used to remediate the social communication impairments in autism, would promote a greater amount of social attention. However, surprisingly, this group engaged in the lowest levels of social attention compared to the other two groups. Instead, children spent maximum time attending to objects/supplies (see Figures 4-3C & 4-4C and Table 4-3). This finding was consistently seen during all conditions within training (see Figure 4-4C). We think that the very nature of the context and the type of activities practiced might have led to the distinct attentional patterns. Children engaged in familiar activities that were designed to promote joint engagement and shared attention between children and their social partners, as they took turns reading a book or as they built theme-based creations together. The building and art-craft conditions required children to follow several steps to build a creation. The trainer and the adult model provided a demonstration of the steps for each creation, but additionally we provided children with a visual instruction sheet that outlined the main steps to build each creation. We

noticed that many children chose to use the instruction sheet to make their creation instead of attending to the demonstration provided by their social partners. Secondly, in contrast to the activities in the music group that promoted social monitoring, activities in the academic group required children to attend to the supplies to build projects, thus leading to lower levels of sustained social monitoring. Lastly, the context allowed children ready access to non-social objects. Previous research suggests that children with ASDs prefer to attend to non-social compared to social stimuli (Annaz, Campbell, Coleman, Milne, & Swettenham, 2012; Ben-Sasson et al., 2007; Charman et al., 1998; Chawarska, Macari, & Shic, 2012; Klin et al., 2002; Ozonoff et al., 2010; Swettenham et al., 1998). In fact, salient non-social objects may act as a sort of “visual trap”, thereby limiting children’s opportunities to explore their social environment. Moreover, once “trapped”, children find it very hard to disengage their attention and focus on their social partners (Bird et al., 2006; Courchesne et al., 1994; Landry & Bryson, 2004; Leekam et al., 2000; Townsend & Courchesne, 1994). For example, a comparison of attentional patterns of TD individuals and individuals with ASDs using eye tracking, as they viewed dynamic social scenes suggested that individuals with ASDs spent greater time focused on the non-social elements of the scene (objects vs. faces) compared to TD individuals. Moreover, the time spent fixating on objects was negatively correlated with the individual’s level of social adjustment, suggesting that increased salience of non-social objects might have reduced opportunities for social attention in individuals with ASDs (Klin et al., 2002). Similarly, in a study where young 20-month old toddlers with ASDs, TD infants, and infants with DD were observed during a free play task with their CGs, it was found that infants with ASDs spent greater overall time attending to objects than people compared to the other 2 groups. Infants with ASDs also showed fewer attention shifts between objects and people and between two people compared to the control groups (Swettenham et al., 1998). Overall, we think that the nature of the context and the type of supplies provided afforded non-social visual fixation at the cost of social attention.

Along the same lines as the findings in the robot group, children in the academic group engaged in greater responsive compared to spontaneous social attention episodes with their adult interaction partners (see

Figure 4-5 and Table 4-5). Also, consistent with the nature of the training setup, children directed greater attention towards the trainer compared to the adult model (see Table 4-4). Given children's visual fixation with objects, we noticed that trainers and models had to provide multiple verbal bids to redirect children's attention towards them. This might have contributed to higher levels of responsive social attention in this group. Moreover, as mentioned before, the academic group was designed to mimic typical ABA settings, and literature suggests that behavioral interventions are more effective in promoting responsive compared to spontaneous verbal and non-verbal communication (Schreibman, 1997; Vismara & Rogers, 2010; Whalen & Schreibman, 2003). Our study suggests that table-top academic activities are not able to effectively promote spontaneous initiation of engagement in children with ASDs. We think that our finding has important clinical implications and adds to the literature that emphasizes the importance of devising play-based, loosely structured interventions that are engaging and intrinsically motivating for children with ASDs, and build on children's interests to facilitate spontaneous engagement and social initiations (Greenspan & Wieder, 1997; Kasari, Freeman, & Paparella, 2006; Koegel & Koegel, 1995; Prizant et al., 2006; Rogers, 2000; Schreibman & Pierce, 1993).

4.4.5. Generalized changes in RJA: Music, Robot, & Academic Groups

The music and academic groups improved their scores on the standardized test of RJA, the JTAT, in the posttest compared to the pretest (see Figures 4-2A & 4-2C). Specifically, children improved their verbal response scores on the JTAT in the posttest compared to the pretest (see Figures 4-2A & 4-2C). Children in the robot group did not demonstrate any significant improvements in RJA (see Figure 4-2B). All three groups involved the practice of 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 music group, during the setup and cleanup phases of each condition, the trainers and the models encouraged children to respond to their attentional bids involving distal objects in the environment including the PECS board, props, or musical instruments. Similarly, in the academic group, adults prompted children to direct their attention to specific objects by asking them to help pass

supplies, label specific objects, and cleanup supplies. These activities required children to follow the gaze of their social partners and shift attention between people and objects. Children in the music and academic groups might have improved their ability to respond to the verbal JA bids within the training context and might have further generalized learned skills to a standardized test of JA with a novel tester in the posttest. In contrast, lack of engagement and progressive boredom with the context might have limited opportunities to train JA in the robot group, leading to lack of improvements on the standardized test of RJA.

It was surprising that children in the music and academic groups showed generalized improvements in RJA without accompanying training-related improvements in the task-specific test of social attention within the training context. It is possible that our current coding scheme was not sensitive enough to capture changes in social attention. We used behavioral video coding to assess social attention, which might not have been able to capture instances when children used peripheral vision to attend to their 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 task-specific (duration of social attention) and generalized tests (response to joint attention bids) might have contributed to these findings. It is possible that improvements in social attention patterns might be evident not in the duration of social attention episodes but instead in the frequency of shared attention episodes between children and their social partners across training weeks. This might be a more sensitive variable to detect change in attention patterns in children following short-term behavioral interventions. In relation with our findings, recent work by Chawarska and colleagues suggests that sustained social monitoring within dyadic contexts might be a greater deficit in toddlers with ASDs compared to brief attentional bids within joint attention contexts (Chawarska et al., 2012). They assessed attentional patterns of 13- to 25-month old TD toddlers, toddlers with ASDs, and toddlers with DDs as they watched a video display of a model making a sandwich in a setting that included toys. The experiment included a dyadic condition where the model engaged with the toddler using eye contact and

child-directed speech, and a joint attention condition during which the model briefly made eye contact and then directed her gaze to one of the toys in the setting. They found that compared to the control groups, toddlers with ASDs directed greater attention to the non-social toys and the background, with lower attention directed towards the model during the dyadic condition; group differences were not pronounced in the joint attention condition which demanded relatively brief social orienting. The authors suggested that sustained dyadic orienting might be a more fundamental impairment in autism (Chawarska et al., 2012). Along the same lines, in our study, sustained social monitoring during the training activities might have been more challenging for children than response to brief bids for JA. Our training might have led to improvement in RJA, but the training intensity and duration might not have been enough to lead to robust improvements in sustained social monitoring skills of children. Future RCTs providing training for prolonged periods of time should test this hypothesis.

4.5. Clinical Implications

The findings of our study suggested that the music group engaged in higher social attention levels compared to the robot and academic groups. In the robot and academic groups, children spent maximum time attending respectively to the robot and the objects/supplies, which significantly restricted their opportunities to engage with their social partners. These findings underscore the importance of promoting dyadic engagement between children and their social partners in “object-free” contexts that facilitate sustained engagement with people in the absence of environmental distractors such as objects or an additional robotic entity. Dyadic engagement in turn has implications for the future development of triadic joint attention, verbal communication, empathy, and affective skills (Dawson et al., 2004; Kirschner & Tomasello, 2010; Leekam & Ramsden, 2006; Overy & Molnar-Szakacs, 2009; Toth, Munson, Meltzoff, & Dawson, 2006). Music-based movement contexts that promote whole-body joint action games seem to be a great context to promote shared attention and spontaneous engagement in children with ASDs. Other data from our lab also suggest that children in the music group enjoyed the activities and demonstrated high levels of positive affect and smiling during the training sessions.

Moreover, though the activities practiced in this group were novel and challenging for children, leading to higher levels of negative behaviors in the early training sessions, children showed a significant reduction in negative behaviors over time, and in fact improved their ability to imitate and synchronize with their social partners. In terms of verbal communication, children learned the songs and began to spontaneously sing the songs and initiate interactions with their social partners. In the robot group, our overall findings suggest that children were initially enamored with the robot, but over time they became bored with the context, and there was a resultant increase in negative affect and negative behaviors including tantrums in the later training sessions. Moreover, similar to social attention results reported in this paper which suggested that the robot did not serve as an effective mediator to enhance non-verbal communication between children and their social partners, findings from coding of verbalization patterns of children suggested that though there was some increase in socially-directed verbalizations with training, children in this group had overall greater levels of scripting and self-directed verbalizations compared to the other two groups. Overall, we think that the current robotic technology might not be able to sustain engagement of children and lead to meaningful improvements in core impairments associated with ASDs. The academic group was designed to serve as the standard-of-care comparison group and we were interested in evaluating whether the effects of novel, movement-based interventions would be comparable to those seen in the academic group. In line with our hypotheses, children found the activities practiced familiar, and therefore demonstrated maximum compliance with training activities and lower levels of negative behaviors compared to the other groups, even during the early training sessions. Children also demonstrated high levels of verbal communication during these training activities. However, surprisingly, engagement in academic contexts did not afford sustained social monitoring and in fact led to higher levels of non-social, object-related engagement. Our attention findings were also validated by results from video coding of repetitive behaviors during training sessions, which suggested that this group demonstrated greatest repetitive sensory behaviors including primitive and repeated, non-purposeful visual and tactile exploration of objects. To summarize, our work suggests that novel, embodied movement-based music interventions within group settings are engaging for children with ASDs and have

promising potential for promoting non-verbal and verbal social communication skills in children with ASDs. Future studies should replicate our procedures using larger and more homogeneous samples.

4.6. Limitations

Our study was an RCT with a limited sample size of 36 participants and a relatively short duration of training lasting for 16 sessions delivered over 8 weeks. We included both high- and low-functioning children with ASDs, which might have influenced our results. Future studies should develop separate protocols for high- and low-functioning children with ASDs to assess differential effects of interventions on these populations. In terms of behavioral coding, our coders were not blinded to the grouping of the child. Moreover, in the current study we evaluated the duration of attentional episodes of children towards their social partners. We are currently in the process of analyzing data on the frequency of social and non-social attentional episodes within training sessions. We think that future studies should use more sensitive measures to assess social attention including eye tracking technology. Further, in our study, we did not conduct any follow up assessments to evaluate whether improvements in RJA were sustained over time. Even though we provided intensive training to parents for conducting home sessions, we found that there was considerable variability in the adherence levels of parents with the home program. We think that the improvements in the robot group were limited due to the technical limitations of the robot including its limited movement repertoire, lack of dynamic and contingent responding, and frequent maintenance and equipment failure/over-heating issues.

4.7. Conclusions

In the current study, we compared the effects of music, robotic, and academic interventions on the social attention patterns of children with ASDs between 5 and 12 years of age using an RCT design. We found that the music context afforded greater social attention compared to the robotic and academic contexts. The robot group spent maximum time attending to the robot; however, across sessions there was progressive boredom with the context as demonstrated by a decrease in attention to the robot with a

concurrent increase in attention to elsewhere and to non-social objects in the room. The academic context afforded maximum attention to non-social objects. Further, while the music context afforded spontaneous initiation of engagement by children, the robot and academic groups afforded greater responsive social attention episodes. The music and academic groups demonstrated an improvement in RJA skills in the posttest compared to the pretest. In the future, we would like to explore the effects of other movement-based interventions including creative yoga and dance in children with ASDs. We would also like to develop parent- and peer-mediated interventions grounded in music and movement to maximize children's generalization of learned skills to naturalistic interactions.

Chapter 5

The effects of embodied rhythm interventions on spontaneous and responsive verbal communication skills of children with Autism Spectrum Disorders (ASDs)

5.1. Introduction

5.1.1. Overview of Autism Spectrum Disorders and implications of verbal and non-verbal communication in autism

According to the recent guidelines given by the Diagnostic and Statistical Manual of Mental Disorders, impairments in verbal and non-verbal communication skills are among the hallmark criteria for a diagnosis of Autism Spectrum Disorders (ASDs) (DSM-V) (American Psychiatric Association, 2013). Specifically, ASDs are characterized by a failure to engage in a typical back-and-forth conversation during communicative exchanges. This may be due to an impaired ability to use language for social interactions, difficulty in initiating conversations and in responding to conversations initiated by others, and engagement in one-sided monologues (Eigsti, de Marchena, Schuh, & Kelley, 2011; Landa, 2007; Tager-Flusberg, Paul, & Lord, 2005). Moreover, children have difficulty in both understanding and integrating non-verbal behaviors such as eye contact, body language, gestures, and facial expressions into interactions with their social partners (Mitchell et al., 2006; Shumway & Wetherby, 2009; Tager-Flusberg & Caronna, 2007). In fact, delays in achieving early language milestones such as the onset of first words are amongst the earliest causes for parental concern and physician referral in children who eventually go on to develop a diagnosis of ASD (Dahlgren & Gillberg, 1989; De Giacomo & Fombonne, 1998; Lord, Risi, & Pickles, 2004). There is, however, tremendous variability in the language profiles of children on the spectrum. While about 25% of children with ASDs never develop functional speech (Kjelgaard & Tager-Flusberg, 2001; Tager-Flusberg et al., 2005), at the other end, high-functioning children with ASDs develop vocabularies and grammatical abilities comparable to those of TD children (Luyster, Kadlec, Carter, & Tager-Flusberg, 2008; Thurm, Lord, Lee, & Newschaffer, 2007). However, even HF children with ASDs continue to demonstrate subtle difficulties in using their language appropriately during

reciprocal social interactions (Allen & Rapin, 1992; Luyster et al., 2008). Early language skills in children on the spectrum have been associated with their long term outcomes and future prognoses (Gillberg & Steffenburg, 1987; Gillberg, 1991; Kobayashi, Murata, & Yoshinaga, 1992; Lincoln, Courchesne, Kilman, Elmasian, & Allen, 1988; Rutter, 1970). Specifically, language skills at age 5 were predictive of later academic achievement and social competence in individuals with ASDs (Howlin, Mawhood, & Rutter, 2000; Sigman & Ruskin, 1999; Venter, Lord, & Schopler, 1992). Impairments in critical verbal and non-verbal communication skills negatively affect children's abilities to engage in meaningful interactions with peers and social partners, which in turn may lead to missed opportunities for children to learn skills associated with adaptive functioning, academic competence, and social engagement. Given the cascading long-term effects of communication impairments, significant research efforts have been directed towards understanding the nature of communication impairments in ASDs and developing effective interventions to address these impairments.

5.1.2. Impairments in receptive and expressive language in ASDs

Children with ASDs demonstrate impairments in both receptive and expressive language. In fact, in preschool-age children with ASDs, language comprehension was more affected relative to language production when measured using the parent report questionnaire, MacArthur Bates Communicative Development Inventory (MacCDI) (Charman, Drew, Baird, & Baird, 2003). When typically developing children listen to the linguistic input of a speaker, they make use of additional non-verbal cues such as the speaker's facial expressions, the tone of their voice, the speaker's proximity to the listener, etc., to comprehend their speech (James & Tager-Flusberg, 1994). Children with autism demonstrate both a core difficulty in understanding linguistic input and an impaired perception of subtle non-verbal and verbal cues that accompany speech, making language comprehension a significant challenge for them (Landa, 2007; Tager-Flusberg et al., 2005; Tager-Flusberg & Caronna, 2007). In terms of language production, children demonstrate impairments in both spontaneous and responsive speech production. For example, children had difficulty in commenting on topics initiated by others or offering relevant information that

was appropriate in terms of quantity and quality to the ongoing conversation (Adams, Green, Gilchrist, & Cox, 2002; Chuba, Paul, Miles, Klin, & Volkmar, November, 2003; Lord et al., 1989; Surian, Baron-Cohen, & Van der Lely, 1996; Ziatas, Durkin, & Pratt, 2003). Instead of engaging in reciprocal social dialogues involving frequent turn taking, high functioning children with ASDs tended to engage in speech monologues without due consideration of the needs of their listeners (Ghaziuddin & Gerstein, 1996; Ramberg, Ehlers, Nydén, Johansson, & Gillberg, 1996). In addition to impaired responsive communication, a majority of children with ASDs demonstrate significant difficulties in spontaneously initiating speech and had overall lower rates and less variation of speech compared to TD children (Koegel, Koegel, Harrower, & Carter, 1999; Tager-Flusberg et al., 2005). For example, on an average, children produced only 2 to 3 spontaneous communicative acts per hour during school hours (Stone & Caro-Martinez, 1990). Moreover, instead of using language in meaningful ways to communicate with their social partners, many children engaged in self-directed speech and echolalia, where they repeated/echoed words and phrases they had heard in the past (Eigsti et al., 2011; Tager-Flusberg & Calkins, 1990). Even very young preverbal children with ASDs showed atypical pre-linguistic vocalizations such as atypical phonation of produced syllables as well as greater rates of atypical vocalizations such as growls, squeals, raspberries, and clicks (Sheinkopf, Mundy, Oller, & Steffens, 2000; Wetherby, Cain, Yonclas, & Walker, 1988). Overall, language impairments are pervasive in nature and emerge very early in life in autism. In addition to obvious impairments in speech production and comprehension, children with ASDs also demonstrate impairments in skills such as joint attention, motor imitation, and play, which are foundational for the development of language in the first few years of life (Amato Jr, Barrow, & Domingo, 1999; Baron-Cohen, 1997; Charman et al., 1998; Dawson et al., 1998; Mundy & Hogan, 1994; Rogers, 1999; Sigman & Kasari, 1995; Smith & Bryson, 1994). Specifically, joint attention skills were predictive of current and future language abilities in children with ASDs (Bono, Daley, & Sigman, 2004; Charman et al., 2003; Dawson et al., 2004; Murray et al., 2008; Sigman & Ruskin, 1999; Toth et al., 2006). Similarly, early motor imitation abilities were predictive of future language skills (Charman et al., 2003; McDuffie, Yoder, & Stone, 2005; Stone, Ousley, & Littleford,

1997; Stone & Yoder, 2001). Lastly, functional and symbolic play skills have been linked to receptive and expressive language abilities in children with ASDs (Mundy, 1987; Sigman & Ruskin, 1999). Developmentally, both preverbal TD children and children with ASDs need to use joint attention, imitation, and play skills to engage in meaningful reciprocal communicative exchanges with their caregivers and learn critical skills which facilitate future language development (Landa, 2007). Given these developmental links, it is imperative that interventions targeting communication skills in ASDs also promote precursors of language including joint attention, play, and motor imitation.

5.1.3. Traditional interventions for communication impairments in ASDs

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 behavioral interventions that facilitate language as well as other related skills such as joint attention, play, and motor imitation (Delprato, 2001; Paul & Sutherland, 2005). Communication interventions include traditional and contemporary behavioral interventions (Hart & Risley, 1968; Lovaas, 2003; Lovaas, 1987; McGee, Krantz, Mason, & McClannahan, 1983) based on principles of applied behavioral analysis (ABA), and augmentative and alternative communication strategies such as sign language training (Sundberg & Partington, 1998), pictorial communication systems (Bondy & Frost, 2003), and voice output communication aids (Paul & Sutherland, 2005). Traditional ABA interventions use structured environments and multiple trials to teach children various adult-selected language skills through intense practice; however, children had difficulties in generalizing skills to novel environments (Delprato, 2001; Goldstein, 2002). In contrast, in contemporary ABA interventions, language skills are taught within naturalistic environments using stimuli that are centered on the child's interests and preferences (Rogers, 2006). Such approaches led to greater gains in language skills and generalization of learned skills to everyday activities (Delprato, 2001; Goldstein, 2002; Rogers, 2006). In contrast to behavioral interventions, alternative and augmentative interventions provide children with non-vocal means for communication (Paul, 2008). Interventions that combined sign and speech training led to increases in

receptive and expressive language skills, especially in children with poor imitation skills (Goldstein, 2002). The Picture Exchange Communication System (PECS) teaches children functional communication including requesting and commenting using pictures (Bondy & Frost, 2003). Following PECS training, children showed concurrent improvements in verbal speech and social skills such as initiations and requests, as well as a decrease in problem behaviors (Charlop-Christy et al., 2002). Lastly, voice output communication aids (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 include developmental pragmatic approaches such as Floortime (Greenspan & Wieder, 1997), the Denver Model (Rogers, Herbison, Lewis, Pantone, & Reis, 1986), and Social Communication, Emotional Regulation and Transactional Support (SCERTS) (Prizant et al., 2006). These interventions aim at facilitating the full range of communicative skills including eye contact, gestures, shared affect, vocalizations, and speech (Landa, 2007; Paul & Sutherland, 2005; Rogers, 2006). These approaches provide children with enriched experiences within naturalistic settings to mimic the developmental sequence of language acquisition seen in TD children (Rogers, 2006). Though appealing in ideology, there is currently limited evidence supporting the use of developmental pragmatic approaches (Paul & Sutherland, 2005; Rogers, 2006). Overall, several different approaches have been used to facilitate communication skills in children with ASDs.

5.1.4. Novel interventions for communication impairments in ASDs

In addition to the conventional approaches discussed above, there has been increasing research in recent times on the use of novel ideas and technologies to facilitate communication in autism. Music-based and robotic therapies are two promising adjunct intervention tools that may be appealing to children with ASDs for different reasons (Diehl et al., 2011; Simpson & Keen, 2011). In spite of significant impairments in the comprehension and production of language, children with ASDs have relatively preserved musical skills (Bonnell et al., 2003; Heaton, 2003). In fact, high functioning individuals with

autism performed better than control subjects on a pitch perception task (Bonnell et al., 2003). Similarly, in spite of their significant difficulties in processing affective information conveyed through speech, children with ASDs were successfully able to identify the affective signals in musical pieces (Heaton, Pring, & Hermelin, 1999). It is possible that these enhanced musical perception abilities in children with autism might be due to children's greater preference for musical input compared to linguistic input. In line with this hypothesis, children showed enhanced responses in the form of greater positive affect, vocalizations, and attention to musical stimuli compared to linguistic and other auditory cues (Molnar-Szakacs & Heaton, 2012). In addition to music being enjoyable and non-intimidating for children with autism, it has been proposed that whole-body musical experiences are multisystem in nature and have the potential of alleviating both core social communication and secondary perceptuo-motor and behavioral impairments in autism (Srinivasan & Bhat, 2013). Music and language are closely related to each other, allowing potential transfer of learning between these domains (Tallal & Gaab, 2006). Structurally, both music and language are hierarchically arranged, with higher-level units such as chords or words composed of lower-level units such as notes or syllables. Similarly, processing of musical and linguistic input requires the individual to parse out complex acoustic information by using memory and attentional resources (Foxton et al., 2003; Kraus & Chandrasekaran, 2010; Patel et al., 1998). Moreover, group-based musical activities involving singing, humming, and chanting provide great opportunities to facilitate verbal and non-verbal communication in children within meaningful yet enjoyable social exchanges (Overy & Molnar-Szakacs, 2009). Within such contexts, children can be taught skills such as turn taking, listening, responding, imitation, and reciprocity, all of which are essential for communicative exchanges between children and their social partners (Overy & Molnar-Szakacs, 2009; Srinivasan & Bhat, 2013). Given this theoretical evidence on the potential positive effects of music therapies in autism, we wanted to systematically examine the effects of an embodied music-based rhythm intervention on the social communication and motor skills of children with ASDs.

Socially interactive robots have been used anecdotally to promote social communication skills in children with ASDs (Feil-Seifer & Mataric, 2005; Fong, Nourbakhsh, & Dautenhahn, 2003). The underlying premise for this approach is that children with ASDs find technology - particularly robots - extremely motivating (Diehl et al., 2011; Scassellati, 2007). Children with autism find social interactions with humans very challenging and distressing, since they are required to simultaneously attend to and process multiple cues in speech, gestures, and facial expressions (Annaz et al., 2012; Klin, Lin, Gorrindo, Ramsay, & Jones, 2009). In contrast, the relative simplicity and predictability of robots allows children to practice isolated social skills in relatively non-intimidating environments involving robot-child interactions (Scassellati et al., 2012). Robots can be programmed to provide intense one-on-one interactions that are adapted to the developmental level of the child (Dautenhahn & Werry, 2004; Gillesen, Barakova, Huskens, & Feijs, 2011; Werry et al., 2001). Moreover, the robot can be used as a mediator to foster prosocial behaviors, such as joint attention, turn taking, imitation, and positive affect, between children and their social partners (Dautenhahn, 2003; Diehl et al., 2011). In fact, robots can provoke social behaviors that are typically not seen within interactions of children with their social partners (Duquette et al., 2008; Robins et al., 2005). Additionally, the robot could model specific social communication behaviors for the child, which the child could subsequently practice with the robot before transferring the learned skills to contexts involving interactions with humans (Diehl et al., 2011; Scassellati, 2007; Tapus et al., 2007). Given the potential uses of robotic technology, several attempts have been made to use robots as therapeutic tools for children with ASDs. However, a review of evidence from 15 studies that used robots in children with ASDs suggested that a majority of the studies were preliminary or exploratory in nature with limited sample sizes and lack of usage of standardized tools to assess treatment effects (Diehl et al., 2011). In addition, a majority of the studies assessed children's interactions with the robot over a single session (Diehl et al., 2011). In the current project, we used state-of-the-art robotic technology to examine the effects of an 8-week robot- child-adult interaction context on the social, communication, and motor skills of children with ASDs.

5.1.5. Rationale for current study and specific aims and hypothesis for spontaneous and responsive verbal communication

We compared the effects of two novel movement-based interventions, music and robotic, with the effects of a stationary, standard-of-care academic intervention on the social communication and motor skills of 36 children with ASDs between 5 and 12 years of age, using a randomized controlled trial (RCT) design. Children in the movement groups engaged in socially-embedded imitation and synchrony-based games that harnessed children's strengths and predilections using either music-based or robotic contexts. In contrast, in the academic group, children engaged in academic and fine motor imitation-based table-top activities within a group setting to mimic the kind of therapy environment that children with ASDs receive during contemporary ABA interventions. However, all three interventions were designed to provide children with abundant opportunities to engage in reciprocal communicative exchanges, involving back-and-forth conversations, turn taking, shared attention, and imitation, with their social partners. In this paper, we will report on the effects of these 8-week interventions on children's spontaneous and responsive communication skills. Effects of interventions on the social attention, synchrony, imitation, affective, and behavioral skills are reported elsewhere. Here, we will specifically report on changes from the pretest to the posttest in children's abilities to respond to the verbal and attentional cues initiated by a novel tester within a standardized test, as well as task-specific changes in children's vocalization and verbalization patterns within the training context across training weeks. Given children's difficulties in engaging in verbal interactions with their social partners and their tendency to engage in echolalia and self-directed vocalizations/verbalizations, we assessed the amount of time for which children verbalized to their social partners, to themselves, or to the robot (only in the robot group) during the entire duration of an early, a mid, and a late training session. Based on evidence of deficits in spontaneous initiation of speech in autism, we were further interested in assessing the nature of children's vocalizations/verbalizations as being either spontaneous (initiated without external prompting) or responsive (initiated in response to external prompting). We had three main research aims: (1) to

understand context-related group differences in vocalization and verbalization patterns; (2) to examine training-related changes in spontaneous and responsive communication skills of children within each group as assessed using standardized and task-specific measures; and (3) to examine condition-related differences in verbalization patterns within each group. In terms of context-related differences, we hypothesized that the movement groups, music and robotic, would engage in verbalization levels that would be comparable to those seen in the academic group. Moreover, given the nature of the training activities, we expected the music and robot groups to engage in greater spontaneous compared to responsive verbalizations. In contrast, we expected children in the academic group to engage in greater responsive speech compared to the other two groups. In terms of training-related changes, we expected that children in all three groups would improve their ability to initiate communication and to respond to the communicative bids of their social partners, both during a standardized test and within the training context. Lastly, in each group, children practiced imitation-based activities within different conditions. We were interested in examining the specific conditions within each group that promoted verbalization. We hypothesized that conditions which facilitated social interactions and/or singing without additional motor demands would elicit greater verbalization than conditions which required children to imitate gross and fine motor movements of their social partners.

5.2. Methods

5.2.1. Participants

Thirty-six children between 5 and 12 years of age were recruited for the study. Participating families fell within the upper-middle to upper socioeconomic classification as described by the Hollingshead scale of socioeconomic status (Hollingshead, 1975). Out of the thirty-six families, twenty were Caucasian, six were African American, four were Asian, three were Hispanic, and three were of mixed ethnicity (two children were mixed Caucasian-Hispanic and one child was of mixed Caucasian-African American ethnicity). Participants were recruited through fliers distributed to local autism centers, schools, and early intervention centers, as well as through online announcements. Participants were enrolled in the study

after parents provided medical or school records confirming the child's diagnosis. Eligibility of children was further confirmed using the Social Communication Questionnaire (Rutter et al., 2003), a parent screening instrument, and the Autism Diagnostic Observation Schedule, 2nd edition (ADOS-2) (Lord et al., 2012), a gold standard assessment for the diagnosis of ASDs. Children with additional orthopedic, cardiovascular, and neurological disorders or known visual or hearing impairments were excluded from the study. Children participated in the study following written parental consent as approved by the Institutional Review Board of the University of Connecticut.

Children were matched on age bands (4-5, 6-7, 8-9, 10-12 years), level of functioning, and amount and types of services received, prior to random allocation to the music, robot, or academic group. We assessed children's level of functioning using a subjective assessment of their social, communication, and motor skills based on their pretest performance. Specifically, expert testers rated children on a scale of 1 to 4 (1 – extremely low, 2 – low, 3 – moderate, 4 – high) on each of the above mentioned domains, and we obtained a composite score based on these subjective ratings. Following matching, we assigned Excel-generated random numbers to all children and within a matched triad, the child with the lowest number was assigned to the control group, the child with the highest number was assigned to the robot group, and the remaining child was assigned to the music group. In addition to matching, we also assessed for post-hoc differences between groups on age, gender, level of functioning, and scores on the communication domain of the Vineland Adaptive Behavior Scales (VABS) (Sparrow et al., 2005). The three groups did not differ significantly on age (Music: M (SD) = 7.88(2.56); Robot: M (SD) = 7.52 (2.22); Academic: M (SD) = 7.36(2.02), $ps > 0.05$), gender (Music: 10 Males, 2 Females; Robot: 11 Males, 1 Female; Academic: 11 Males, 1 Female, $\chi^2 p > 0.05$), and level of functioning (Music: M(SD) = 2.49 (0.78); Robot: M(SD) = 2.57(0.81); Academic: M (SD) = 2.90 (0.43), $ps > 0.05$). In addition, as mentioned above, we used the communication domain scores from the Parent/Caregiver rating form of the VABS (Sparrow et al., 2005), which is a standardized measure to assess the adaptive functioning of the child. The communication domain is made up of 3 sub-domains – receptive, expressive, and written. Each item

on the sub-domains is scored on a scale from 0 to 2 (0 – Never, 1- sometimes or partially, 2 – Usually) based on the child’s communication abilities. Out of the 36 children in the study, parents of 33 children filled out the questionnaire (2 children from the music group and 1 child from the robot group did not have questionnaire data). There were no significant group differences on the communication domain standard scores (Music: M (SD) = 75.6 (12.08); Robot: M (SD) = 69.45(20.87); Academic: M (SD) = 83.58 (21.76), $ps > 0.05$) of the VABS.

5.2.2. Procedure

Our study was conducted over 10 weeks, with the standardized pretest and the posttest conducted during the first and the last weeks of the study, respectively (see Table 5-1 for training protocol). The training was delivered over the intermediate 8 weeks, with 2 sessions conducted each week for a total of 16 sessions. Each session lasted for approximately 45 minutes. Out of the 36 children, 15 children missed 1 session each due to scheduling conflicts.

Pretest (Week 1)	Training sessions (Weeks 2-9)	Posttest (Week10)
Standardized test: Joint Attention Test (JTAT)	Training: Frequency: 2 sessions/week (expert trainer) 2 sessions/week (parent/caregiver) Intensity: 16 sessions over 8 weeks Time: 45 minutes/session Type: Music, Robot, or Academic training Task-specific test: Vocalization/verbalization patterns during an early (session 1), a mid (session 8), and a late (session 16) training session	Standardized test: Joint Attention Test (JTAT)

Table 5-1: Study timeline and testing measures

5.2.3. Training Protocol

The training was provided within a group setting where the child interacted with a trainer and an adult model to promote social interactions, joint action, and communication skills (see Figures 5-1A, 5-1B, and 5-1C). Commonalities existed within the session structure across groups: initial greeting, group-specific activity, and farewell. While the session structure remained consistent throughout the entirety of the training, activities were varied to stimulate the child's interest with general progression from simple to more complex tasks. We videotaped all sessions in order to code for a variety of relevant behaviors. All expert trainers and testers involved in the study were physical therapists or physical therapy/kinesiology graduate students with pediatric expertise, and they received significant training from the last author. All adult models received a 6-hour in-person, written, and video-based training prior to participation in training sessions. All trainers and adult models were required to follow instruction manuals that provided detailed instructions for the various activities in each group and outlined the trainer's and model's roles during each activity. Further, we also assessed training fidelity by choosing random sessions and scoring the behaviors of the trainers and the models based on a comprehensive checklist that assessed the trainer and model behaviors during all conditions of a session for each group. An unbiased undergraduate student coded an early, mid, and late training session for each child to score training fidelity.



Figure 5-1: Experimental set-up for training sessions - (A) Music group, (B) Robot group, (C) Academic group.

The music group engaged in singing and synchronous joint action activities to the beat of music (see Figure 5-1A). In this group, children were encouraged to sing songs for the hello and farewell conditions. In addition, children practiced the following conditions in each session – musical routines/action songs involving finger play, a beat keeping routine involving movements of the whole body, music-making activities with different musical instruments, a moving game involving walking-based synchronous games, and a calming song (see details of training activities in Table 5-2). We encouraged children to engage in free exploration with their body and with the instruments during a free play period.

Music Group	Robot Group	Academic Group
Hello Song	Hello	Hello
Action Song	Warm up Game	Condition Introduction
Beat Keeping	Action Game	Reading
Music Making	Drumming Game	Building
Moving Game	Walking Game	Arts & Crafts
Farewell Song	Farewell	Farewell

Table 5-2: Training conditions in the music, robot, and academic groups

The robot group engaged in imitation and synchronous movement games with a 23-inch humanoid robot, Nao (Aldebaran Robotics) and a mobile robot, Rovio™ (WowWee®) (see Figure 5-1B). The trainer controlled the robots via a laptop using custom software. The training involved the following conditions – a warm up game involving stretching movements of the upper and lower limbs, a whole-body movement-based action game, a drumming game involving the practice of simple and complex drum sequences, and a walking game involving tracing letters and shapes using the mobile Rovio™ robot (see details of training activities in Table 5-2). Training activities in the music and robot groups were based on themes such as start and stop, moving on a steady beat, turn taking, slow and fast, soft and loud, and moving on a count.

In the academic group, children engaged in sedentary, table-top activities that mimicked the type of social settings commonly used in special education (see Figure 5-1C). The training activities of the academic group included reading, where children read books that were appropriate to their developmental level,

building, where children built creations with Play-Doh®, Duplo®/Lego® blocks, building blocks, and Zoob (Infinity®), and arts & crafts, where children engaged in drawing, coloring, tracing, and cutting activities to make theme-based creations (see Table 5-2). The activities in the academic group were based on themes such as the solar system, basic shapes, people and the human body, weather and seasons, healthy foods, living things, and a sea theme. For all building and art-craft activities, children were provided with a visual instruction sheet of the steps necessary to complete the project. We provided children with opportunities for free play with the given supplies.

Home program: In addition to expert training sessions, we also encouraged parents to provide two additional home sessions to practice activities learned during expert training sessions. We provided parents/caregivers with materials/ props/CDs/robots depending on the grouping of the child. Parents were also provided with instruction manuals for the activities for each week. In addition, we provided in-person training to parents each week. Siblings were also encouraged to participate in the home sessions. We asked parents to videotape an early and a late training session.

5.2.4. Testing Protocol

The testing protocol consisted of a standardized test of responsive communication skills and a task-specific measure of verbal communication skills. We used the standardized measure, the Joint Attention Test (JTAT) (Bean & Eigsti, 2012), in the pretest and posttest sessions, to assess for generalized changes in responsive communication abilities of children following training. Joint attention is the ability to focus one's attention on the attentional focus of a social partner. The original JTAT (Bean & Eigsti, 2012) assesses the child's ability to respond to 6 naturalistic verbal and gestural bids initiated by the tester. We modified the JTAT to suit the needs of our study with permission from Dr. Eigsti, who was a collaborator on the project. The revised JTAT used in this study assesses the child's response to 9 naturalistic verbal and gestural prompts made by the tester to elicit the child's attention and/or verbal response (see Table 5-3 for details). The child and the tester were seated in front of each other across a table and the

environment was set up with objects at specific locations. The test includes gestural bids initiated by the tester, such as a bid to wave hi or a bid for a high-five, as well as verbal bids, where the tester verbally draws the child's attention to objects in the environment such as a picture on the wall or a novel object on the floor. For each prompt, the measure provides a hierarchy of bids, wherein if the child does not respond to the first level of bidding, the tester provides an additional verbal and/or gestural bid to elicit a response from the child. For example, if the child did not respond to a gestural bid to elicit a high-five, the tester prompted the child by saying, "Hey, Joey" and continued to gesture for a high-five. If the child still did not respond, the tester explicitly stated, "Hey Joey, can you give me a high-five?" while gesturing for a high-five. The child's responses were scored on a scale of 0 to 5. A higher score indicated better performance and points were provided for each of the following responses: (a) correct action, which was an appropriate response for each specific prompt, for example, for the "hand pen" prompt, we awarded a point for a correct response if the child took the pen from the tester (see Table 5-3 for details), (b) making eye contact with the tester, (c) looking at the face or in the appropriate direction, which included instances where the child did not make eye contact with the tester but instead looked at the tester's face, or when the child did not look at the exact object being referred to by the tester but instead looked in the general direction of the object, (d) smiling at the tester, and (e) producing verbalization that was relevant to the context, for example, providing details about the picture/poster on the wall at which the tester was looking. The tester embedded the JTAT prompts within the other standardized gross and fine motor assessment items conducted during the testing sessions. Testers provided the JTAT prompts during transitions or clean-up phases to ensure that the child was engaged with other objects or tasks. However, we avoided instances when children were intensely focused on the activities of the standardized tests which made attention disengagement difficult for them. Two coders coded the entire dataset after establishing inter-rater reliability of > 85% on 20% of the dataset.

Prompts	Correct responses
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, wristwatch etc.)	Looks at the tester/appropriate direction and the object
Gestural prompts	
Wave “hi”/shake hand	Waves “hi” or shakes hand
Hand pen	Takes pen
High-five	Gives high-five
Low-five	Gives low-five
Wave “bye”	Waves “bye”

Table 5-3: Verbal and gestural prompts of the Joint Attention Test (JTAT)

In addition to the standardized test for responsive communication skills, we also assessed for task-specific changes in vocalization/verbalization patterns of children within the training context. Specifically, we used custom video coding software called OpenSHAPA (GitHub Inc.) to code for training-related changes in vocalization/verbalization patterns of children in all groups during the entire duration of an early, a mid, and a late training session. A single coder coded all videos after establishing intra- and inter-rater reliability of greater than 85% using 20% of the dataset. Specifically, we coded for the duration of the following types of vocalizations/verbalizations -

1. Vocalization/verbalization to self: This included bouts where the children spontaneously vocalized/verbalized to themselves without any external prompting. This category included bouts of vocalizations such as shouting, squealing, giggling, whining, and low moaning. In addition, we included verbalization of children that was not clearly directed towards their social partners, including unclear word approximations, for example, use of “da” or “dra” for “drum”, delayed echolalia where children repeated words they remembered from a different context, and repeated words and sentences where children repeated words or sentences that the trainer/model/caregiver just said.

2. Verbalization to social partners: This included bouts where children verbalized to their social partners including the trainer, the model, and their caregiver. Verbalization to social partners included instances where children used words or sentences that were clearly directed to any of their social partners. We further classified verbalization to social partners as being directed towards the trainer, or the model, or the caregiver.
3. Verbalization to the robot: This included bouts where children in the robot group used words or sentences to verbalize with the Nao and Rovio robots.

In addition to categorizing the target of children's vocalizations/verbalizations (to self, to social partner, and to robot), we further classified the vocalization/verbalization type as being spontaneous or responsive. The vocalization/verbalization was considered spontaneous when the child initiated it spontaneously without any prompting from their social partners. In contrast, the verbalization was considered to be responsive when it was produced by the child in response to a prompt/comment/question initiated by their social partners.

5.2.5. Dependent Variables

For the generalized measure of responsive communication skills, the JTAT, we calculated a total response score for the pretest and posttest sessions for each child. The total response score for a session was a sum of the response scores on all 9 individual items of the JTAT. The JTAT scores ranged from 0 to 38, with higher scores indicating better performance. In addition, we calculated separate verbal and gestural response scores. The verbal response score (maximum possible score – 16) was a sum of response scores on the 4 verbal prompts, and the gestural response score (maximum possible score – 22) was the sum of the response scores on the 5 gestural items of the JTAT (see Table 5-3 for details). In terms of the task-specific measure of verbal communication skills, we calculated the percent duration of different types of vocalizations/verbalizations with respect to the total duration of the session.

5.2.6. Statistical Analysis

We used SPSS Version 16 (SPSS, Inc., Chicago, IL) for statistical analysis of our data. We checked our data for assumptions of parametric statistics including normal distribution and homogeneity of variances. Data from the JTAT satisfied all assumptions of parametric statistics. Hence, we used dependent *t*-tests to assess for generalized changes in the raw total, verbal, and gestural response scores of the JTAT between the pretest and the posttest sessions within each of the groups. For the task-specific measure of verbal communication skills, our analysis revealed that the data were not normally distributed and had a moderate number of outliers. Hence, we applied a square root transformation to our variable of percent duration of vocalizations/verbalizations. We used transformed data to conduct two repeated measures ANOVAs to assess training-related changes in vocalization/verbalization patterns. The first ANOVA included verbalization target (to self, to social partners, to robot), verbalization type (spontaneous, responsive), session (early, mid, late), and condition (5 conditions within a session for each group – see table 5-2 for details) as the within-subjects factors and group as the between-subjects factor. We were interested in further examining the within-group changes and between-group differences in verbalization to different social partners (trainer vs. model/caregiver (CG)). Hence, we conducted a second ANOVA on data from only verbalization to social partners. We included social partner (trainer, model/ CG), verbalization type (spontaneous, responsive), session (early, mid, and late), and condition (conditions 1-5 in each group) as within-subjects factors and group as a between-subjects factor. In case of violations of the Mauchly's test of sphericity, we applied Greenhouse Geisser corrections. If there was a significant main effect and an interaction, we conducted post-hoc *t*-tests to evaluate the significant interactions only. In case of significant 2-way and 3-way interactions involving the same factors, we further analyzed the 3-way interactions using post-hoc *t*-tests. We report data in the form of means and standard deviations (M (SD)). For the standardized JTAT test, we will report data in terms of raw scores, whereas for the task-specific measure of vocalization/verbalization patterns, we will report data in terms of percent duration of time. We report effect sizes using the partial eta-squared (η_p^2) and standardized mean difference (SMD) values (calculated using Hedge's *g*) (Hedges, 1981). Statistical significance was set at $p \leq 0.05$.

5.3. Results

5.3.1. Generalized changes in responsive communication skills

We report on the generalized changes in social attention from the pretest to the posttest session using the standardized JTAT test. Three children out of the total 36 children were excluded from the analysis of the standardized test since they were very low-functioning and could not remain seated and attend to the tester's instruction, both in the pretest and the posttest sessions. The final analysis for the JTAT test was based on 11 children in each group. We report results in the form of within-group changes below.

In the music group, dependent *t*-tests indicated a significant increase in total response scores of the JTAT from the pretest ($M (SD) = 20.27(5.50)$) to the posttest ($M (SD) = 23.55(4.27)$, $p = 0.005$, $SMD = 0.55$). Specifically, individual data suggested that 9 out of 11 children followed the group trends. Further, this improvement in performance was seen for the verbal items of the JTAT (Pretest: $M (SD) = 9.64(4.80)$, Posttest: $M (SD) = 11.82(3.52)$, $p = 0.02$) (see Figure 5-2A).

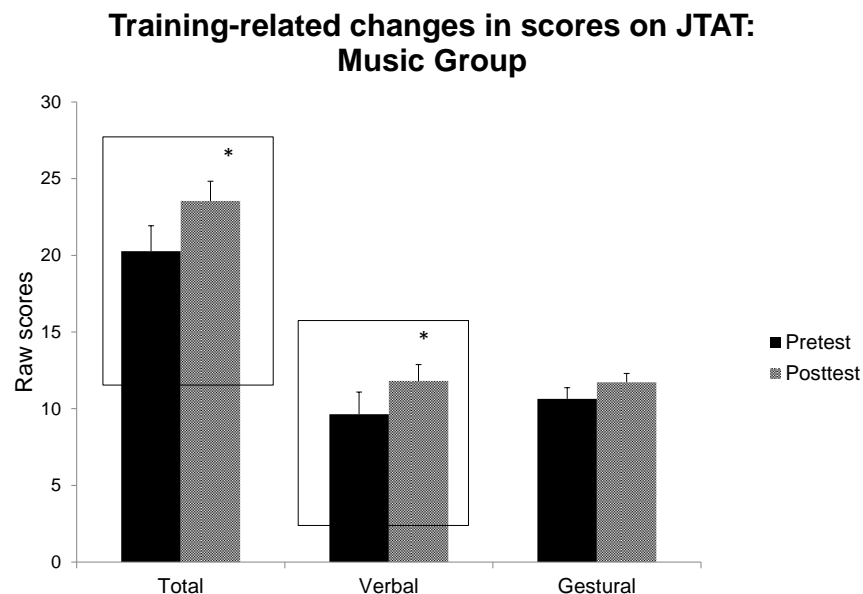


Figure 5-2A: Training-related changes in total, verbal, and gestural response scores of the JTAT in the music group. Error bars represent standard errors. $*p \leq 0.05$

In the robot group, there were no significant improvements on the total, verbal, and gestural response scores of the JTAT from the pretest to the posttest session (see Figure 5-2B).

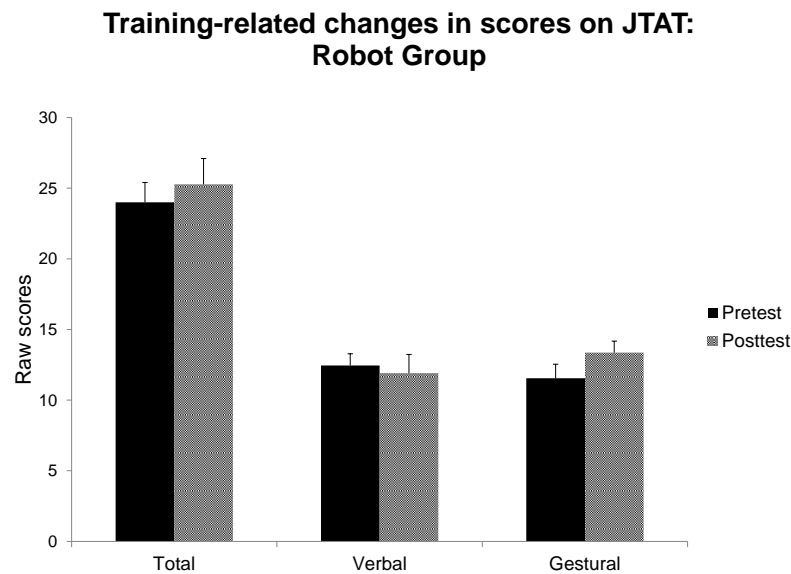


Figure 5-2B: Training-related changes in total, verbal, and gestural response scores of the JTAT in the robot group. Error bars represent standard errors.

In the academic group, children demonstrated a significant improvement in total response scores in the posttest ($M (SD) = 25.36 (4.11)$) compared to the pretest ($M (SD) = 21.18 (5.47)$, $p = 0.003$, $SMD = 0.71$) (see Figure 5-2C). Individual data suggested that 9 out of 11 children improved their performance in the posttest session. Further, we found that children showed significant improvements in the JTAT verbal response scores with training (Pretest: $M (SD) = 10.73 (4.03)$, Posttest: $M (SD) = 13.55 (2.02)$, $p = 0.008$) (see Figure 5-2C). No significant differences between pretest and posttest scores were seen for the gestural items of the JTAT.

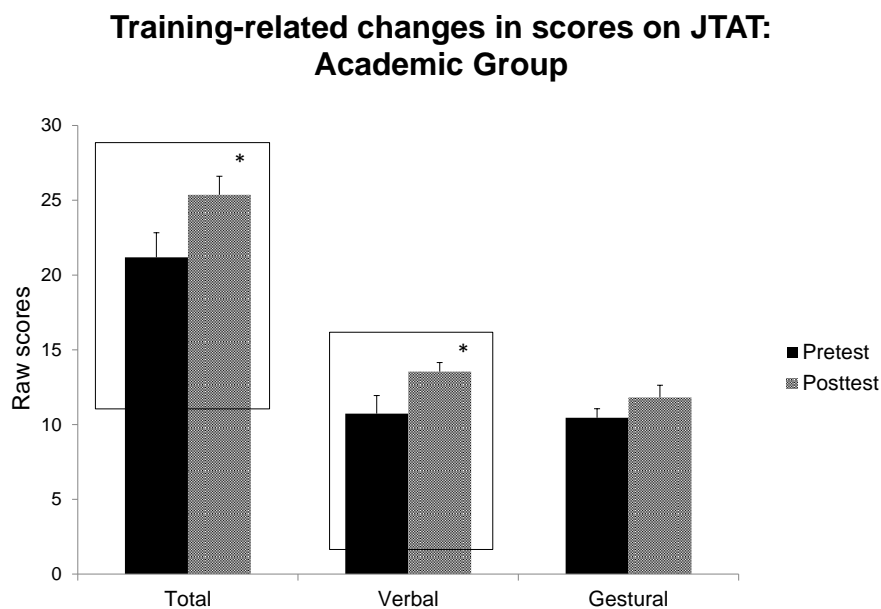


Figure 5-2C: Training-related changes in total, verbal, and gestural response scores of the JTAT in the academic group. Error bars represent standard errors. * $p \leq 0.05$

5.3.2. Task-specific changes in verbal communication skills

A. Task-specific changes in vocalization/verbalization targets –

The repeated measures ANOVA suggested a significant main effect of session ($F(2, 66) = 9.63, p < 0.001, \eta_p^2 = 0.23$), a main effect of condition ($F(3.25, 107.09) = 29.51, p < 0.001, \eta_p^2 = 0.47$), a main effect of verbalization target ($F(1.08, 35.66) = 70.45, p < 0.001, \eta_p^2 = 0.68$), a main effect of verbalization type ($F(1, 33) = 192.30, p < 0.001, \eta_p^2 = 0.85$), a condition x group interaction ($F(8, 132) = 19.33, p < 0.001, \eta_p^2 = 0.54$), a verbalization target x group interaction ($F(4, 66) = 3.91, p = 0.007, \eta_p^2 = 0.19$), a verbalization type x group interaction ($F(2, 33) = 3.56, p = 0.04, \eta_p^2 = 0.18$), a session x verbalization target interaction ($F(3.02, 99.75) = 12.31, p < 0.001, \eta_p^2 = 0.27$), a condition x verbalization target interaction ($F(4.36, 143.83) = 28.39, p < 0.001, \eta_p^2 = 0.46$), a condition x verbalization type interaction ($F(2.74, 90.42) = 2.80, p = 0.05, \eta_p^2 = 0.08$), a verbalization target x

verbalization type interaction ($F(1.16, 38.34) = 21.06, p < 0.001, \eta_p^2 = 0.39$), a session x condition x group interaction ($F(16, 264) = 1.69, p = 0.05, \eta_p^2 = 0.09$), a condition x verbalization target x group interaction ($F(16, 264) = 12.35, p < 0.001, \eta_p^2 = 0.43$), a condition x verbalization type x group interaction ($F(8, 132) = 3.61, p = 0.001, \eta_p^2 = 0.18$), a verbalization target x verbalization type x group interaction ($F(4, 66) = 2.67, p = 0.04, \eta_p^2 = 0.14$), a session x verbalization target x verbalization type interaction ($F(2.94, 96.92) = 3.78, p = 0.01, \eta_p^2 = 0.10$), and a condition x verbalization target x verbalization type interaction ($F(3.93, 129.68) = 4.41, p = 0.002, \eta_p^2 = 0.12$).

We analyzed the three meaningful interactions of verbalization target x verbalization type x group, condition x verbalization target x group, and condition x verbalization type x group by conducting further post-hoc *t*-tests. The results are reported below as within-group changes and between-group differences. All data reported below are in terms of percent duration of vocalizations/verbalizations.

1. Within-group changes:

- a. *Music group*: Overall, irrespective of session and condition, children engaged in a greater duration of spontaneous verbalization with social partners ($M(SD) = 10.73(11.88)$) compared to vocalizations/verbalizations directed towards self ($M(SD) = 3.67(4.43)$), $p = 0.007$) (see Figure 5-3). In terms of verbalization type, children engaged in greater spontaneous ($M(SD) = 10.73(11.88)$) versus responsive verbalization with their social partners ($M(SD) = 2.54(2.19)$), $p < 0.001$) (see Figure 5-3).

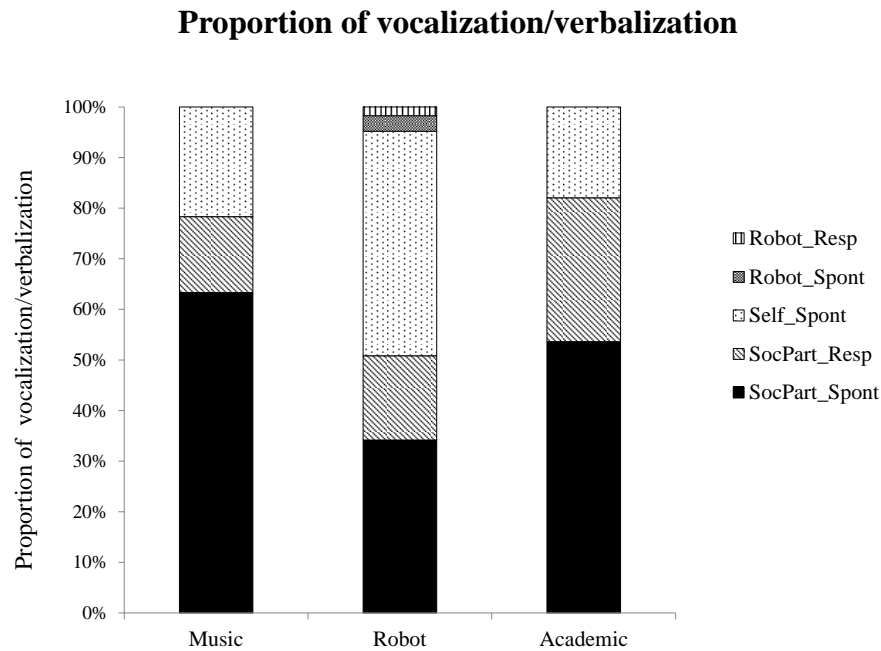


Figure 5-3: Proportion of spontaneous and responsive vocalizations/verbalizations to social partners, to self, and to the robot in the music, robot, and academic groups.

In terms of condition-related differences in verbalization targets, children verbalized more with social partners than with themselves during the social interaction phase, action song, beat keeping, and moving game conditions (p values range from < 0.001 to 0.01) (see Figure 5-4A). Specifically, children verbalized more with social partners during the social interaction and action song conditions compared to all other conditions (p values range from < 0.001 to 0.03) No such condition-related differences in amount of vocalizations/verbalizations to self were observed. In terms of condition-related differences in verbalization type, the music group demonstrated greater spontaneous compared to responsive vocalizations/verbalizations in all conditions (p values range from < 0.001 to 0.01) (see Figure 5-4A).

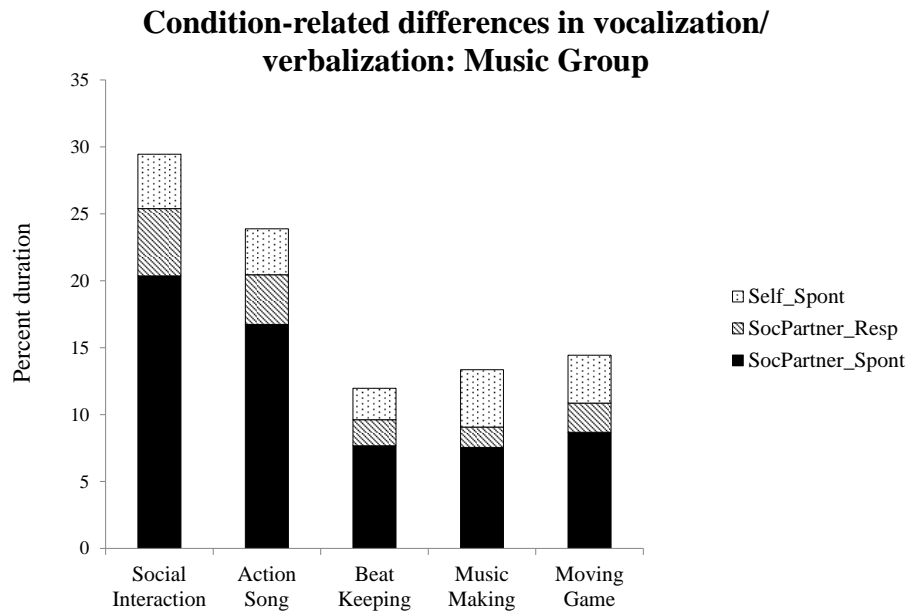


Figure 5-4A: Condition-related differences in spontaneous and responsive vocalizations/verbalizations to social partners and to self in the music group.

- b. *Robot Group:* Children verbalized spontaneously to their social partners and to themselves (To social partners: $M (SD) = 5.82 (5.57)$; to self: $M (SD) = 7.56 (5.51)$) for a greater duration compared to verbalization with the robot ($M (SD) = 0.52 (0.74)$, p values < 0.001) (see Figure 5-4B). They also engaged in greater responsive verbalization with their social partners ($M (SD) = 2.83 (1.98)$) than with the robot ($M (SD) = 0.29 (0.30)$, $p < 0.001$) (see Figure 5-3). Between the two verbalization types, irrespective of session and condition, children verbalized more spontaneously ($M (SD) = 5.82 (5.57)$) than in a responsive manner ($M (SD) = 2.83 (1.98)$, $p < 0.001$) with their social partners (see Figure 5-3). Along the same lines, children verbalized more with the robot spontaneously ($M (SD) = 0.52 (0.74)$) than in a responsive manner ($M (SD) = 0.29 (0.30)$, $p = 0.05$) (see Figure 5-3).

In terms of condition-related differences in verbalization targets, there were no significant differences between the amounts of vocalizations/verbalizations targeted towards social

partners and towards self in all conditions except the social interaction phase. In the social interaction phase, children verbalized more to their social partners compared to vocalizing/verbalizing to themselves ($p < 0.001$) (see Figure 5-4B). Children verbalized more with social partners compared to verbalization with the robot in all conditions (p values < 0.001) (see Figure 5-4B). Similarly, they verbalized more to themselves compared to the robot in all conditions (p values < 0.001) except the social interaction phase (see Figure 5-4B). Moreover, the amount of verbalization to social partners was maximum during the social interaction phase followed by the action game condition as compared to all other conditions (p values range from < 0.001 to 0.05) (see Figure 5-4B). Children verbalized most to themselves in the drumming game compared to the social interaction phase and the warm up game (p values ≤ 0.05) (see Figure 5-4B). Lastly, children verbalized more to the robot in the social interaction phase compared to the other conditions, with least verbalization to the robot during the walking game condition (p values range from < 0.001 to 0.03) (see Figure 5-4B). In terms of condition-related differences in verbalization type, children verbalized more spontaneously than in a responsive fashion in all the conditions (p values < 0.001) (see Figure 5-4B).

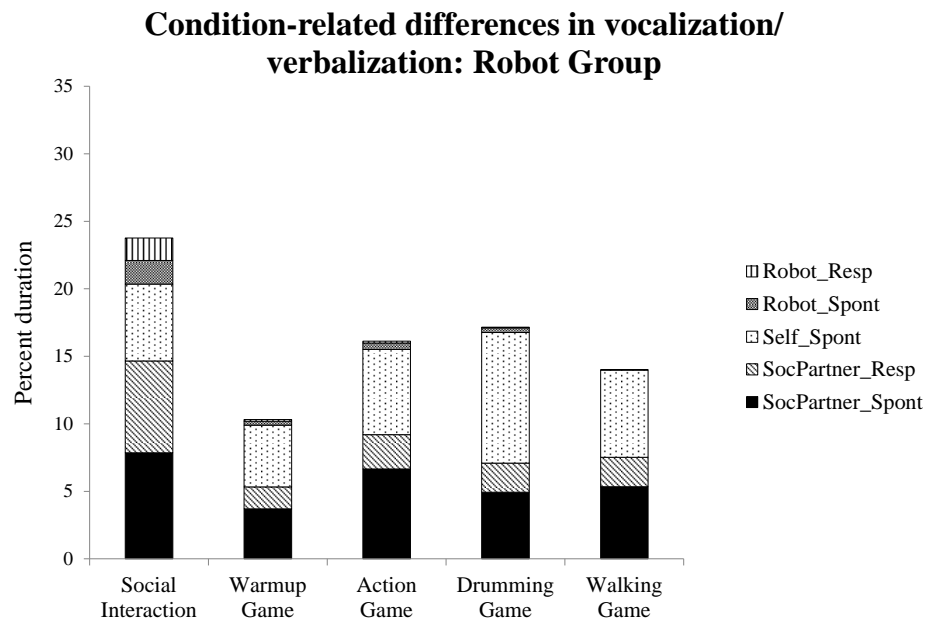


Figure5-4B: Condition-related differences in spontaneous and responsive vocalizations/verbalizations to social partners, to self, and to the robot in the robot group.

- c. Academic Group: Along the lines of the music group, irrespective of session and condition, the academic group spontaneously verbalized more with social partners (M (SD) = 10.42 (8.66)) than with themselves (M (SD) = 3.49 (4.55), $p = 0.001$) (see Figure 5-3). In terms of differences in types of verbalization, children demonstrated greater spontaneous (M (SD) = 10.42 (8.66)) compared to responsive verbalization (M (SD) = 5.52 (3.12), $p < 0.001$) with their social partners (see Figure 5-3).

In terms of condition-related differences in verbalization targets, children verbalized with social partners for a longer duration compared to verbalization directed to themselves during all the conditions (p values < 0.001) (see Figure 5-4C). Moreover, children verbalized the most with their social partners during the social interaction phase and the reading conditions compared to all other conditions (p values < 0.001) (see Figure 5-4C).

In terms of condition-related differences in verbalization type, children engaged in greater spontaneous compared to responsive verbalization during all conditions except

the social interaction phase (p values range from < 0.001 to 0.01), in which there were no differences between the types of verbalization.

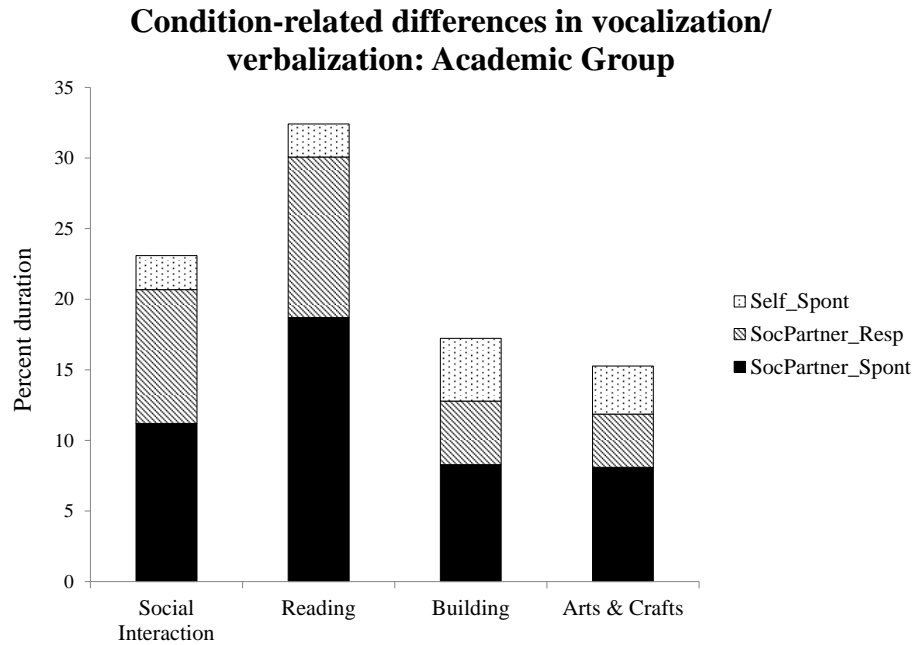


Figure 5-4C: Condition-related differences in spontaneous and responsive vocalizations/verbalizations to social partners and to self in the academic group.

2. Between-group differences:

Overall, irrespective of session, the music ($M (SD) = 10.73 (11.88)$) and academic groups ($M (SD) = 10.42 (8.66)$) engaged in greater spontaneous verbalization with social partners compared to the robot group ($M (SD) = 5.82 (5.57)$, p values ≤ 0.05 (see Figure 5-3).

Similarly, the academic group ($M (SD) = 5.52 (3.12)$) engaged in greater responsive verbalization with social partners compared to the music ($M (SD) = 2.54 (2.19)$) and robot groups ($M (SD) = 2.83 (1.98)$, p values < 0.001) (see Figure 5-3). Lastly, the robot group ($M (SD) = 7.56 (5.51)$) engaged in greater spontaneous verbalization to themselves compared to the music ($M (SD) = 3.67 (4.43)$) and academic groups ($M (SD) = 3.49 (4.55)$, p values ≤ 0.05) (see Figure 5-3).

B. Task-specific changes in verbalization patterns to social partners –

The repeated measures ANOVA suggested a significant main effect of session ($F(2, 66) = 15.98, p < 0.001, \eta_p^2 = 0.33$), a main effect of condition ($F(3.05, 100.78) = 38.59, p < 0.001, \eta_p^2 = 0.54$), a main effect of social partner target ($F(1, 33) = 60.21, p < 0.001, \eta_p^2 = 0.65$), a main effect of verbalization type ($F(1, 33) = 21.48, p < 0.001, \eta_p^2 = 0.39$), a condition x group interaction ($F(8, 132) = 14.02, p < 0.001, \eta_p^2 = 0.46$), a social partner target x group interaction ($F(2, 33) = 10.78, p < 0.001, \eta_p^2 = 0.40$), a condition x social partner target interaction ($F(2.84, 93.75) = 17.14, p < 0.001, \eta_p^2 = 0.34$), a session x verbalization type interaction ($F(2, 66) = 5.40, p = 0.007, \eta_p^2 = 0.14$), a social partner target x verbalization type interaction ($F(1, 33) = 6.95, p = 0.01, \eta_p^2 = 0.17$), a session x social partner target x group interaction ($F(4, 66) = 3.51, p = 0.01, \eta_p^2 = 0.18$), a condition x social partner target x group interaction ($F(8, 132) = 11.77, p < 0.001, \eta_p^2 = 0.42$), a condition x verbalization type x group interaction ($F(8, 132) = 2.81, p = 0.007, \eta_p^2 = 0.15$), a condition x social partner target x group interaction ($F(8, 132) = 11.77, p < 0.001, \eta_p^2 = 0.42$), and a condition x social partner target x verbalization type interaction ($F(2.61, 86.25) = 4.04, p = 0.013, \eta_p^2 = 0.11$).

We analyzed the two meaningful interactions of session x social partner target x group and condition x social partner target x group by conducting further post-hoc *t*-tests. The results are reported below as within-group changes and between-group differences. All data reported below are in the form of percent duration of verbalization.

1. Within-group changes:

- a. Music group: Overall, the music group verbalized more towards the trainer (Early: $M(SD) = 6.07(5.71)$, Mid: $M(SD) = 12.80(14.52)$, Late: $M(SD) = 14.84(14.99)$) compared to the model/CG in all 3 sessions (Early: $M(SD) = 2.10(2.32)$, Mid: $M(SD) = 1.76(1.88)$, Late: $M(SD) = 2.24(2.27)$, p values < 0.05) (see Figure 5-5). Moreover, children showed a training-related increase in verbalization to the trainer in the late session ($M(SD) = 14.84(14.99)$) compared to the early session ($M(SD) = 6.07(5.71)$), $p = 0.02$, $SMD = 1.43$) (see Figure 5-5). Specifically, this group trend was followed by 11

out of 12 children in the group. In terms of condition-related changes, children verbalized more to the trainer compared to the model/CG in all conditions (p values range from < 0.001 to 0.01).

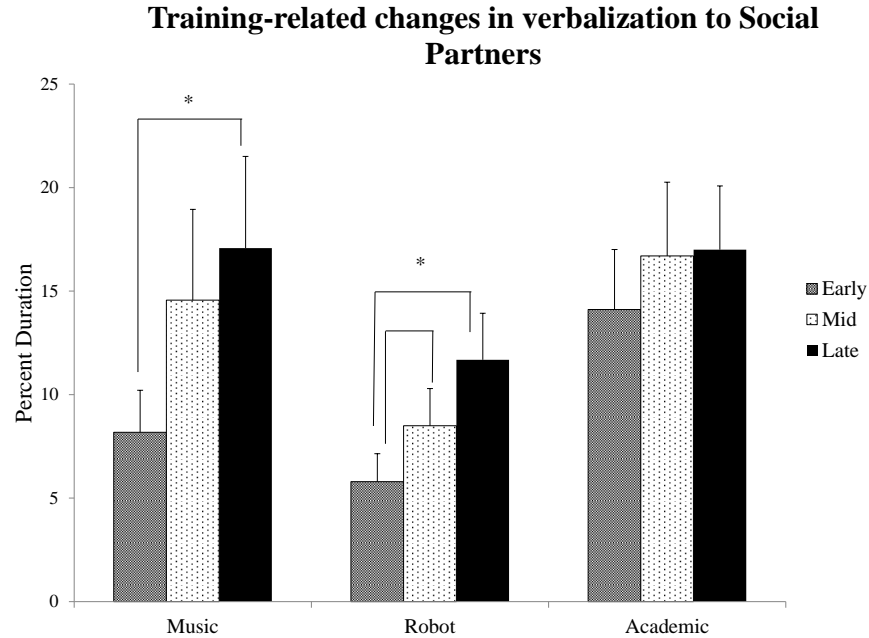


Figure 5-5: Training-related changes in verbalizations to social partners in the music, robot, and academic groups. Error bars represent standard errors. $*p \leq 0.05$

- b. Robot group: Overall, in all 3 sessions, children showed no significant differences in verbalization to the trainer and the model/CG. Children showed a training-related increase in verbalization to the model/CG from the early ($M (SD) = 1.92 (1.13)$) to the mid ($M (SD) = 3.36 (1.65)$, $p = 0.003$, $SMD = 1.18$) and to the late ($M (SD) = 5.39 (4.22)$, $p = 0.009$, $SMD = 2.84$) sessions (see Figure 5-5). In terms of individual data, 11-12 out of 12 children followed the group trends. In terms of condition-related changes, children showed no differences in the verbalization to the trainer and the model/CG except in the warm up game, where children verbalized more with the trainer compared to the model/CG ($p = 0.01$).

- c. Academic group: Overall, in all 3 coded sessions, children verbalized more with the trainer (Early: M (SD) = 12.08 (8.62), Mid: M (SD) = 14.49 (11.25), Late: M (SD) = 14.44 (8.56)) compared to the model/CG (Early: M (SD) = 2.03 (1.61), Mid: M (SD) = 2.21 (1.93), Late: M (SD) = 2.56 (2.40), p values < 0.001) (see Figure 5-5). There were no training-related improvements in verbalization to the trainer or the model. In terms of condition-related changes, children verbalized more to the trainer compared to the model/CG in all the conditions (p values < 0.001).
2. Between-group differences:
- The academic group (Early: M (SD) = 12.08 (8.62), Mid: M (SD) = 14.49 (11.25), Late: M (SD) = 14.44 (8.56)) verbalized for a longer duration with the trainer than the robot group (Early: M (SD) = 3.87 (4.15), Mid: M (SD) = 5.13 (5.30), Late: M (SD) = 6.29 (6.13), p values < 0.05) in all 3 sessions. In contrast, the robot group (Mid: M (SD) = 3.36 (1.65), Late: M (SD) = 5.39 (4.22)) engaged in greater verbalization with the model/CG in the mid and late sessions compared to the music group (Mid: M (SD) = 1.76 (1.88), Late: M (SD) = 2.24 (2.27), p values < 0.05).

5.4. Discussion

5.4.1. Summary of results

Our randomized controlled trial compared the effects of 8 weeks of movement-based interventions to those of a stationary academic-based intervention on the social communication skills of 36 children with ASDs between 5 and 12 years of age. Specifically, we compared the effects of music and robotic therapies with those of a standard-of-care academic intervention on the spontaneous and responsive communication skills of children. We found context-related group differences in vocalization/verbalization patterns of children. Children in the music and academic groups verbalized spontaneously with their social partners for a longer duration compared to those in the robot group. In contrast, children in the robot group verbalized spontaneously to themselves more than children in the

other two groups (see Figure 5-3). In terms of responsive verbalization, children in the academic group engaged in greater responsive speech with their social partners compared to the children in the music and robot groups. Lastly, though the robot was an added social entity in the robot group, children spent a very small proportion of time verbalizing to the robot (see Figure 5-3). Next, we were interested in examining *training-related changes* in children's communication skills within each group. Children in the movement groups, music and robotic, showed an increase in the duration of verbalization to their social partners across sessions (see Figure 5-5). Specifically, children in the music group increased the amount of verbalization to the trainer from the early to the late session, whereas children in the robot group increased time spent talking to the model from the early to the mid and from the early to the late sessions (see Figure 5-3). Children in the music group also demonstrated improvements in their ability to respond to the verbal and attentional cues of a novel tester during the standardized JTAT test, suggesting that there was generalization and carry-over of learned skills to a novel context (see Figure 5-2A). Children in the academic group spent a greater amount of time verbalizing with their social partners even in the early session; they maintained this amount of verbalization across training sessions, with no further significant increase in the amount of verbalization (see Figure 5-3). However, the children in the academic group did improve their responsive communication skills, as suggested by improvements in their ability to respond to the verbal and attentional bids initiated by a novel tester during the posttest compared to the pretest (see Figure 5-2C). Lastly, we were interested in examining *condition-related differences* within each group to understand the types of training contexts that promoted verbalization within each group. We found that in all three groups, conditions that focused on social interactions without concurrent motor demands afforded greater verbalization (see Figures 5-4A, 5-4B, & 5-4C). Additionally, in the music group, conditions that encouraged singing were enjoyable and facilitated verbalization in children with ASDs (see Figure 5-4A). Similarly, in the robot group, the action game - where children engaged in rhythmic synchrony games with the adult model to the beat of music - promoted greater verbalization compared to other conditions (see Figure 5-4B).

5.4.2. Context-related group differences in verbalization patterns

Children in the music and academic groups verbalized spontaneously with their social partners for a longer duration compared to children in the robot group (see Figure 5-3). We hypothesized that the amount of verbalization in the movement groups would be comparable to that seen in the standard-of-care academic group. The stationary academic group engaged in activities such as reading and fine motor imitation, which are typically practiced by children in school-based ABA settings. Conventionally, these sedentary contexts have been used to facilitate verbal communication in children (Goldstein, 2002; Paul & Sutherland, 2005). Such table-top contexts are ideal to promote verbal skills, since children are relatively confined at the table, and trainers are provided with abundant opportunities to engage children in reciprocal conversations. In contrast, in the music and robot groups, children engaged in rhythmic synchrony and imitation-based gross motor games with their social partners to the beat of music. In spite of the relatively unconstrained nature of training activities in the music and robot groups, we expected children to engage in high levels of interactions with their social partners, since the activities practiced were tapping into children's inherent strengths and predilections. In comparison to adult-selected activities within highly structured and confined table-top settings, children showed greater improvements in language skills following child-led activities that took place within unconfined play-based settings, as suggested by a comprehensive review based on 10 studies (Delprato, 2001). Moreover, interventions that promoted skills such as motor imitation, play, and joint attention led to collateral increases in language skills of children with ASDs (Ingersoll & Schreibman, 2006; Jones, Carr, & Feeley, 2006; Kasari, Paparella, Freeman, & Jahromi, 2008; Kasari et al., 2006). 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 the same lines, our movement groups were designed to promote joint engagement through imitation-based games, and we expected children to verbalize at levels that were comparable to those seen in the academic group. Although the music group followed our expectations by the late session, the robot

group verbalized at levels that were significantly lower than the music and academic groups even in the late session.

We think that the current limitations of our robotic technology might have restricted the amount of verbalization in the robot group. Behaviors exhibited by the robot influence the social behaviors exhibited by the child within the robot-child interaction context. Specifically, children verbalized more, both towards the robot and towards their parents, when the actions of the robot were contingent to those of the child compared to a non-contingent condition (Feil-Seifer & Mataric, 2008). The Nao robot we used had limited pre-programmed verbiage. Although we utilized the online speech capabilities of the robot, there was some time lag to the responses of the robot, as a result of the trainer having to manually type in responses to the child's verbiage using control software. Hence, the robot's speech was not very contingent to the speech of the child. Moreover, many children found the robot's speech unclear, which required the trainer to repeat the robot's verbiage to aid children's comprehension. Overall, we think that the lack of contingent responding by our robot might have limited its ability to act as an effective social mediator to facilitate children's communication skills, resulting in a lower amount of verbalization in this group compared to the human-delivered music and academic groups. A few previous studies have compared the effects of a human versus robot mediator on the social communication abilities of children with ASDs (Duquette et al., 2008; Huskens, Verschuur, Gillesen, Didden, & Barakova, 2013; Kim et al., 2013). Children directed greater number of utterances towards an adult confederate during a single session of interaction with a robot partner compared to a human interaction partner within a triadic context involving the child, the adult confederate, and the interaction partner (Kim et al., 2013). In the robot condition, children initiated spontaneous conversation with the adult confederate to share their interest and curiosity about the robot (Kim et al., 2013). In another study, following ABA-based training to promote self-initiated questions either using a human or a robot trainer, children in both groups improved equally in their abilities to ask questions during a follow-up session, suggesting that there were no added benefits obtained with a robot trainer (Huskens et al., 2013). Lastly, more in lines with our

findings, Duquette and colleagues demonstrated that children showed better verbal imitation abilities with a human mediator compared to a robot mediator (Duquette et al., 2008). Although the first two studies showed either comparable (Huskens et al., 2013) or in fact superior (Kim et al., 2013) communication skills following interactions with a robot compared to a human, we argue that the effects were limited to a single session of training. In contrast, in our study, we were able to compare the effects of a prolonged 8-week robot-delivered intervention with the effects of a comparable human-delivered intervention on the communication skills of children with ASDs. We observed that once the initial novelty of the robot wore off, children did not find the robotic context as engaging as the music and academic groups, which might have led to lower overall verbalization in the robot group compared to the other groups.

A related finding in the robot group was a greater amount of vocalizations/verbalization towards self across sessions (see Figure 5-3). During the movement-based action game, children were required to synchronize their movements with the adult model. Many children chose to spontaneously count the movements as they were synchronizing with the model. In addition, children in the robot group practiced simple and complex drumming patterns during the drumming condition. Specifically, children practiced quarter and eighth patterns while associating them with verbal labels such as “Pal-Buddy” (quarter note on “Pal” and eighth note on “Buddy”) or “Grape-Lemon” (quarter note on “Grape” and eighth note on “Lemon”) to facilitate the mapping between sounds and their motor actions (Wan, Demaine, Zipse, Norton, & Schlaug, 2010). We found that children effectively learned complex sequences of quarter and eighth notes using this strategy and across sessions, children chose to spontaneously use these verbal cues as they practiced drumming patterns. Since, the verbal cues used during action game and drumming game were not directed towards any of their social partners or to the robot, they were coded as self-directed verbalizations. However, we noticed that children verbalized to themselves not just during the drumming and action game conditions but also during other conditions within training. Our observations suggest that this might be due to the limitations of the current robotic technology. As discussed above, the limited verbal repertoire of the robot prevented it from being a compelling social entity and children quickly lost

interest in the training activities. Instead of engaging in meaningful communicative exchanges with their social partners using the robot as an effective mediator, children engaged in scripting, echolalia, and self-directed vocalizations including squealing, giggling, and whining. Other data from our lab on social attention, affect, and repetitive behaviors also lend support to our hypothesis. Specifically, children showed progressive boredom with an increase in negative affect and negative behaviors across training weeks. Our observations fit with the findings of an existing 18-day trial on typically developing (TD) children, where children were allowed to interact with a humanoid Robovie robot that helped them learn new words. Although some children learnt new words following training, there was a sharp decline in their interest and interactions with the robot during the second week of training (Kanda et al., 2004). We recommend that future efforts be directed towards improving the robotic technology to make the robot's actions and verbal interactions contingent on the child initiating the exchange, and also towards designing functionally relevant activities that can sustain the engagement of children over multiple sessions.

We also found group differences in the amount of responsive verbalization to social partners (see Figure 5-3). The academic group engaged in greater responsive verbalization across sessions compared to the other two groups. Although the quantity of spontaneous verbalization was greater than the amount of responsive communication within the academic group, there were significant between-group differences in the amount of responsive verbalization (see Figure 5-3). As outlined previously, the environmental setup of the academic group was in some ways similar to that used in traditional ABA settings, in that children were seated at the table and the trainer initiated several bids requiring a response from the child (Delprato, 2001; Goldstein, 2002); however, unlike traditional ABA interventions that are completely instructor-driven, we provided children with multiple opportunities for engaging in spontaneously-initiated communicative exchanges. Nevertheless, we think that the very nature of the context afforded several bouts of responsive communication between children and their social partners. To elaborate, in the academic group, trainers had greater opportunities to engage verbally with the child and to present several prompts to elicit appropriate verbal responses from children. For example, the trainer frequently

questioned children about the book they were reading, asked them to make choices in terms of usage of supplies, and encouraged children to read out listed instructions that were provided for the building and art-craft projects. Similar contexts used during traditional ABA interventions have been shown to increase responsive communication more than spontaneous initiations by children with ASDs (Kasari et al., 2006; Schreibman, 1997; Vismara & Rogers, 2010; Whalen & Schreibman, 2003). In contrast, in the music and robot groups, children engaged in movement-based games to background music during a majority of the conditions, which might have restricted the amount of communication that could be initiated by the trainer. Hence, a majority of the conversation afforded by the movement contexts was spontaneous in nature. Thus, we think that the movement and academic groups afforded different types of communication between children and their social partners, due to the differences in the nature of the training context.

5.4.3. Training-related changes in verbalization patterns

Children in the music group demonstrated a training-related increase in verbalization to their social partners, specifically to the trainer from the early to the late session (see Figure 5-5). The increase in verbal communication skills over training was in line with our hypothesis. Support and possible mechanisms for the positive effects of our music-based intervention come from two areas of research. First, in line with mainstream research on autism interventions, evidence on the efficacy of developmental pragmatic approaches in autism suggests that holistic treatments which promote pre-linguistic correlates of verbal communication including motor imitation, joint attention, and play, in fact led to carry-over improvements in language skills (Ingersoll & Schreibman, 2006; Kasari et al., 2008). Our intervention was designed to incorporate imitation and rhythmic synchrony-based games between children and their social partners. As children engaged in play-based episodes involving music and movement, they had to frequently monitor the trainer and the model to synchronize with them. Hence, across training sessions, children learned to effectively engage in turn-taking, shared attention, and imitation games, which might have promoted precursor skills that are integral to all communicative exchanges. The second line of

support comes from collective evidence from the fields of music education, music therapy, and neuroscience that recommends the use of music therapies for enhancing communication skills. As discussed previously, commonalities in the structure and processing of linguistic and musical inputs might lead to collateral improvements in verbal communication skills following music-based training (Besson, Schön, Moreno, Santos, & Magne, 2007; Butzlaff, 2000; Chan, Ho, & Cheung, 1998; Forgeard, Winner, Norton, & Schlaug, 2008; Ho, Cheung, & Chan, 2003; Srinivasan & Bhat, 2013). Moreover, music and language share neural substrates such that music-making engages brain areas which are also activated during speech production (Meyer, Alter, Friederici, Lohmann, & Von Cramon, 2002; Srinivasan & Bhat, 2013; Wan et al., 2010; Wan, Rüber, Hohmann, & Schlaug, 2010). Hence, music-based activities have the potential to facilitate speech in both TD children and children with communication impairments such as ASDs (Srinivasan & Bhat, 2013). Further, empirical studies that used different forms of music therapies for children with autism have also indicated positive effects of training on children's communication skills (Buday, 1995; Edgerton, 1994; Farmer, 2003; Gattino, dos Santos Riesgo, Longob, Leite, & Faccini, 2011; Lim & Draper, 2011; Lim, 2010; Tindell, 2010; Wan et al., 2011). Several reviews have suggested that music interventions can facilitate communication, social, and behavioral skills of children with ASDs (Gold, Wigram, & Elefant, 2006; Simpson & Keen, 2011; Whipple, 2004). In fact, a Cochrane meta-analysis suggested that short-term music interventions led to improvements in verbal and gestural communication skills of children with ASDs (effect size = 0.36 for verbal skills and 0.50 for gestural skills) (Gold et al., 2006). Along the same lines, we found that over time children increased their vocal and verbal production following musical training. We observed that children enjoyed the music-based context and they learned the songs practiced during training, and chose to spontaneously join in and sing the songs with the trainer and the model during latter sessions. Similar to our study, Edgerton reported that following improvisational music therapy for 10 weeks, in addition to demonstrating improvements in musical communicative behaviors, children also increased their non-musical communicative behaviors including speech production (Edgerton, 1994). Moreover, we also observed that children improved their rapport with the trainer and the model and spontaneously engaged

in general conversations with them, which might have contributed to the increase in verbal communication in the late session compared to the early session. In addition to changes within the training context, we found that children generalized learned skills to a standardized test assessing their responsive communication skills with a novel tester. A majority of the current music literature does not assess generalization of skills learned during musical training to other contexts (Simpson & Keen, 2011). In the current study, we assessed for generalization of learned skills to novel contexts, and we think that the group-based training context might have facilitated children's social monitoring skills, leading to their improved ability to respond to the verbal and attentional cues of their social partners.

We found that children in the robot group showed improvements in the amount of verbalization to the model/CG (CGs were not present for sessions involving a majority of the children, hence the results were reflective of changes in amount of social interactions with the model) from the early to the mid and from the early to the late session (see Figure 5-5). Within this context, the trainers were constrained in terms of their ability to initiate interactions with the children, since they were primarily responsible for controlling the robot and triggering its responses. In contrast, the model was able to engage with the child more. Moreover, children were required to synchronize with the adult model, which provided them with multiple opportunities to engage with the model, which in turn might have provoked greater verbalization with the model compared to the trainer. Over time, children showed improvements in the quantity of verbalization with the model. Previous studies have also found positive effects of humanoid and non-humanoid robots on the verbalization skills of children with ASDs (Duquette et al., 2008; Hanson et al., 2012; Huskens et al., 2013; Kim et al., 2013; Kozima et al., 2007; Malik, Shamsuddin, Yussof, Miskam, & Hamid, 2013; Shamsuddin et al., 2012; Tanaka & Matsuzoe, 2012). However, as mentioned previously, a majority of these studies assessed the effect of robotic interactions on the speech of children during a single session with the robot (Hanson et al., 2012; Kim et al., 2013; Malik et al., 2013; Shamsuddin et al., 2012). Only two studies assessed the effects of prolonged robotic interactions on the verbalization skills of children with ASDs (Kozima et al., 2007; Tanaka & Matsuzoe, 2012). Tanaka and

Matsuzoe successfully used the Nao robot to teach new verbs to children with ASDs over 6 sessions. Instead of using the robot in its conventional role as a “teacher”, the authors used the robot in a “care-receiving” role, where children were prompted to teach the robot specific actions, as well as words labelling those actions (Tanaka & Matsuzoe, 2012). In a different study, a creature-like robot, Keepon, was placed in the playroom of children for 15 sessions conducted over 5-9 months. They found that some children with ASDs approached the robot and spontaneously initiated conversation with it (Kozima et al., 2007). Along the same lines, in a previous pilot study from our lab, we found that there was some improvement in the spontaneous verbalization skills of 2 children with ASDs following training (Srinivasan & Bhat, 2013). We replicated our previous findings in the current study using a larger sample size and a longer duration of training. However, we recommend that our positive findings be interpreted with caution. In the current study, we were additionally able to compare the effects of robot-delivered interventions with those of human-delivered interventions, and our data clearly suggest that, across sessions, children showed greater verbalization towards their social partners in the human-delivered music and academic activities compared to the robot-delivered intervention. Our related finding that children directed the least amount of verbalization towards the robot in all sessions also suggests that the robot was not considered an engaging social entity, and this severely limited its ability to be an effective mediator of interactions between children and their social partners. Moreover, children did not show any significant improvements in the standardized test of responsive communication following robotic interactions. Children with ASDs have difficulty generalizing learned skills to novel situations (Delprato, 2001; Hwang & Hughes, 2000; Kasari, 2002; Vismara & Rogers, 2010). Moreover, it might have been difficult for children to generalize skills learned during robot-based interactions to a novel context with a novel tester. The current literature in the field of socially assistive robotics is lacking in its examination of the long terms effects of robotic therapies and generalization of skills learned during robotic interactions to novel contexts involving humans (Kim et al., 2013). Our own previous work using a small humanoid robot, I-sobot, within karate- and dance-based imitation games in children with ASDs suggested that in spite of significant improvement in imitation skills on a task-specific test within the training context, there

was a limited generalization of learned skills to a standardized test of motor skills (Srinivasan et al., 2013). Overall, in spite of improvements in verbalization following robotic training, our data suggest that our current robotic technology was limited in its ability to adjust to the individual child's needs and in its ability to promote sustained spontaneous and responsive communication in children with autism.

Children in the academic group did not show any significant improvement in their verbalization to social partners across training sessions (see Figure 5-5). The academic group engaged in a greater amount of verbalization with their social partners to begin with, and they maintained their speech levels over training with no further increase in verbalization across sessions possibly due to a ceiling effect. In spite of no significant increase in the task-specific measure, children demonstrated an increase in responsive communication in a standardized test with a novel tester during the posttest compared to the pretest. Specifically, children improved their ability to respond to verbal cues of the tester. Other studies using developmental pragmatic approaches in children with ASDs have shown that children learn skills within the training context but also generalize the learned skills to novel contexts. For example, children who received intervention focusing on joint attention skills improved their abilities to initiate and respond to joint attention bids of the trainer and also generalized this to an episode of play with their caregivers. In the same study, children who received play-based intervention showed improvements in the diversity of their play within the training context as well as outside the training context during play-based interactions with their mothers (Kasari et al., 2006). Similarly, given that our play-based training activities were embedded within the natural environment of the child (home/school), it might have been possible for children to generalize learned communication skills to a standardized test within a novel context with a novel tester.

5.4.4. Condition-related differences in verbalization patterns

Within each group, we were interested in identifying specific conditions that facilitated greater verbalization compared to other conditions. We hypothesized that children would engage in greater

verbalization with social partners during conditions that promoted social interactions without added motor demands. In contrast, we expected children to verbalize less during conditions in which they engaged in movement games involving imitation and synchrony. Our hypotheses were based on previous evidence on executive function deficits and motor impairments commonly seen in children with ASDs. We expected that conditions which required dual tasking i.e. conditions in which children were required to talk or sing songs as they were engaging in gross and fine motor activities, would elicit lower verbalization, given children's impairments in executive function including problems in attention shifting and working memory (Griffith, Pennington, Wehner, & Rogers, 1999; Hill, 2004; Ozonoff & Jensen, 1999). In addition, training activities involved imitation-based motor games, and given the motor impairments in this population, we expected children to demonstrate difficulty in speaking while simultaneously engaging in movement-based activities. Children with ASDs demonstrate impairments in gross motor skills including bilateral coordination (Fournier et al., 2010; Green et al., 2009), imitation/praxis (Dewey et al., 2007; Mostofsky et al., 2006), postural control (Minshew et al., 2004), balance, and gait (Hallett et al., 1993; Vilensky et al., 1981). Similarly, children also demonstrate impairments in fine motor control including poor visuomotor coordination, bimanual coordination, manual dexterity, and handwriting skills (Bhat et al., 2011; Fuentes, Mostofsky, & Bastian, 2009; Ghaziuddin et al., 1994; Ghaziuddin & Butler, 1998; Provost, Heimerl, & Lopez, 2007). Hence, we expected that conditions which involved practice of imitation and/or synchrony games in all 3 groups would be challenging for children and would therefore afford lower amounts of socially-directed verbalizations compared to conditions without any concurrent motor demands. In line with our hypothesis, all three groups demonstrated greater verbalization during conditions that promoted social interactions with minimal movement demands (see Figures 4A, 4B, & 4C). In the music group, children verbalized most during the social interaction phase and the action song condition compared to all other conditions. During the social interaction phase, children were encouraged to sing hello and farewell songs. Similarly, in the action song condition, where we used common nursery rhymes, children chose to spontaneously sing these songs with their social partners (see Figure 5-4A). In contrast, children verbalized less during the more complex conditions that

required them to synchronize with their social partners (see Figure 5-4A). Children seemed to focus on the motor demands of the task at the cost of verbal communication. Similarly in the robot group, children verbalized most with their social partners during the social interaction phase compared to other conditions (see Figure 5-4B). Lastly, in the academic group, children verbalized most during the social interaction phase and the reading condition. During the building and art-craft conditions, children focused on the fine motor aspects of the task and thereby demonstrated a lower quantity of verbalization compared to the first two conditions (see Figure 5-4C).

Children in the robot group also engaged in maximum self-directed verbalization during the drumming game compared to the warm up and social interaction conditions (see Figure 5-4B). As discussed previously, children associated quarter-eighth drumming patterns with words such as “Pal-Buddy” or “Grape-Lemon”. Children chose to spontaneously use these verbal cues as they practiced the drumming patterns. This might have led to the higher levels of self-directed verbalization during this condition compared to other conditions. Lastly, compared to all other verbalization targets, children verbalized the least to the robot across all conditions. However, comparing between conditions, children verbalized most to the robot during the social interaction phase and least during the walking game. During the social interaction phase, the robot greeted the child and also engaged in general conversation with the child such as asking children about their day, asking them about their family, favorite foods etc., which might have elicited responses from children. In contrast, we used the mobile non-verbal Rovio robot during the walking game, which might explain lower levels of verbalization to the robot during this game.

5.5. Clinical Implications

We compared the effects of novel movement-based therapies with a stationary, standard-of-care treatment on the spontaneous and responsive communication skills of children with ASDs. We were interested in examining what each type of context – music, robotic, and academic- affords in terms of verbal communication skills for children with ASDs. Not surprisingly, conventional ABA-based table-top

contexts, in which children and their social partners were relatively confined at the table, naturally afforded trainers and models with multiple opportunities to initiate communicative exchanges with children. In contrast, the movement-based contexts required children and their social partners to engage in gross motor imitation and joint action to background music; both the movement and the music naturally restricted the number of opportunities available to trainers and models for initiating conversation with children. Secondly, the activities practiced in the standard-of-care intervention were highly familiar to children, since they often engaged in these activities in special education settings. In contrast, the activities practiced in the movement groups were highly novel and challenging for children, since they are not conventionally included within the treatment plan for autism. Our data suggest that children in the movement groups might have found it harder to communicate while moving to the beat of music, leading to lower amounts of socially-directed verbalization in the music and robot groups in the early session compared to the academic group. However, it was very encouraging to see that over time, children in the music group showed a large magnitude of increase in the duration of social verbalization that reached levels comparable to those in the academic group. The robot group demonstrated improvements in verbalization to the model following training but the levels were lower than that seen in the music and academic groups even at the end of training. The academic group did not show any training-related increase in socially-directed verbalizations possibly due to a ceiling effect. We also found that the nature of the movement contexts, music and robotic, promoted predominantly spontaneous communication, whereas the academic context promoted greater amounts of responsive communication compared to the other 2 groups. In the music group, children were very engaged in the context and over sessions learned songs and began to spontaneously sing songs. The enjoyable context also fostered greater communication between children and their social partners. Although children increased their conversation with the model across sessions, contrary to our hypothesis, children did not find the robots very engaging and the robots failed to maintain children's interests across sessions. As a result, children engaged in behaviors characteristic of ASDs such as scripting, echolalia, and non-social vocalizations. Lastly, in all 3 groups,

conditions that focused on communication without any added motor demands afforded greater verbal communication compared to conditions that placed dual task demands on children.

Overall, we think that movement-based contexts have great potential in facilitating social communication skills. Specifically, children find music and movement activities enjoyable and engaging and these contexts can be used to promote reciprocal communication between children and their social partners. Other data from our lab also suggest that children in the music group demonstrated greater social attention, an increase in positive affect, and a reduction in negative behaviors across training sessions. In contrast, the robot group showed greater boredom, more negative affect, and no reduction in negative behaviors across sessions. Lastly, the academic group directed greater attention to objects and engaged in greater sensory behaviors with objects. However, this group showed the greatest compliance with training, probably due to the familiarity of the practiced activities. Our study suggested that the current robotic technology has limited utility as an adjunct tool in the treatment of children with ASDs. Future attempts at using robotics for autism will need to address the limitations of the current technology by making robots more autonomous and dynamically contingent to children and by providing robots with human-like capacities to adapt to the needs of each individual child. The verbal repertoire of the robot needs to be broadened, and efforts must be made to make the robot's speech comprehensible to children with ASDs. To summarize, our work suggests that movement-based interventions, especially music-based activities, are engaging for children with ASDs, and by capitalizing on their inherent strengths can serve as promising tools to promote social communication and motor skills in this population.

5.6. Limitations and Future Directions

Our study was an RCT with only 36 subjects. We included both low and high functioning children within a broad age range of 5 to 12 years, which might have been a source of variability in the 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 carry out any follow-up testing to evaluate carry-over effects of

training. Even though we provided intensive training to parents for conducting home sessions, we found that there was considerable variability in the adherence levels of parents with the home program. In terms of data coding, our coders were not blind to the grouping of the children. In this paper, we only reported on the quantity of verbalization. Currently, we are assessing the quality of verbalizations within all 3 groups. We also only reported on the duration of verbalization here. We are in the process of evaluating changes in rates of verbalization within all groups. Future studies should replicate our procedures with larger and more homogeneous samples, longer training durations, and follow-up testing measures. We also recommend the use of additional standardized assessments and functional language samples in the pretest and posttest sessions to assess changes in language skills following training. Lastly, in the robot group, we think that the current limitations of the robotic technology limited potential improvements following training. In the future, we plan to extend this work by assessing the effects of other novel, engaging, movement-based interventions including dance and creative yoga in children with ASDs.

5.7. Conclusions

In the current study, we compared the effects of two novel, movement-based, music and robotic interventions with those of a stationary, standard-of-care academic intervention on the spontaneous and responsive communication skills of 36 children with ASDs between 5 and 12 years of age. We coded for communication skills within a standardized test assessing responsive communication, and also in a task-specific test of vocalization/verbalization patterns within the training context. Specifically, we assessed changes in the quantity of socially- and self-directed vocalizations/verbalizations within an early, mid, and late session. The music and academic groups engaged in greater quantities of socially-directed verbalization compared to the robot group. The robot group engaged in greater self-directed verbalization compared to the other two groups. In all three groups, children engaged in greater spontaneous compared to responsive communication. With training, there was an increase in children's verbalization to social partners in the music and robot groups. Children in the music and academic groups generalized learned skills to the standardized test of responsive communication with a novel tester. Movement-based and

stationary contexts afforded different types and amounts of communication for children with ASDs. Overall, movement-based music interventions are a promising tool to enhance spontaneous and responsive communication in children with ASDs.

Chapter 6

The effects of embodied rhythm interventions on repetitive and problem behaviors of children with Autism Spectrum Disorders (ASDs)

6.1. Introduction

6.1.1. Overview of Autism Spectrum Disorders and implications of repetitive and problem behaviors in autism

When most people think of Autism Spectrum Disorders (ASDs), they picture a child lining up toys, incessantly spinning the wheels of a toy car, peering oddly at objects, obsessively adhering to fixed routines in play, or engaging in hand flapping or body rocking routines for hours on end. From the very earliest accounts of autism, restricted and repetitive behaviors have been among the hallmark diagnostic symptoms of ASDs (Asperger, 1944; Kanner, 1943). The current diagnosis of ASDs is based on persistent deficits in social communication skills and the presence of restricted and repetitive behaviors and interests (American Psychiatric Association, 2013). Individuals with ASDs encounter difficulties in social interactions, including lack of social and emotional reciprocity, difficulties sharing interests with others, and delayed as well as atypical verbal and non-verbal communication skills (Dawson et al., 2004; Mundy & Sigman, 2006; Sullivan et al., 2007; Tager-Flusberg, 1999). In terms of repetitive behaviors, children with ASDs demonstrate stereotyped movements with their bodies or with objects, tend to insist on sameness of routines and become upset by changes in schedule, have intense interests and preoccupations that are very narrow in focus, and also demonstrate problems with modulation of sensory inputs including hypo- or hyper-responsiveness (Baranek et al., 2013; Leekam et al., 2011; Richler, Bishop, Kleinke, & Lord, 2007; Turner, 1999). In addition to repetitive behaviors (RBs), many children also exhibit maladaptive and problem behaviors including aggression, defiance, tantrums, and self-injurious behaviors (Dominick, Davis, Lainhart, Tager-Flusberg, & Folstein, 2007; Hartley, Sikora, & McCoy, 2008; Reese, Richman, Belmont, & Morse, 2005). Engagement in RBs and elaborate routines

reduces the opportunities available to children to learn by interacting with their social world, and hence has negative implications for children's social, communication, and cognitive development (Cunningham & Schreibman, 2008; Koegel & Covert, 1972; Koegel, Firestone, Kramme, & Dunlap, 1974; Lam & Aman, 2007; Richler et al., 2007; Richler, Huerta, Bishop, & Lord, 2010). In fact, the presence and severity of RBs in autism is negatively associated with the acquisition of social and language skills, daily living skills, adaptive behavior and play skills, as well as cognitive skills, and is also socially stigmatizing for the child (Bishop, Richler, & Lord, 2006; Bopp, Mirenda, & Zumbo, 2009; Cunningham & Schreibman, 2008; Dominick et al., 2007; Gabriels, Cuccaro, Hill, Ivers, & Goldson, 2005; Hartley et al., 2008; Honey, Leekam, Turner, & McConachie, 2007; Koegel et al., 1974; Morgan, Wetherby, & Barber, 2008). Moreover, in addition to costs for the individual with ASD, RBs are a crippling cause of caregiver stress and impaired family dynamics (Bishop et al., 2006; Gabriels et al., 2005). Overall, RBs are non-functional, invariant, and inappropriate; hence, considerable research has been devoted to understanding their causes and reducing their occurrence in children with ASDs (Gabriels et al., 2005; Turner, 1999).

6.1.2. Repetitive and problem behaviors in ASDs

Retrospective as well as prospective studies suggest that RBs are observed as early as the latter part of the second year of life in children later diagnosed with ASDs (Loh et al., 2007; Morgan et al., 2008; Osterling et al., 2002; Richler et al., 2007; Watson et al., 2007; Watt, Wetherby, Barber, & Morgan, 2008; Werner, Dawson, Munson, & Osterling, 2005; Wetherby et al., 2004). A comparative study of children with ASDs, developmental delays (DD), and typically development (TD) using retrospective parent report questionnaire called the Early Development Interview suggested that children with ASDs had significantly greater RBs compared to age-matched DD and TD groups as early as 16-18 months of age (Werner et al., 2005). Similarly, in a prospective longitudinal study that used the Communication and Symbolic Behavior Scales Development Profile (CSBS), children with ASDs between 18 and 24 months demonstrated a higher rate and a greater variety of RBs with their bodies and with objects, compared to TD children and children with DD (Morgan et al., 2008). Moreover, the scores on measures of RBs were

related to children's current levels of social and communication skills, and were also predictively related to the severity of their autism symptoms at 4 years of age (Morgan et al., 2008). As mentioned previously, RBs in children with ASDs encompass a broad range of behaviors and have been associated with several variables, including developmental level, level of functioning, adaptive level, measures of autism severity, and age (Bishop et al., 2006; Cuccaro et al., 2003; Dominick et al., 2007; Esbensen, Seltzer, Lam, & Bodfish, 2009; Gabriels et al., 2005; Goldman et al., 2008; Hartley et al., 2008; Honey, McConachie, Randle, Shearer, & Le Couteur, 2008; Lam, Bodfish, & Piven, 2008; Militeri, Bravaccio, Falco, Fico, & Palermo, 2002; Richler et al., 2010; Shattuck et al., 2007). For example, Turner suggested that RBs could be sub-divided into "lower-level" behaviors characterized by stereotypies, repetitive sensory-motor manipulations of objects, and repetitive self-injurious behaviors, and "higher-level" behaviors characterized by strict adherence to routine, insistence on sameness, circumscribed interests, preoccupations with objects, and use of repetitive language (Turner, 1999). Further, low-level sensory-motor RBs are seen more frequently in children with low verbal and non-verbal Intelligence Quotient (IQ) scores, whereas children with higher IQs demonstrate high-level RBs (Dominick et al., 2007; Gabriels et al., 2005; Goldman et al., 2008; Hartley et al., 2008; Militeri et al., 2002; Richler et al., 2010; Turner, 1999). Along the same lines, occurrence of certain types of RBs may be related to the adaptive functioning level of individuals with ASDs (Baghdadli, Pascal, Grisi, & Aussilloux, 2003; Cuccaro et al., 2003). There was a negative correlation between the level of adaptive functioning measured on the Vineland Adaptive Behavior Scales (VABS) and the low-level repetitive sensory motor behaviors in individuals with ASDs (Cuccaro et al., 2003). Similar associations were not found for high-level behaviors encompassed within the "resistance to change" sub-category (Cuccaro et al., 2003). In addition to RBs, children with lower cognitive, communication, and adaptive skill levels were more likely to exhibit broader maladaptive behaviors such as aggression, inattention, tantrums, anxiety, and withdrawal, compared to higher-functioning individuals on the spectrum (Hartley et al., 2008). Overall, there is unequivocal evidence that the nature of RBs in ASDs varies according to the severity of autism symptomatology - children with greater social communication impairments as measured on standardized

autism severity tests demonstrate greater frequencies of RBs and related problem behaviors (Hartley et al., 2008; Lam et al., 2008; Militeri et al., 2002; Richler et al., 2010). The effect of age on RBs has been an area of much research and debate. The current consensus is that repetitive sensorimotor behaviors are more common in younger children, whereas more complex RBs and circumscribed interests develop with increasing age (Bishop et al., 2006; Militeri et al., 2002). In terms of developmental changes in RBs, simple sensorimotor behaviors tend to either remain stable or eventually decrease over childhood and adulthood, while complex ritualistic and compulsive tendencies increase with age (Honey et al., 2008; Richler et al., 2010; Shattuck et al., 2007; South, Ozonoff, & McMahon, 2005). Given the considerable heterogeneity in the types of RBs and the cascading effects of RBs on the overall development of children with ASDs, we were interested in comparing the training-related changes in RBs and problem behaviors in a sample of 36 children with ASDs following an 8-week intervention using either novel movement-based (i.e. music- and robot-based) activities, or sedentary standard of care-based academic activities.

6.1.3. Traditional intervention for repetitive and problem behaviors in ASDs

Contemporary approaches commonly used for the treatment of children with ASDs include Applied Behavioral Analysis (ABA) (Lovaas, 1987; McGee et al., 1999), Treatment and Education of Autistic and related Communication-Handicapped Children (TEACCH) (Mesibov et al., 2004), and Picture Exchange Communication System (PECS) (Bondy & Frost, 2003). These treatment approaches tend to focus on remediating the core social communication impairments of autism and promoting age-appropriate academic skills in children (Landa, 2007). In terms of the management of RBs and problem behaviors, pharmacological and behavioral interventions have been commonly used in individuals with ASDs. The three main classes of drugs used to reduce RBs and other challenging behaviors are atypical antipsychotics (such as risperidone, clozapine, olanzapine, etc.), serotonin reuptake inhibitors (such as clomipramine, fluoxetine, citalopram, etc.), and opioid antagonists (such as naltrexone) (Leekam et al., 2011; Leskovec, Rowles, & Findling, 2008; Soorya, Kiarashi, & Hollander, 2008). Although there is some evidence for the efficacy of medications as a treatment for RBs, there are several short-term and

long-term side-effects of these drugs for the pediatric population (Aman et al., 2002; Leekam, Prior, & Uljarevic, 2011; Leskovec et al., 2008; McDougle, Kresch, & Posey, 2000; Soorya et al., 2008; Stigler, Posey, & McDougle, 2004). In addition to pharmacological treatments, several behavioral interventions have been used for addressing RBs and other maladaptive behaviors in ASDs. Behavioral interventions are based on the principles of ABA and can be categorized as either antecedent approaches or consequence-based approaches (Boyd et al., 2012; Kern, Choutka, & Sokol, 2002; Rapp & Vollmer, 2005). Both approaches are based on the premise that any behavior occurs subsequent to some type of environmental event (antecedent) and the behavior is maintained if it is followed by another event (consequence) which is reinforcing/pleasurable for the individual (Kern et al., 2002). All ABA-based approaches conduct a functional analysis to identify the function of any challenging behavior and use treatment strategies to modify either the antecedents or the consequences of the behavior to reduce its occurrences (Cunningham & Schreibman, 2008). In antecedent interventions, the aim is to use strategies to modify the environment in a way that the challenging behavior is avoided even before it occurs (Boyd et al., 2012; Kern et al., 2002). Examples of strategies used in antecedent approaches include preparing individuals for transitions by using PECS, allowing individuals to engage in preferred activities prior to a demanding task, providing individuals with appropriate and competing sources of reinforcement (such as preferred objects) during the demanding task, simplifying the steps of the task, and teaching individuals acceptable forms of communication and adaptive skills (Boyd et al., 2012; Kern et al., 2002; Rapp & Vollmer, 2005). In contrast, consequence-based approaches use techniques such as punishment, differential reinforcement (reinforce alternative behavior and ignore the challenging behavior), and physically blocking the individual from engaging in the problematic behavior, to reduce the occurrence of RBs (Boyd et al., 2012; Rapp & Vollmer, 2005). A meta-analysis based on 9 studies suggested that early behavioral interventions based on ABA principles led to moderate improvements on the adaptive behavior composite of the Vineland Adaptive Behavior Scales (Eldevik et al., 2009). Similarly, a systematic review based on 26 studies addressing challenging behaviors using ABA-based interventions within school settings suggested that such interventions led to successful reductions in challenging

behaviors (Machalicek, O'Reilly, Beretvas, Sigafoos, & Lancioni, 2007). Anecdotal evidence suggests that eclectic approaches that target the core social communication impairments in autism additionally lead to collateral reduction in RBs and problem behaviors. These approaches include sensory integration therapy (Smith, Press, Koenig, & Kinnealey, 2005), peer-mediated interventions (Lee & Odom, 1996; Lee, Odom, & Loftin, 2007), parent-mediated interventions (Green et al., 2010), developmental affective relationship-based approaches such as the Early Start Denver Model (Rogers & Dawson, 2010), and cognitive-behavioral interventions (Bauminger, 2002). Overall, there has been considerable research on different treatment strategies to address RBs and maladaptive behaviors in individuals with ASDs.

6.1.4. Novel interventions in ASDs

While a majority of the contemporary intervention approaches for ASDs are primarily focused on addressing the core social communication and behavioral impairments in autism, there is growing evidence that ASDs are in fact multisystem disorders with significant perceptuo-motor impairments (Baranek et al., 2013; Bhat et al., 2011; Fournier et al., 2010; Tomchek & Dunn, 2007). Motor difficulties are seen in more than 50% of children diagnosed with ASDs (Green et al., 2009; Manjiviona & Prior, 1995). Perceptuo-motor impairments can limit learning opportunities available for children and can therefore have cascading adverse effects on children's social communication and cognitive development (Bhat et al., 2011; Jansiewicz et al., 2006; Leary & Hill, 1996). Yet, it is surprising that there is a lack of evidence in the current autism literature on multisystem, holistic interventions that address social communication, behavioral, and perceptuo-motor impairments in individuals with ASDs.

In the current study, we explored the effects of two multisystem interventions - music-based and robot-based - that are grounded in whole-body movements within a triadic setting to enhance multisystem development in children with ASDs. Music-based interventions contribute to around 45% of alternative therapies employed for preschool to 12th grade children with ASDs within school settings (Hess et al., 2008). Given the inherent musical strengths of children with ASDs, music therapies seem to be promising

treatment tools for this population. Children with ASDs generally enjoy musical experiences and have heightened musical perception abilities compared to their TD peers (Bonnell et al., 2003; Heaton, 2003). Music-based experiences could provide children with a non-intimidating context to freely explore their environment and use music as a medium to express their creative potential (Srinivasan & Bhat, 2013; Wigram & Gold, 2006). Moreover, the essence of all musical experiences is that they are multisystem in nature, and when embedded within social contexts, can be a great tool to promote social, verbal and non-verbal communication, behavioral, and perceptuo-motor skills (Srinivasan & Bhat, 2013). A Cochrane meta-analysis on the efficacy of music therapies for individuals with ASDs suggested that there were significant improvements in verbal and gestural communication skills following music-based training compared to placebo therapy (Gold et al., 2006). Similar to music therapies, robots have been used in recent times as therapeutic tools to facilitate social communication and motor skills in children with ASDs. Robot-based interventions are one of the many emerging technology-based interventions, including virtual reality, interactive computer-assisted instructional programs, and video-based technologies, that have been employed to promote the academic, social, communication, and emotional skills of children with ASDs (Chen, 2012; Diehl et al., 2011; Mitchell, Parsons, & Leonard, 2007; Moore & Calvert, 2000; Pennington, 2010; Ramdoss et al., 2012; Wainer & Ingersoll, 2011). All technology-based interventions for ASDs are based on the appealing premise that the contexts allow children to learn in an environment that is highly predictable, standardized, and consistent, and also reduce the complexity of social interactions associated with learning within conventional environments (Chen, 2012; Pennington, 2010; Wainer & Ingersoll, 2011). Moreover, children with ASDs have a predilection for electronic media and technology-based applications, making these interventions extremely motivating for this population (Shane & Albert, 2008). For example, robotic technologies can be programmed to provide individualized and structured practice, and can be used within a social context as a focus of shared attention and as a mediator to promote interactions of children with their social partners (Dautenhahn & Werry, 2004; Diehl et al., 2011; Scassellati et al., 2012). Our previous work suggests that robot-based interactions within a group setting can be used to promote motor skills, including imitation, praxis, and

bilateral coordination, as well as social communication skills, including social attention and verbalization, in a small sample of children with ASDs (Kaur et al., 2013; Srinivasan et al., 2013; Srinivasan & Bhat, 2013). We systematically extended our previous work to a larger sample of children with ASDs and compared the effects of music-based and robot-based interventions on the social communication, perceptuo-motor, and behavioral skills of children. In the current paper, we will restrict our discussion to the behavioral effects of music and robot interventions; training-related changes in social communication and motor skills are reported elsewhere.

6.1.5. Rationale for current study and specific aims and hypothesis for repetitive and problem behaviors

Our study was a randomized controlled trial (RCT) where we randomly assigned 36 children with ASDs between 5 and 12 years of age to the music, robot, or academic groups. We evaluated training-related changes in frequencies of RBs and problem behaviors in children during an early, a mid, and a late training session. We categorized RBs/problem behaviors into the following sub-categories: sensory behaviors, stereotyped behaviors, and self-injurious/negative behaviors. We had three main research aims: first, to investigate context-related group differences in RBs/problem behaviors at baseline; second, to examine training-related changes in RBs/problem behaviors in the three groups; and third, to examine within-group condition-related differences in RBs/problem behaviors. In the first aim, we were interested in understanding the differential effects of the three training contexts on the frequencies of RBs/problem behaviors at baseline. We hypothesized that the movement groups would engage in greater self-injurious/negative behaviors compared to the academic group. We believe that activities such as reading, building, and arts & crafts practiced in the academic group are familiar to children with ASDs because they are often used within school settings. In contrast, movement-based activities are not typically encouraged as a standard treatment for children with ASDs, which might lead to increased initial anxiety and greater self-injurious/negative behaviors in the movement groups compared to the stationary academic group at baseline. We hypothesized that given the nature of the supplies used in the academic group, such as Play-Doh®, Duplo® blocks, Zoob (InfiniToy®), or building blocks, children would engage

in greater sensory behaviors compared to the movement groups. Children in all three groups would engage in equal amounts of stereotypical behaviors at baseline. In our second research aim, we expected that across training weeks, children in all three groups would demonstrate a reduction in frequencies of RBs/problem behaviors. As discussed previously, interventions aimed at broadening the behavioral and social repertoire of children with ASDs lead to collateral reduction in the frequencies of RBs post-intervention (Lee & Odom, 1996; Lee et al., 2007; Leekam et al., 2011; Loftin, Odom, & Lantz, 2008; Lord & Hopkins, 1986; Oke & Schreibman, 1990). For example, a peer-mediated intervention where children were taught social initiation skills led not only to an increase in children's interactions with their peers but also to a reduction in their RBs and problem behaviors (Loftin et al., 2008). Along the same lines, we actively encouraged children to engage in social interactions with their adult partners in all three groups. Hence we expected to observe training-related reductions in RBs/problem behaviors in all groups as children increased their social interactions within the training contexts. Lastly, in terms of within-group condition-related differences, we hypothesized that the types of RBs/problem behaviors would vary according to the nature of the conditions and their task complexity. For example, conditions that involved the use of props and objects, such as drums or xylophones in the music and robot groups, or building supplies, such as Duplos® or Zoob (InfiniToy®) in the academic group, would elicit greater sensory behaviors. Conversely, conditions that did not involve the use of objects but encouraged free movement would elicit greater stereotypies. We expected that conditions which were more challenging for children would elicit greater frequencies of negative and non-compliant behaviors compared to easier conditions.

6.2. Methods

6.2.1. Participants

36 children with ASDs (32 males and 4 females) between 5 and 12 years of age ($M (SD) = 7.63(2.24)$) were recruited. Participating families fell within the upper-middle to upper socioeconomic classification as described by the Hollingshead scale of socioeconomic status ($M (SD) = 49.18 (10.03)$) (Hollingshead,

1975). Twenty of the families were Caucasian, six were African American, four were Asian, three were Hispanic, and three were of mixed ethnicity (two children of mixed Caucasian and Hispanic ethnicity and one of mixed Caucasian and African American ethnicity). Participants were recruited through phone calls and fliers distributed to autism centers, schools, ASD advocacy groups, and early intervention centers as well as through online announcements. Children with ASDs were enrolled in the study after parents provided a diagnostic evaluation report such as medical or school records confirming the child's diagnosis. In addition, eligibility for the study was confirmed using the Social Communication Questionnaire (Rutter et al., 2003) and the Autism Diagnostic Observation Schedule, 2nd edition (ADOS-2) (Lord et al., 2012), a gold standard assessment for diagnosis of ASDs. We excluded children with additional hearing, visual, orthopedic, cardiovascular, or neurological abnormalities. Children were enrolled in the study following written parental consent approved by the Institutional Review Board of the University of Connecticut.

Children were matched on age bands (4-5, 6-7, 8-9, and 10-12 years) and level of functioning and then randomly assigned to one of the three groups: music, robot, or academic. Specifically, once all children were matched, the whole dataset was assigned random numbers generated by Microsoft Excel. Within a matched triad, children were assigned to the academic, music, and robot groups, respectively, in increasing order of their generated random numbers. We assessed children's level of functioning based on their pretest performance. Expert testers subjectively rated children's motor and social communication skills on a scale of 1 to 4 (1 – extremely low, 2 – low, 3 – moderate, 4 – high). In addition to matching children prior to randomization, we also conducted a post-hoc assessment of differences between groups on age, gender, level of functioning, Vineland Adaptive Behavior Scales (VABS) maladaptive behavior domain scores (Sparrow et al., 2005), and Repetitive Behavior Scale – Revised (RBS-R) (Lam & Adam, 2007) total scores. Children in the 3 groups did not differ significantly on age (Music: $M (SD) = 7.88(2.56)$; Robot: $M (SD) = 7.52 (2.22)$; Academic: $M (SD) = 7.36(2.02)$, $p_s > 0.05$), gender (Music: 10 Males, 2 Females; Robot: 11 Males, 1 Female; Academic: 11 Males, 1 Female, $\chi^2 p > 0.05$), and level of

functioning (composite rating score from subjective ratings of children's motor and social communication skills – Music: $M(SD) = 2.49 (0.78)$; Robot: $M(SD) = 2.57(0.81)$; Academic: $M(SD) = 2.90 (0.43)$, $ps > 0.05$). The VABS (2nd edition) is a standardized measure of adaptive functioning of the child (Sparrow et al., 2005). We used the Maladaptive Behavior domain scores from the Parent/Caregiver rating form for our analysis. The domain is scored on a scale ranging from 0 (Never) to 2 (Often) based on how frequently the child demonstrates a problem behavior. The questionnaire provides information on the degree of maladaptive behaviors in the child, which could be average (child displays frequencies of behaviors that are within 1 standard deviations (SD) above the mean of the normative sample), elevated (child demonstrates frequencies of behaviors that are greater than 2 SDs above the mean of the normative sample), or clinically significant (child demonstrates frequencies of behaviors that are greater than 3 SDs above the mean of the normative sample). Out of the 36 children in our study, parents of 34 children filled out the questionnaire (questionnaire data were not available from 2 children in the music group). There were no significant group differences in the number of children in each group that fell into the average and elevated/clinically significant range based on the Maladaptive behavior index scores (Music: 1 average, 9 elevated/clinically significant, Robot: 1 average, 11 elevated/clinically significant, Academic: 3 average, 9 elevated/clinically significant, $\chi^2 p = 0.45$). Lastly, the RBS-R is a 43-item caregiver report of the broad range of RBs seen in ASDs (Lam & Aman, 2007). The measure has 6 distinct sub-scales including Stereotyped Behavior, Self-injurious Behavior, Compulsive Behavior, Routine Behavior, Sameness Behavior, and Restricted Behavior, that are scored on a scale of 0 to 3, where 0 indicates that the behavior does not occur and 3 indicates that the behavior is a severe problem for the child. We have RBS-R scores from 34 out of 36 subjects in the study (RBS-R questionnaire data were not available for 2 children in the music group). There were no significant group differences for the RBS-R total score (Music: $M(SD) = 30.45 (16.90)$, Robot: $M(SD) = 28.17 (20.23)$, Academic: $M(SD) = 28.17 (17.32)$, $ps > 0.05$) as well as the number of items endorsed on the scale (Music: $M(SD) = 19.09 (8.28)$, Robot: $M(SD) = 17.17 (10.48)$, Academic: $M(SD) = 17.58(8.76)$, $ps > 0.05$).

6.2.2. Procedure

The study was conducted over 10 weeks, and the pretest and posttest were conducted during the first and last weeks of the study. The training was provided over the intermediate 8 weeks, with 2 sessions provided each week, for a total of 16 sessions. Each session lasted approximately 45 minutes. Training involved group-based activities with the child, an adult trainer and an adult confederate model with the overall goal of promoting social interactions, communication, and joint action (See figures 6-1A, 6-1B, and 6-1C). Children in all groups were encouraged to engage in social bids such as greeting and bidding farewell to the trainer, model, and the robot (in the robot group only), with eye contact and waving. Within the music group, various songs were used to promote this activity. In all three groups, in addition to the structured play conditions, we provided children with multiple opportunities for spontaneous play and free exploration of their body movements to music and/or the supplies/musical instruments. 15 out of the 36 children missed 1 session each due to scheduling conflicts.



Figure 6-1: Experimental set-up for training sessions - (A) Music group, (B) Robot group, (C) Academic group

The music group engaged in singing and synchronous movement and imitation to the beat of music or songs. The training involved the following conditions – an introductory song, a musical routine/action song involving finger play, a beat keeping activity involving the whole body, improvisational music making using musical instruments, a moving game involving walking-based imitation, a calming song, and a farewell song (see details of training conditions in Table 6-1).

Music Group	Robot Group	Academic Group
Hello Song	Hello	Hello
Action Song	Warm up Game	Condition Introduction
Beat Keeping	Action Game	Reading
Music Making	Drumming Game	Building
Moving Game	Walking Game	Arts & Crafts
Farewell Song	Farewell	Farewell

Table 6-1: Training conditions in the music, robot, and academic groups

In the robot group, the training was delivered by a 23” humanoid robot, Nao (Aldebaran Robotics) and a mobile robot, Rovio™ (WowWee®). The trainer simply controlled the robot via custom software and a laptop system (see Figure 6-1B). The robot group engaged in synchronous movement and imitation games to the beat of music. The training involved the following conditions – a warm up game involving whole body stretches, an action game involving rhythmic whole body actions to music, a drumming game involving practice of simple and complex drumming patterns, and a walking game involving following the Rovio™ robot to trace letters and shapes on the floor (see Table 6-1 for training conditions). In the music and robot groups, sessions were based on action themes such as start and stop, slow and fast, moving on a count, moving on a steady beat, and turn taking, and each theme was used thrice across the training period.

In contrast to the music and robot groups, the academic group engaged in sedentary, academic activities such as reading, building, and art-craft to promote reading and fine motor skills and to mimic the social settings typically used in special education (see Table 6-1 for training conditions). Sessions were based on academic themes such as basic shapes, solar system, community, people and the human body, healthy foods, living things, weather and seasons, and a sea theme. During the reading condition, children read a book appropriate to their developmental and reading level. During the building condition, children built creations using supplies such as Play-Doh®, Duplo® blocks, Zoob (Infinitoy®), or building blocks. During the art-crafts condition, children engaged in coloring, cutting, and gluing to make theme-based

creations. Children were provided a visual instruction guide illustrating the steps required to complete each building and art-craft creation.

Home Program: In addition to expert sessions, we encouraged parents/caregivers to provide two additional in-home sessions per week to practice and reinforce skills learned during the training. We provided in-person training, a parent manual, session-specific instructions, and various props, robots, or art-building supplies to conduct the home sessions. Siblings were also involved in the home training activities and additional supplies were provided accordingly. All expert sessions and an early and late parent-provided home session were videotaped for coding a variety of relevant behaviors. All expert trainers and testers involved in the study received considerable training from the last author and expert collaborators. All trainers were physical therapists or physical therapy/kinesiology graduate students with substantial pediatric training. All models received a 6-hour in-person, written, and video-based training before they were involved in the training sessions. We provided instruction manuals specific to each training group to trainers and models. To ensure training fidelity, we asked an unbiased undergraduate student code each trainer and model's behavior on a comprehensive checklist. For each child, three randomly selected sessions were coded to assess training fidelity.

6.2.3. Behavioral Coding

A single coder coded videos for the frequency of RBs/problem behaviors for children in all three groups during the entire duration of an early, a mid, and a late session, after establishing inter- and intra-rater reliability of > 85% using 20% of the dataset. Our coding scheme for RBs/problem behaviors is based on the sub-categories of the RBS-R questionnaire (Lam & Aman, 2007) and the range of behaviors observed by the trainer. Repetitive behaviors and problem behaviors coded were:

1. Sensory behaviors: These included bouts of movements (> 2 movements per bout) involving visual, auditory, tactile/proprioceptive, olfactory, or vestibular modalities. Sensory behaviors involved repetitive movements with objects including atypical peering, sniffing, smelling, spinning, twirling, twiddling,

slapping, and throwing objects as well as repetitive movements of the body such as spinning, rubbing, squeezing, and pressing.

2. Stereotyped behaviors: These included bouts of repetitive movements (> 2 movements per bout) of the whole body such as rocking or swaying, or of the head such as rolling, nodding, or turning, or of the arm such as flapping, waving, shaking, or wiggling, or finger flicking or leg shaking or bouncing.

3. Self-injurious/negative behaviors: These included bouts of movements causing redness, bruising, or injury to the body and could range from picking, scratching, rubbing, biting, or poking of the skin to hitting oneself with objects or hitting body parts against objects such as the wall. In addition, episodes of non-compliance such as yelling, crying, running away, and tantrums, inappropriate social conduct with others such as the use of inappropriate language, lack of social distance, and ritualistic behaviors such as the use of restricted topics or phrases in conversation, were also coded within this category.

6.2.4. Dependent Variables

Frequencies of each subcategory – sensory, stereotypes, and self-injurious/negative behaviors - were coded for a standard time frame for each condition across the early, mid, and late sessions.

6.2.5. Statistical Analysis

We used SPSS Version 16 (SPSS, Inc., Chicago, IL) for statistical analysis of our data. We checked our data on frequency for standard time for assumptions of parametric statistics including normal distribution and homogeneity of variances. Our analysis revealed that our data were not normally distributed and had a moderate number of outliers. Hence, we applied a square root transformation to our variable (frequency for standard time) for the different categories of repetitive behaviors. We used transformed data for conducting repeated measures ANOVA with repetitive behavior type (sensory, stereotyped, self-injurious/negative), session (early, mid, late), and condition (5 conditions within a session for each group – see Table 6-1 for details) as the within-subjects factors, and group as the between-subjects factor. In

case of violations of the Mauchly's test of sphericity, we applied Greenhouse Geisser corrections. If there was a significant main effect and an interaction, we conducted post-hoc t-tests to evaluate the significant interactions only. In case of significant 2-way and 3-way interactions involving the same factors, we further analyzed the 3-way interactions using post-hoc t-tests. We will report data in terms of means and standard deviations (M (SD)). We report effect sizes using the partial eta-squared (η_p^2) and standardized mean difference (SMD) values (Hedges, 1981). Statistical significance was set at $p \leq 0.05$.

6.3. Results

The repeated measures ANOVA suggested a significant main effect of RBS type ($F(2, 66) = 5.34, p = 0.007, \eta_p^2 = 0.14$), a main effect of condition ($F(2.71, 89.53) = 35.16, p < 0.001, \eta_p^2 = 0.52$), an RBS type x group interaction ($F(4, 66) = 7.53, p < 0.001, \eta_p^2 = 0.31$), a condition x group interaction ($F(8, 132) = 9.91, p < 0.001, \eta_p^2 = 0.38$), an RBS type x condition interaction ($F(5.36, 176.76) = 9.86, p < 0.001, \eta_p^2 = 0.23$), a session x RBS type x group interaction ($F(8, 132) = 2.01, p = 0.05, \eta_p^2 = 0.11$), and a condition x RBS type x group interaction ($F(16, 264) = 2.67, p = 0.001, \eta_p^2 = 0.14$). The results of post-hoc testing of the session x RBS type x group and condition x RBS type x group interactions are discussed below, in terms of within-group and between-group differences. All data reported below are in terms of frequencies of repetitive/problem behaviors in standard time.

Group	Music Group M(SD)			Robot Group M(SD)			Academic Group M(SD)		
	<i>Early</i>	<i>Mid</i>	<i>Late</i>	<i>Early</i>	<i>Mid</i>	<i>Late</i>	<i>Early</i>	<i>Mid</i>	<i>Late</i>
Sensory	12.3 (10.5)	13.2 (10.1)	10.8 (12.6)	23.7 (30.9)	15.0 (14.7)	10.5 (8.6)	37.6 (27.6)	31.3 (28.5)	29.7 (19.3)
Stereotyped	16.0 (19.6)	20.5 (30.6)	17.4 (20.9)	26.3 (23.7)	29.4 (30.9)	19.3 (20.2)	10.1 (12.3)	12.4 (15.0)	12.2 (13.3)
Self-injurious/ negative	60.9 (46.8)	35.8 (17.7)	27.8 (24.8)	35.4 (29.8)	28.8 (29.4)	39.4 (33.3)	13.4 (16.1)	28.2 (45.1)	20.2 (19.5)

Table 6-2: Frequencies in standard time of sensory (S), stereotyped (ST), and self-injurious/negative (SN) behaviors in the music, robot, and academic groups across the early, mid, and late sessions

1. Within-group differences:

- a. Music group: Children demonstrated greater frequencies of self-injurious/negative behaviors ($M (SD) = 60.86 (46.82)$) compared to stereotyped ($M (SD) = 16.02 (19.61)$, $p = 0.01$) and sensory behaviors ($M (SD) = 12.33 (10.51)$, $p = 0.007$) in the early session (see Table 6-2). Similarly, in the mid-session, children demonstrated greater self-injurious/negative behaviors ($M (SD) = 35.76 (17.72)$) compared to sensory behaviors ($M (SD) = 13.21 (10.15)$, $p = 0.003$) (see Table 6-2). No such differences between types of RBs were observed in the late session. Individual data suggest that 10-11 out of 12 children followed the group trends. In terms of training-related changes, children in the music group demonstrated significantly lower frequencies of self-injurious/negative behaviors in the late ($M (SD) = 27.76 (24.79)$, $SMD = 0.66$) and mid-sessions ($M (SD) = 35.76 (17.72)$, $SMD = 0.50$) compared to the early session ($M (SD) = 60.86 (46.81)$, $ps \leq 0.05$) (see Table 6-2 and Figure 6-3C for details). In terms of individual data, 9 out of 12 children followed the group trends.

In terms of condition-related differences in RBs/ problem behaviors within the music group, children demonstrated greater sensory behaviors in the music making condition followed by the beat keeping condition compared to the social interaction phase and action song condition (p values range from < 0.001 to 0.04) (see Figure 6-2A). Children engaged in greater stereotyped behaviors during the beat keeping condition compared to all other conditions (p values range from 0.002 to 0.04) (see Figure 6-3A). Children engaged in greater negative behaviors in the music making condition compared to all other conditions (p values between < 0.001 and 0.05) (see Figure 6-2A).

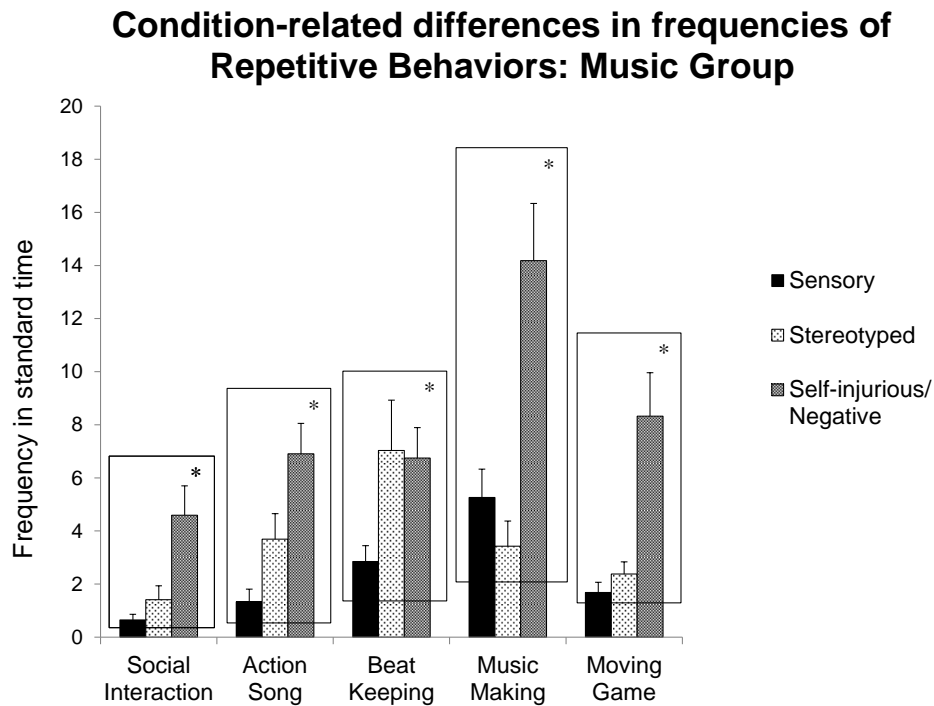


Figure 6-2A: Condition-related differences in frequencies of repetitive behaviors in the Music group.

- b. *Robot group*: There were no differences in frequencies of types of RBs/problem behaviors in the early and mid-sessions. In the late session, children demonstrated greater self-injurious/negative behaviors ($M (SD) = 39.44 (33.30)$) compared to sensory behaviors ($M (SD) = 10.53 (8.56)$), $p = 0.01$) (see Table 6-2). Individual data suggest that 9 out of 12 children followed the group trends. There were no training-related changes in frequencies of RBs in the robot group.

In terms of condition-related differences in RBs/ problem behaviors, children demonstrated greater sensory behaviors in the drumming game followed by the action game, the walking game, and the social interaction phase compared to the warm up game (p values range from 0.004 to 0.05) (see Figure 6-2B). In terms of stereotyped behaviors, children demonstrated maximum behaviors in the action game followed by the social interaction phase and the walking game compared to the warm up game (p values range from < 0.001 to 0.02) (see Figure 6-2B). Lastly, in terms of self-injurious/negative behaviors, children demonstrated greater frequencies of

behaviors during the action and drumming games compared to all other conditions (p values range from < 0.001 to 0.009) (see Figure 6-2B).

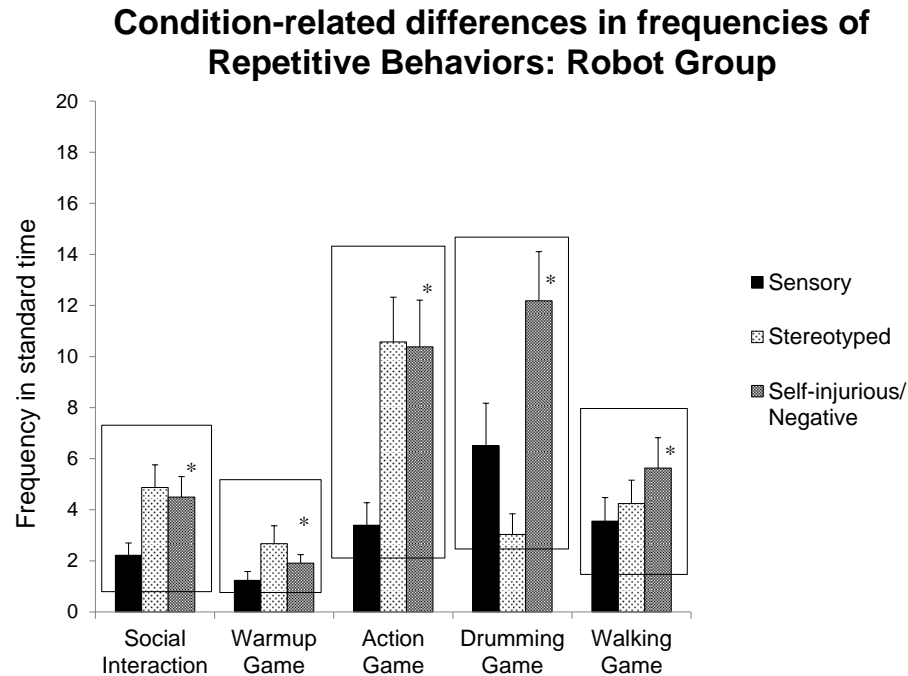


Figure 6-2B: Condition-related differences in frequencies of repetitive behaviors in the Robot group.

- c. Academic group: Children exhibited greater sensory behaviors ($M (SD) = 37.60 (27.63)$) compared to stereotyped ($M (SD) = 10.07 (12.29)$, $p = 0.005$) and self-injurious/negative behaviors ($M (SD) = 13.39 (16.07)$, $p = 0.018$) in the early session (see Table 6-2). In the mid and late sessions, children showed greater sensory behaviors (Mid: $M (SD) = 31.28 (28.47)$, Late: $M (SD) = 29.72 (19.31)$) compared to stereotyped behaviors (Mid: $M (SD) = 12.37 (14.94)$, Late: $M (SD) = 12.16 (13.27)$, $ps < 0.05$) (see Table 6-2). In terms of individual data, 10-12 out of 12 children followed the group trends. There were no training-related changes in RBs/problem behaviors in the academic group.

In terms of condition-related differences in types of RBs/problem behaviors, children demonstrated greatest sensory behaviors during the building and art & craft conditions followed by the reading condition compared to the social interaction phase (p values ranging from < 0.001

to 0.05) (see Figure 6-2C). In terms of stereotyped behaviors, children engaged in greater behaviors during the building and art & craft conditions followed by the reading condition compared to the social interaction phase (p values range from < 0.001 to 0.01) (see Figure 6-2C). Lastly, children engaged in greater frequencies of self-injurious/negative behaviors during the building and art and crafts conditions compared to the reading condition and the social interaction phase (p values range from < 0.001 to 0.02) (see Figure 6-2C).

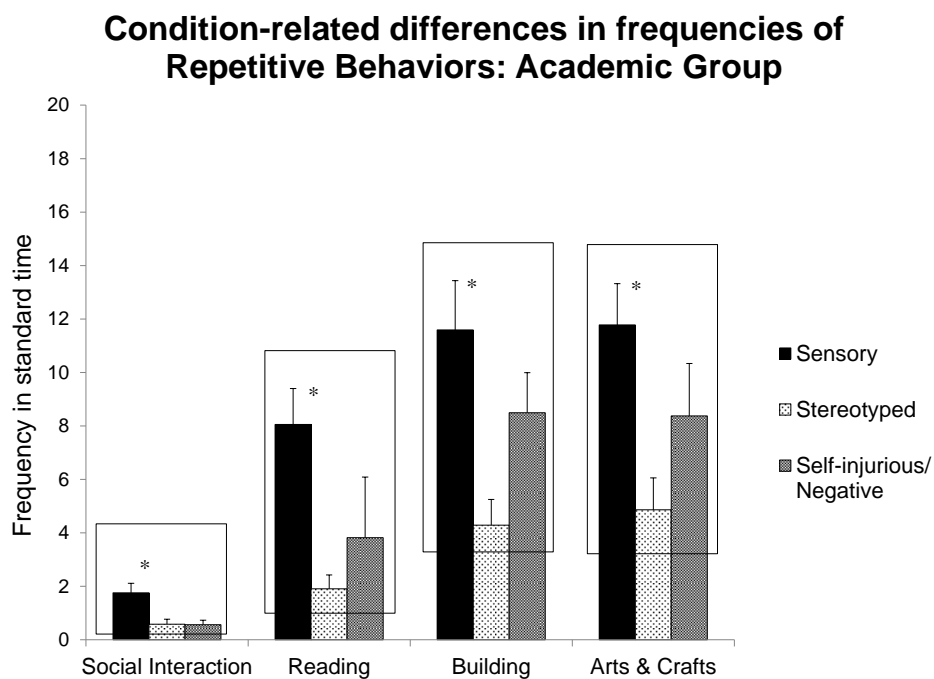


Figure 6-2C: Condition-related differences in frequencies of repetitive behaviors in the Academic group.

2. Between-group differences – In terms of sensory behaviors, children in the academic group (Early: $M (SD) = 37.60 (27.63)$, Mid: $M (SD) = 31.28 (28.47)$) demonstrated significantly greater frequencies of behaviors compared to the music group (Early: $M (SD) = 12.33 (10.51)$, Mid: $M (SD) = 13.21 (10.15)$, $p < 0.05$) in the early and mid-sessions (see Figure 6-2A). In the late session, the academic group ($M (SD) = 29.72 (19.31)$) demonstrated greater sensory behaviors compared to both music ($M (SD) = 10.79 (12.62)$, $p = 0.01$) and robot groups ($M (SD) = 10.53 (8.56)$, $p = 0.007$) (see Figure 6-3A). In

terms of self-injurious/negative behaviors, children in the music ($M (SD) = 60.86 (46.81)$) and robot groups ($M (SD) = 35.39 (29.81)$) exhibited greater frequencies of behaviors compared to the academic group ($M (SD) = 13.39 (16.07)$), $ps < 0.05$) in the early session (see Figure 6-3C). No significant group differences were observed for stereotyped behaviors (see Figure 6-3B).

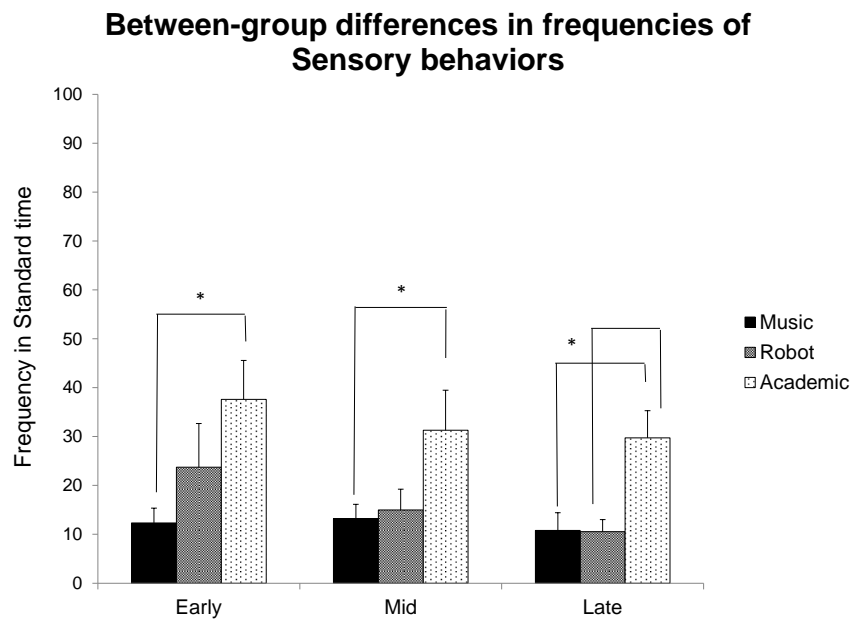


Figure 6-3A: Between-group differences in frequencies of sensory behaviors in the music, robot, and academic groups

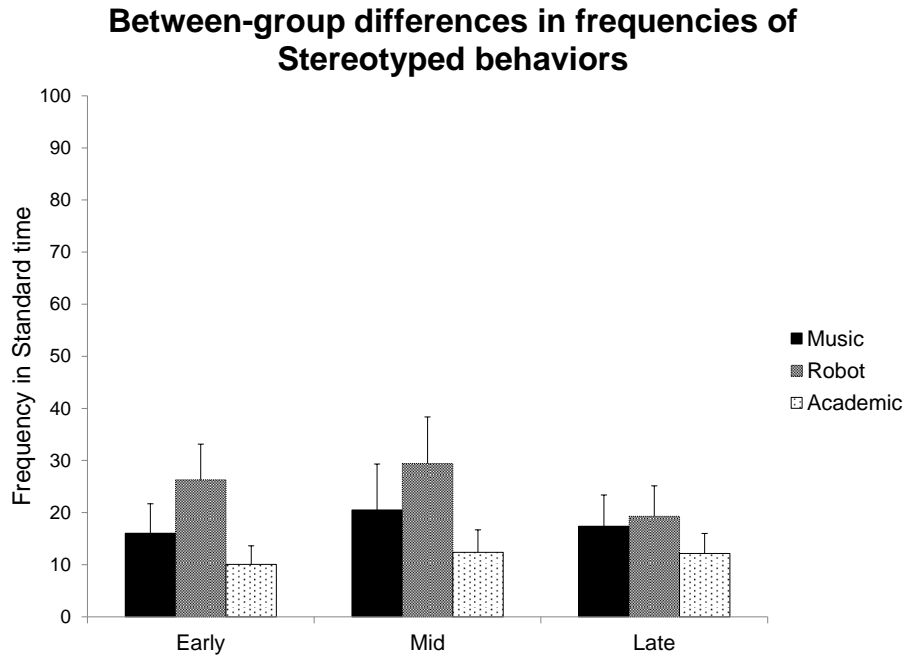


Figure 6-3B: Between-group differences in frequencies of stereotyped behaviors in the music, robot, and academic groups

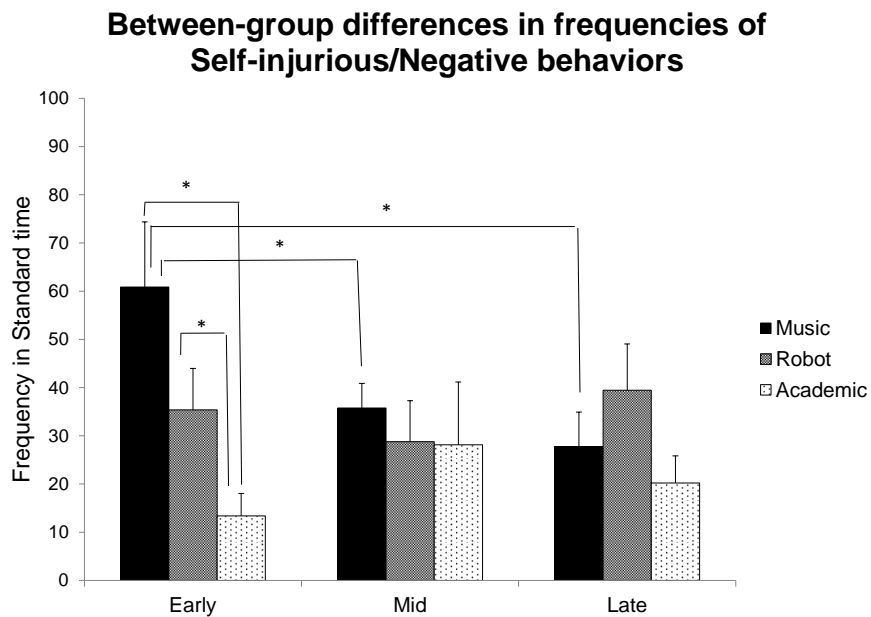


Figure 6-3C: Between-group differences in frequencies of self-injurious/negative behaviors in the music, robot, and academic groups. $*p \leq 0.05$

6.4. Discussion

6.4.1. Summary of results

We compared the effects of novel, movement-based (music and robot) interventions with those of a stationary, academic intervention on the RBs/problem behaviors of children with ASDs. Our 3 research aims were as follows – first, to identify context-related differences in RBs/problem behaviors between groups; second, to identify training-related differences in behaviors across early, mid, and late sessions within each group; and third, to examine condition-related differences in RBs/problem behaviors within each group. At baseline, the three groups did not differ in their frequency and severity of repetitive behaviors as measured on the RBS-R. We believe that any differences in types of RBs in the early session and across training were therefore reflective of *context-specific differences* evoked by the nature of the training activities. Accordingly, in the early training session, the music and robot groups demonstrated greater self-injurious/negative behaviors compared to the academic group (see Figure 6-3C). The academic group demonstrated greater sensory behaviors compared to the music and robot groups (see Figures 6-3A). In terms of *training-related changes*, the music group reduced the frequency of self-injurious/negative behaviors from the early to the mid and from the early to the late sessions (see Figure 6-3C). There were no training-related changes in frequencies of RBs/problem behaviors in the robot and academic groups. In terms of *condition-related differences* in each group, in line with our hypotheses, we found that the types of RBs varied according to the nature of the conditions and their complexity. Children in the music group engaged in most sensory behaviors during the music-making condition; they showed greater stereotypies in the beat keeping condition; and lastly, they showed maximum self-injurious/negative behaviors during the music-making condition (see Figure 6-2A). Along the same lines, the robot group engaged in greatest sensory behaviors during the drumming game; maximum stereotyped behaviors during the action game; and greatest self-injurious/negative behaviors in the action and drumming games (see Figure 6-2B). Lastly, in the academic group, children showed greater amounts of

all three types of RBs/problem behaviors during the building and art & crafts activities compared to the other conditions (see Figure 6-2C).

6.4.2. Context-related differences in RBs/problem behaviors between groups

Children in the music and robot groups demonstrated greater frequencies of self-injurious/negative behaviors compared to the academic group in the early session (see Figure 6-3C). Both intrinsic and extrinsic factors could contribute to RBs/problem behaviors in children with ASDs (Joosten, Bundy, & Einfeld, 2009). Intrinsic factors, such as the need to obtain more sensory input or to reduce excessive sensory input, as well as attempts to modulate arousal levels and reduce stress in challenging situations, could motivate children to engage in RBs (Cunningham & Schreibman, 2008; Gabriels et al., 2008; Joosten et al., 2009; Leekam et al., 2011; Lewis & Bodfish, 1998; Turner, 1999). Moreover, extrinsic motivators such escape from a challenging activity and increased attention from teachers and caregivers could also serve as triggers for RBs/problem behaviors. The music and robotic contexts involved the practice of gross and fine motor tasks requiring imitation, praxis, balance, and bilateral coordination skills. Given the pervasive motor difficulties in this population (Bhat et al., 2011; Downey & Rapport, 2012; Fournier et al., 2010), these activities might have been challenging, and hence may have led to considerable stress in the music and robot groups. Moreover, unlike academic and fine motor activities, gross movement-based activities are not typically included within the standard of care treatment of children with ASDs (Landa, 2007). Hence, the novelty of the contexts and the practiced activities might have further contributed to increased frustration, leading to RBs in children. Children with ASDs increased their stereotyped behaviors when the difficulty of the task that children engaged in was increased (Durand and Carr, 1987). In fact, children used stereotypies as a way to communicate with teachers and escape from the demanding situation, since most teachers used ‘time out’ as a strategy to decrease their problem behaviors (Durand & Carr, 1987). Anxiety is one of the strongest motivators of RBs and problem behaviors (Joosten et al., 2009; Leekam et al., 2011). Children with ASDs become anxious when there is an unanticipated change in routine, or if they are agitated/upset, or if they are faced

with novel and demanding situations (Joosten et al., 2009). When children engaged in high-demand activities such as math, there was an increase in stereotypy (Conroy, Asmus, Sellers, & Ladwig, 2005). The authors reasoned that children engaged in stereotypies to gain an optimal level of arousal and to reduce anxiety levels (Conroy et al., 2005). Along the same lines, the music and robot groups might have engaged in higher levels of negative behaviors as a way to reduce their anxiety, regulate their stress/arousal levels, or as a mode of communication in an attempt to escape from the unfamiliar and novel context. In contrast, the academic group engaged in academic and fine motor table-top tasks, which were generally more familiar and predictable than the activities in the movement groups. Academic and cognitive skills are the main targets of traditional ABA interventions that are commonly provided to children with ASDs within school settings (Landa, 2007; Lovaas, 2003). Our observations of affective states of children while they engaged in training activities also suggest that the academic group showed maximum interested affect and compliance with activities compared to the movement groups. The familiarity of the context and training activities might have led to lower frequencies of self-injurious/negative behaviors in this group. Moreover, the structure of the environment was more constrained as a result of the nature of the table-top activities, which might have limited children's opportunities to demonstrate non-compliant behaviors such as running away or physical tantrums. Overall, the novelty and unpredictability of the training activities and the unconstrained nature of the training environment might have led to greater negative behaviors in the music and robot groups.

The academic group demonstrated greater sensory behaviors compared to the music group in the early session and compared to both music and robot groups in the late session (see Figure 6-3A). Possible reasons for these findings could include the nature of our training activities, children's preference for non-social object play, their difficulties with disengaging attention, and the limited nature of object play in children with ASDs. Our training aimed to promote triadic social interactions within a stationary setting in the academic group. For this purpose, children engaged in goal-oriented activities with their social partners, using supplies such as Play-Doh®, Duplo® blocks, Zoob (InfiniToy®), crayons, and glue. We

believe that the proximity of the supplies/objects in the academic context provided children with multiple opportunities to engage in non-social object-based play. Our findings are consistent with other studies in which children who later developed ASDs engaged in greater episodes of non-social exploration with objects instead of social interactions with caregivers and peers during infancy and early childhood (Maestro et al., 2002; Maestro et al., 2005; Maestro et al., 2006; Williams, Reddy, & Costall, 2001; Williams, 2003). Along the same lines, young children with ASDs preferred to look at objects for a longer duration in contrast to children with developmental delays and TD children, who attended more to people during a free play session with toys in the presence of caregivers (Swettenham et al., 1998). Further, difficulties with disengaging attention (Landry & Bryson, 2004) and shifting attention between objects and people (Lewy & Dawson, 1992; McArthur & Adamson, 1996; Swettenham et al., 1998) might also explain children's restricted and repetitive actions with objects (Turner, 1999). Children with autism demonstrated greater frequencies of gaze shifts between two objects and fewer gaze shifts between people and objects or between two people compared to TD children (Swettenham et al., 1998). Given their preference for object play and the nature of the environmental setup for the training activities in the academic group, we believe that children engaged in greater object-related sensory behaviors in this group than in the other groups. In contrast, the movement groups did not provide children with easy access to objects during training, which might have led to lower frequencies of sensory behaviors in these groups. Our reasoning is also supported by our observation of the attention patterns of children within the training contexts. While children in the academic group looked most at objects, children in the movement groups, music and robotic, looked more at social partners during the training activities. Lastly, in terms of the nature of object-based play, we found that the academic group engaged in different forms of primitive sensorimotor exploration with objects, including odd visual exploration, tactile behaviors such as rubbing or tapping, and olfactory behaviors such as repetitive sniffing of objects. These findings are consistent with studies that found that when children with ASDs played with toys, the sensorimotor properties of objects were most salient for them leading to simple and repetitive forms of manipulations with toys instead of more age-appropriate and functional actions (Jarrold, Boucher, & Smith, 1993; Libby, Powell,

Messer, & Jordan, 1998). Moreover, both high-functioning and low-functioning children with ASDs used primitive forms of exploration employing vision, touch, taste, and smell while interacting with objects in restricted and inflexible ways (Freeman, Ritvo, & Schroth, 1984; Libby et al., 1998; Williams, 2003). A possible reason for children engaging in restricted and repetitive sensory manipulation of objects could be their difficulty in generating new types of behaviors (Turner, 1999). This lack of creativity might lead to less diverse and more restricted patterns of play (Hobson, Lee, & Hobson, 2009; Jarrold, Boucher, & Smith, 1996; Lewis & Boucher, 1995). Overall, both children's predilection for objects and the nature of our training activities might have led to higher frequencies of sensory behaviors in the academic group compared to the movement groups.

6.4.3. Training-related changes in RBs/problem behaviors within groups

The music group reduced the frequencies of self-injurious/negative behaviors across training weeks (see Table 6-2 and Figure 6-3C). We believe that improvements in social communication, behavioral, and motor skills might have contributed to positive effects of music-based training. Music training led to improvements in social engagement skills including eye contact and reciprocal interactions with caregivers and peers in children with ASDs (Kern & Aldridge, 2006; Kim et al., 2008; Wimpory et al., 1995). Similarly, children with autism reduced the frequencies of problem behaviors following active and passive musical therapies involving listening, singing, and instrument playing (Boso et al., 2007; Brownell, 2002; Lundqvist, Andersson, & Viding, 2009; Orr, Myles, & Carlson, 1998; Pasiali, 2004; Rapp, 2007). In fact, music sessions led to greater joy and compliance with therapy compared to toy play in children with ASDs (Kim et al., 2009). We propose that when children engage in musical experiences within a social setting, such shared experiences promote the development of imitation, turn taking, joint attention, social synchrony, and verbal communication skills (Srinivasan & Bhat, 2013). Moreover, the non-intimidating yet enjoyable nature of musical experiences could induce positive affective states, improve compliance, and reduce negative and problem behaviors in children with ASDs (Srinivasan & Bhat, 2013). Along the same lines, our observations of the music group suggest that across training

weeks, children engaged in task-appropriate social behaviors including turn taking, synchronous singing and joint action, social monitoring, and verbal interactions with social partners. Moreover, we observed that the repeated practice of gross and fine motor activities within sessions also led to improved motor and imitation skills in the music group. In line with our hypotheses, we believe that the improved social communication and motor skills might have led to increased compliance with and enjoyment of activities across sessions and a collateral reduction in negative behaviors in the mid and late sessions compared to the early session (Leekam et al., 2011; Loftin et al., 2008).

In contrast to our hypotheses, the robot and academic group did not show any training-related improvements in RBs/problem behaviors. Individual data suggested that 7 out of 12 children in the robot group showed a reduction in self-injurious/negative behaviors from the early to the mid-session with a subsequent increase in negative behaviors from the mid to the late session in 8 out of 12 children. We believe that the lack of improvement and a trend for worsening in negative behaviors in the robot group could be attributed to the technical limitations of the robot used in our study that restricted its variability in movements. Although we used the state-of-the-art humanoid robot Nao with 25 degrees of freedom, children seemed to get bored with the limited capabilities of the robot over time. The robot's movements are much slower, noisier, and significantly less diverse than the natural movement repertoire of children. Moreover, the robot was pre-programmed with limited verbiage, and though we utilized the online feature of the robot for typing in contingent responses to children's verbiage, there was a time lag to the responses initiated by the robot. Hence, the conversation during the robotic interactions was artificial, instead of a natural, timely, fluid to-and-fro exchange between the child and the robot. We had several instances of technical problems with the robot due to overheating and equipment failure. Overall, the limitations of our technology made the robotic context less compelling and contingent compared to the other two contexts. We noticed that once the initial excitement and novelty associated with the robot wore off, even low-functioning children with ASDs were bored over time and showed several negative behaviors including physical tantrums and non-compliance with the activities.

Our findings are contrary to the existing literature on the positive effects of robot-based interactions to facilitate prosocial skills such as eye contact, turn-taking, joint attention, and verbal communication in children with ASDs (Cabibihan et al., 2013; Diehl et al., 2011). However, most studies demonstrated improvements in children following a single session of interaction with the robot. Only three studies examined the effects of repeated interactions with humanoid robots such as Robota or KASPAR (Robins, Dautenhahn, & Dickerson, 2009; Robins et al., 2004), or creature-like robots such as Keepon (Kozima et al., 2007), over several months, and found qualitative improvements in social skills such as turn-taking, shared attention and affect, as well as imitation skills, while still sustaining engagement of children with ASDs. In these studies, the robot was either placed in the play room and children were allowed to freely approach and initiate interactions with the robot at any time during their play (Kozima et al., 2007), or, in the more structured interactions where children engaged with the robots for a very short time until they started getting bored (which was after an average duration of 3 minutes) (Robins et al., 2004). In contrast, in our setup, children engaged in structured imitation-based games with the Nao robot for 30-45 minutes per session for a total of 16 sessions over 8 weeks. Clearly, our current protocol could not maintain engagement in children over weeks of training. Other studies using the Nao robot in children with ASDs have ranged between 1 and 10 sessions (Bekele et al., 2013; Huskens et al., 2013; Ismail, Shamsudin, Yussof, Hanapiah, & Zahari, 2012b; Tapus et al., 2012; Warren et al., 2013). For example, during a single interaction session of around 15 minutes involving Nao, children with ASDs showed lower stereotypical behaviors compared to a normal classroom interaction with their teacher (Ismail, Shamsudin, Yussof, Hanapiah, & Zahari, 2012b). Similarly, following a 4-session interaction with Nao, children improved their ability to respond to joint attention cues and also maintained interest in the robot throughout training (Warren et al., 2013). However, 2 other studies with Nao suggested equivocal results (Huskens et al., 2013; Tapus et al., 2012). During an imitation task with the robot mediator compared to a human mediator, improvements in motor initiation, eye contact, and positive affect were seen in only 2 out of 4 children (Tapus et al., 2012). Similarly, an ABA-based intervention to promote self-initiated questions conducted by the robot was only as effective as training provided by a human instructor (Huskens et al.,

2013). Our study further extended previous protocols with the Nao robot by providing an intense and structured protocol based on ABA principles where children engaged in gross and fine motor imitation-based games with Nao within a group setting. Following an initial improvement in RBs, our current paradigm and robotic technology could not maintain children's interest and there was an associated increase in negative behaviors from the mid to the late session. Future studies using robots as adjuncts in therapy should develop more contingent and dynamic technology that allows robots to be activated based on the child's initiation of an interaction and further allows them to adapt to the needs of the child. Such advances in technology are needed for the development of successful robotic interventions that will be able to sustain the child's engagement during prolonged robot-training protocols.

The academic group did not show any improvements in self-injurious/negative behaviors with training. This group had lower negative behaviors to begin with, compared to the other two movement groups. Children with ASDs are typically recommended 30-40 hours of ABA per week, which focusses on facilitating pre-academic, language, and cognitive skills (Landa, 2007; Lovaas, 1987). Our training activities included reading, building, and arts & crafts, which children practice routinely within school settings. Hence, the familiarity and predictability of our academic context led to lower negative behaviors in this group. Our findings are supported by our observations of maximum compliance with training activities and interested affective states in the academic group compared to the movement groups.

6.4.4. Condition-related differences in RBs/problem behaviors within groups

We observed condition-related differences in RBs/problem behaviors within each group. We believe that the nature of the activities practiced in the conditions and the types of supplies used within each condition might have led to condition-related differences in RBs/problem behaviors. The music and robot groups showed similar trends in RBs across conditions; hence, results from these two groups will be discussed together. The results of the academic group are discussed thereafter.

Children demonstrated greater sensory behaviors during the music-making and drumming conditions in the music and robot groups, respectively, compared to all other conditions (see Figures 2A & 2B). In both conditions, children played with objects including musical instruments such as drums in the robot group and xylophones, cymbals, drums, maracas, or shakers in the music group. Children were usually seated on the floor or on a stool and were in a relatively more constrained setting while playing instruments compared to other conditions that involved gross motor movements during standing. Given the easy access to objects within a relatively constrained environment, children had plenty of opportunities to engage in preferred manipulation of objects. Our findings within the music-making and drumming conditions mimic our overall results of greater sensory behaviors in the academic group, suggesting that when children were given access to objects in their proximal space, they engaged in persistent and primitive sensorimotor exploration of objects. Our observations of attention patterns of children also suggest that children directed maximum attention to objects during these two conditions compared to all other conditions. Along the same lines, children engaged in maximum self-injurious/negative behaviors during the music-making condition (music group), and action game and drumming conditions (robot group), compared to all other conditions. The music-making, action, and drumming conditions were based on themes such as start and stop, slow and fast, and turn taking where children were asked to practice complex motor sequences to the beat of music. In the music group, as a part of the music-making condition, we taught children unilateral and bilateral xylophone patterns corresponding to songs such as “Jingle bells” or “Twinkle twinkle little star”. Similarly, in the robot group, children practiced combinations of quarter and eighth patterns to music during the drumming game. They practiced dual and multilimb gross motor actions during the action game. Overall, all these conditions in both groups were very challenging for children since they required imitation, praxis, and bilateral coordination skills. As discussed previously, children demonstrate greater RBs when faced with difficult tasks. Given the greater task-difficulty of the music-making, action, and drumming conditions, children might have engaged in negative behaviors to either escape from the task or to communicate their frustration to their caregivers.

Children in the movement groups engaged in greater stereotypical behaviors during the beat keeping and action game conditions compared to other conditions (see Figures 2A & 2B). In contrast to the relatively more stationary music-making and drumming game conditions, the beat-keeping and action games provided children with multiple opportunities to move freely. Both games involved children practicing upper and lower body actions to music. We believe that the unconstrained nature of the contexts allowed children to engage in whole body stereotypies. Moreover, the trainers and the coder observed that children frequently engaged in stereotypies as they moved to the beat of music, for example, nodding or turning their heads, swaying their bodies, shaking or waving their arms, and jumping or bouncing their bodies rhythmically to the beat. We argue that in contrast to non-purposeful, repetitive movements, these stereotypies are in fact “functional” in nature in that children moved rhythmically to explore the music through their bodies and to demonstrate their enjoyment and engagement with the context. This is not surprising, given the evidence from music education literature that music is in fact a multimodal active experience that involves the whole body (Findlay, 1971; Juntunen & Hyvonen, 2004; Overy & Molnar-Szakacs, 2009; Toiviainen, Luck, & Thompson, 2010). Even typically developing 2-year old toddlers attempted to synchronize their bodily movements and vocalizations to music that they heard (Gruhn, 2002). Similarly, when we hear a musical performance, we do not simply perceive it or think about it, but we rather participate actively in the experience using our bodies (Bowman, 2000). Hence, listening to music is automatically accompanied by bodily movements that are synchronized to the music rhythm (Lesaffre et al., 2008; Overy & Molnar-Szakacs, 2009) and in fact vary depending on the nature of the music and the biomechanical constraints of our bodies (Toiviainen et al., 2010). For example, faster musical pieces evoked movements of the lighter and easier to move extremities whereas slower beats led to movements of the heavier trunk in adults (Toiviainen et al., 2010). In fact, bodily enactment of music seems to enhance the musical understanding of individuals (Juntunen & Hyvonen, 2004). Children with ASDs enjoy music (Blackstock, 1978) and have heightened music perception abilities compared to TD children (Bonnell et al., 2003; Heaton, Pring, & Hermelin, 1999). We believe that the music-based beat keeping and action game conditions evoked functional stereotypies in children, which as a result of their

repetitive nature were coded as “stereotyped” movements according to our coding scheme. However, we argue that these “functional” movements reflect children’s exploration of the music using their bodies as well as their engagement in the context.

Children in the academic group engaged in greater sensory behaviors during the building and art & crafts conditions compared to the reading and social interaction phases (see Figure 2C). In the building and art and crafts conditions, children made projects during each session using supplies such as Play-Doh®, Duplos®, Zoob (Infinitoy®), crayons, construction paper, scissors, and glue. In contrast, the reading and social interaction conditions did not involve interactions with supplies. As discussed previously, our aim was to promote social interactions within a stationary setting as children engaged in academic activities, to mimic the standard of care for children with ASDs. We encouraged verbal and non-verbal communication by prompting children to ask for help, by requesting their help to complete creations or read out steps of the task, by providing them with choices, by asking them to comment on their creations, and by promoting collaborative work. However, we believe that the proximity of objects/supplies in the building and art-craft conditions might have allowed children to engage in repetitive sensory exploration of the supplies. Along the same lines, children also engaged in maximum negative behaviors during the building and art & crafts conditions. Children were provided with a visual instruction guide that broke down the steps for each building and art & craft project. These projects required cognitive and problem-solving skills as well as proficiency in fine motor skills such as cutting, coloring, pasting, and drawing. Children with autism have difficulties in planning and executing their actions (Hughes, Russell, & Robbins, 1994; Ozonoff, Pennington, & Rogers, 1991). They also have significant motor difficulties in manual dexterity and in the use of two hands for fine motor manipulation, which could have implications for performance of academic activities (Bhat et al., 2011; Fuentes et al., 2009; Ghaziuddin et al., 1994; Manjiviona & Prior, 1995; Miyahara et al., 1997; Provost et al., 2007). For example, young children with ASDs demonstrated significant impairments in object manipulation, grasping, and visuomotor integration as measured on the Peabody Developmental Motor Scales (Provost, Lopez, & Heimerl, 2007). Similarly,

children with ASDs also demonstrated poor handwriting skills compared to age-matched controls (Fuentes et al., 2009). Overall, we believe that the fine motor difficulties in autism made the building and art & crafts conditions challenging for children, leading to greater negative behaviors during these conditions compared to other conditions.

6.5. Clinical Implications

We think that novel music and movement-based interventions are valuable contexts to promote critical skills in the motor and social communication domains in children with ASDs. Although movement contexts were initially challenging for children given their motor impairments and the novelty of the training activities, children learned the required motor skills over training and in fact began to enjoy music-based gross motor games. In addition, children began to functionally explore music through their bodies as seen in the music and robot groups but not in the academic group. Our observations also suggest that movement-based contexts provided children with multiple opportunities to engage in shared attention bids with their social partners. Moreover, children increased their rapport and spontaneous verbal communication with trainers across weeks. Although the academic setting promoted responsive verbal communication in children, our results suggest that the easy access to supplies in this context allowed repetitive and restricted sensorimotor play with objects. Such stationary contexts are ideal for promoting academic skills, since children are relatively constrained and their limited mobility makes it easier for teachers to ensure on-task behaviors. However, if the aim is to promote social interactions, movement-based games within group settings provide a natural context for children to learn imitation, turn-taking, social monitoring, joint attention, and communication skills. We recommend that children engage in diverse experiences that facilitate both structured and free exploration within social contexts to enhance learning. Our results suggested that music-based contexts were more engaging and enjoyable for children compared to robotic contexts. Although technology is a predilection for children with ASDs, robotic contexts quickly lose their initial novelty and appeal as children become bored with the limited movement repertoire of the robot. Moreover, our robotic technology did not allow for real-time moment-by-moment

monitoring of the child's behavior and subsequent dynamic adaptation and contingent responding by the robot. We also experienced several technical issues with the robotic technology. We recommend that robots be used with caution as adjuncts in therapeutic settings, since they do not seem to be a feasible technology to reduce caregiver burden at present. Overall, our findings suggest the potential value of novel, music and movement-based contexts as treatment tools to broaden the social communication, behavioral, and motor repertoire of children with ASDs. In the future, we plan to explore the effects of other socially-embedded movement-based therapies such as creative yoga and dance to remediate the core impairments in autism.

6.6. Limitations and recommendations for future research

The aim of our RCT was to assess the feasibility of novel movement interventions in children with ASDs and to develop ideal research practices in preparation for a larger RCT assessing the efficacy of novel, embodied movement therapies in children with ASDs. However, our study had several limitations. The coders were not blinded to the grouping of the child as they watched the training videos of all three groups. In terms of our study design, we did not conduct any follow-up assessments to check for generalization and functional carryover of learnt skills into the daily routines of children with ASDs. With regards to training, our intervention was for a relatively short period of time which might have limited the improvements that children showed with training. Moreover, in spite of extensive training provided to parents for implementing additional sessions at home, we noticed that there was considerable variability in the adherence levels of parents with the home program and this may have influenced our findings. Based on our experiences, we believe that there is a need to develop separate protocols for high- and low-functioning children with ASDs. In the current study, we adapted the training activities for low-functioning children. For example, we had stencils to assist children in drawing shapes in the academic group, or we practiced multiple repetitions of simpler modified movement patterns in the music and robot groups. However, we noticed that high-functioning children with ASDs became bored with the multiple repetitions of activities in the movement groups. Future studies should replicate our results by using

larger sample sizes, longer training durations, and follow-up testing. Moreover, future research should focus on development of activities that are functionally relevant and capable of sustaining engagement of children for prolonged periods.

6.7. Conclusions

Our RCT compared the effects of two novel, embodied movement interventions, music and robotic, with those of a stationary academic standard-of-care intervention, on the perceptuo-motor and social communication skills of children with ASDs. In this paper, we reported the effects of the three interventions on repetitive behaviors, which is a core symptom in autism. We found that the nature of repetitive behaviors varied with the context of the training activities. While the music and robot groups engaged in greater negative behaviors at baseline due to the novelty of the practiced activities, the academic group engaged in greater sensory behaviors with objects. Over time, children in the music and robot groups showed some reduction in negative behaviors from the early to mid-session and began to functionally explore music using their bodies in specific conditions. In the robot group, children increased their negative behaviors in the late session, probably due to the limitations of our current robotic technology. Overall, our study suggests that music-based movement games in group settings are effective and enjoyable activities that could be used to remediate the core impairments in ASDs.

Chapter 7

The effects of embodied rhythm interventions on the imitation skills and motor performance of children with Autism Spectrum Disorders (ASDs)

7.1. Introduction

7.1.1. Overview of Autism Spectrum Disorders and implications of motor skills in autism

Children with a diagnosis of Autism Spectrum Disorders (ASDs) demonstrate persistent impairments in social communication skills and have repetitive and restricted interests (American Psychiatric Association, 2013). In terms of social communication difficulties, children have impaired initiation of social interactions, deficits in sharing interests with social partners, impairments in verbal and non-verbal communication skills, and difficulty forming long term relationships (Bryson et al., 2007; Charman et al., 1998; Gernsbacher et al., 2008; Gernsbacher et al., 2008; Mundy et al., 1986; Rozga et al., 2011; Tager-Flusberg et al., 2005; Yoder et al., 2009). In terms of restricted and repetitive behaviors, children engage in stereotyped movements, stereotyped speech, and repetitive actions on objects, have circumscribed interests, and adhere to fixed routines (Leekam et al., 2011). Research in the past three decades has conclusively shown that additional motor impairments are also consistently present in individuals with ASDs. Although the exact prevalence estimates of motor impairments in ASDs vary considerably across studies, the general consensus is that between 50-100% of children and adolescents diagnosed with ASDs have motor difficulties (Berkeley, Zittel, Pitney, & Nichols, 2001; Green et al., 2002; Green et al., 2009; Hilton, Zhang, Whilte, Klohr, & Constantino, 2012; Hilton et al., 2007; Manjiviona & Prior, 1995; Ming, Brimacombe, & Wagner, 2007; Provost et al., 2007; Provost et al., 2007). Specifically, both high- and low-functioning children with ASDs demonstrate difficulties with gross and fine motor skills as well as impaired imitation and praxis skills from early in life, and these issues persist into adolescence (Bhat et al., 2011; Downey & Rapport, 2012; Fournier et al., 2010; Hobson & Lee, 1999; Rogers et al., 1996). Motor impairments in infancy and early childhood have implications for future social, cognitive, and

communication development in autism (Leary & Hill, 1996). For example, impairments in gross motor skills can severely impact social development by limiting children's opportunities to engage in age-appropriate interactions with their peers, which in turn can restrict their opportunities to build social connections and friendships. To elaborate, much of the active play with peers and team sports in childhood involves motor skills such as running, jumping, hopping, kicking, throwing, and climbing on swings, all of which require good dynamic balance, coordination, and postural control. Clumsiness and poor gross motor skills in ASDs lead to a vicious cycle in which motor difficulties limit social development, and poor social interaction skills also constrain opportunities to learn and refine complex motor skills during peer interactions (Bhat et al., 2011; Jansiewicz et al., 2006; Lloyd et al., 2013; Pan, Tsai, & Chu, 2009; Provost et al., 2007). Similarly, proficiency in fine motor skills such as object manipulation, drawing, coloring, using scissors, writing, stringing beads, buttoning and unbuttoning, tying shoe laces, etc., is critical for cognitive development, academic success, and achieving independence in activities of daily living (Kopp, Beckung, & Gillberg, 2010; Provost et al., 2007; Sacrey et al., 2014). Lastly, motor skills also impact communication development. Specifically, impaired manual motor skills such as pointing, requesting, and reaching out have implications for nonverbal modes of communication such as initiation of and response to joint attention as well as use of gestures (Gernsbacher et al., 2008). Overall, there is substantial evidence supporting the far-reaching cascading effects of motor difficulties on multisystem development. Not surprisingly, motor skills of children with ASDs at age 2 were predictive of optimal outcomes at age 4 (Sutera et al., 2007). Given this unequivocal evidence on the impact of motor skills in ASDs, there is a need for intensive research dedicated towards understanding and remediating the motor impairments in autism.

7.1.2. Gross and fine motor impairments in ASDs

Impairments in gross and fine motor performance in autism are evident in infancy and early childhood and persist into adolescence (Adrien et al., 1993; Baranek, 1999; Bryson et al., 2007; Charman et al., 1997; Downey & Rapport, 2012; Esposito & Venuti, 2009; Flanagan et al., 2012; Fournier et al., 2010;

Hobson & Lee, 1999; Landa & Garrett-Mayer, 2006; Ozonoff et al., 2008; Ozonoff et al., 2010; Rogers et al., 1996; Teitelbaum et al., 1998). Evidence on stability and progression of motor symptoms suggests that motor impairments in fact become worse over development. A cross-sectional study that assessed 162 toddlers with ASDs between the ages of 12-24, 25-30, and 31-36 months suggested that gross and fine motor delays were seen in infants at all ages but impairments became more pronounced at the later ages (Lloyd et al., 2013). Further, these findings were confirmed with a longitudinal study by the same authors that suggested that the developmental trajectory for gross and fine motor skills slowed down progressively and the extent of delays increased with age (Lloyd et al., 2013). Evidence suggests that children with ASDs demonstrate a variety of impairments in gross and fine motor performance. In terms of gross motor performance, children with ASDs have significant impairments in postural control (Adrien et al., 1993; Esposito & Venuti, 2009; Freitag et al., 2007; Minshew et al., 2004; Teitelbaum et al., 1998), gait patterns (Hallett et al., 1993; Rinehart et al., 2006b; Vilensky et al., 1981), and bilateral coordination skills (Isenhower et al., 2012; Marsh et al., 2013). Similarly, in terms of fine motor skills, children have impaired object control and manual dexterity skills (Berkeley et al., 2001; Green et al., 2002; Miyahara et al., 1997), reaching and grasping patterns (Mari, Castiello, Marks, Marraffa, & Prior, 2003; Sacrey et al., 2014), visuomotor integration skills (Provost et al., 2007), handwriting skills (Fuentes et al., 2009; Kushki, Chau, & Anagnostou, 2011; Mayes & Calhoun, 2003), and motor planning abilities (Nayate et al., 2011; Rinehart et al., 2006a; Sacrey et al., 2014). In fact, several studies suggest that children perform at below-average levels on standardized tests of motor performance (Ghaziuddin et al., 1994; Ghaziuddin & Butler, 1998; Green et al., 2002; Green et al., 2009; Manjiviona & Prior, 1995; Matson, Mahan, Fodstad, Hess, & Neal, 2010; Miyahara et al., 1997; Pan et al., 2009; Provost et al., 2007; Staples & Reid, 2010; Whyatt & Craig, 2012). For example, a comparison of locomotor and object control skills of 25 children with ASDs between 9 and 12 years of age with three groups of typically developing (TD) children, matched on chronological age, developmental level, and mental age, suggested that children with ASDs performed worse than all three control groups. Further, motor skills of children with ASDs corresponded to children half their age (Staples & Reid, 2010). Overall, the above evidence suggests that

children with ASDs have pervasive impairments in gross and fine motor skills that are evident on standardized motor tests. In fact, a recent comprehensive meta-analysis based on 51 studies comparing children with ASDs and their TD controls suggested a large effect size of 1.20 for motor issues in gait, postural control, motor coordination, upper limb control, and motor planning in this population (Fournier et al., 2010). Moreover, overall motor performance in autism is associated with levels of symptom severity (Dziuk et al., 2007; Hilton et al., 2012), proficiency in daily living skills (Kopp et al., 2010), and level of social withdrawal (Freitag et al., 2007). Given the pervasive nature of motor impairments in autism, it is critical that goals related to gross and fine motor development are brought to the forefront during planning and implementation of early intervention services for children with ASDs.

7.1.3. Imitation and praxis impairments in ASDs

In addition to impairments in overall motor performance, children with ASDs also have significant impairments in imitation skills. Imitation is considered a pivotal skill and deficits in imitation have been conceptualized as underlying the core social communication, affective, and cognitive impairments in ASDs (Meltzoff & Gopnik, 1993; Rogers & Pennington, 1991); hence, considerable research has been dedicated towards studying imitation impairments in autism. Impaired imitation skills have been documented in toddlers and young children with ASDs (Charman et al., 1997; Rogers et al., 2003; Stone et al., 1997), and are thought to continue into adulthood (Avikainen, Wohlschläger, Liuhanen, Hänninen, & Hari, 2003; Bernier, Dawson, Webb, & Murias, 2007; Hobson & Lee, 1999; Rogers et al., 1996). The existing literature on imitation of actions is based on 2 main distinctions – (1) actions on objects (for example, shaking a maraca, pushing a toy car on the table) versus actions without objects (for example, clapping hands, opening and closing a fist), and (2) meaningful actions (for example, actions that convey communicative intent such as waving “bye”, beckoning using index finger) versus non-meaningful actions (for example, non-communicative actions such as pulling on an earlobe, holding hand against chest) (Smith & Bryson, 1994; Williams, Whiten, & Singh, 2004). Although there is considerable variability in the types of imitation assessed by different studies, it is suggested that meaningful gestures

and actions on objects are less impaired than meaningless gestures and body movements not involving objects in individuals with ASDs (Rogers et al., 1996; Stone et al., 1997; Vanvuchelen, Roeyers, & De Weerdt, 2007; Williams et al., 2004). Thus, imitation within a functional context involving familiar, communicative or descriptive gestures or actions with familiar objects which have known affordances seems to aid imitation performance in children with autism (Rogers et al., 1996; Smith & Bryson, 1994; Williams et al., 2004). For example, Vanvuchelen and colleagues assessed imitation skills in low- and high-functioning boys with autism compared to TD children and children with intellectual disability and found that irrespective of the level of intellectual disability, children with autism had greater impairment in imitation of meaningless versus meaningful actions compared to the control groups. Moreover, the imitation impairment in autism was associated with children's level of motor ability as assessed on standardized tests of motor performance (Vanvuchelen et al., 2007). Similarly, a study that compared imitation performance of young children with ASDs, children with developmental delays, and TD children below 3.5 years of age suggested that children with ASDs had lower imitation scores compared to the other two control groups. Further, between different types of imitation, children with ASDs found imitation of body movements harder than imitation of actions on objects (Stone et al., 1997). Several researchers have suggested that deficits in imitation are in fact part of a broader and more generalized disorder in praxis (Dewey et al., 2007; Mostofsky et al., 2006). Praxis is defined as the ability to plan and execute simple and complex gestures and action sequences not just on imitation but also on verbal command and during tool use (Dewey et al., 2007; Mostofsky et al., 2006; Njikiktjen, Verschoor, Vranken, & Vroklage, 2000). Along the lines of this hypothesis, praxis assessment of 21 high-functioning children with ASDs and 24 TD controls revealed that children with ASDs had impairments in production of gestures on imitation, on verbal command, and during tool use, suggestive of a broader impairment in praxis (Mostofsky et al., 2006). Overall, there is substantial evidence supporting the presence of imitation and praxis impairments in ASDs (Williams et al., 2004). Moreover, these impairments are associated with language and play skills as well as levels of symptom severity (Dziuk et al., 2007; Ingersoll & Meyer, 2011; Stone et al., 1997; Toth et al., 2006; Zachor, Ilanit, & Ben-Itzhak, 2010). In spite of the

considerable literature on impairments in motor performance, imitation, and praxis, more often than not the core social communication impairments in ASDs take precedence over the persistent motor difficulties encountered in this population. However, recently, several groups have emphasized the need for development of early interventions with a focus on active play and enriched movement experiences to promote multisystem development in this population (Bhat et al., 2011; Lloyd et al., 2013).

7.1.4. Traditional interventions for motor impairments in ASDs

Currently, several treatment approaches exist to facilitate imitation skills in autism. Specifically, some of the contemporary interventions that target imitation skills include naturalistic and developmental clinician/caregiver(CG)-mediated interventions such as Reciprocal Imitation Training (RIT) (Ingersoll & Schreibman, 2006) and a developmental curriculum focusing on socially synchronous imitation (Landa et al., 2011), peer-mediated interventions (Carr & Darcy, 1990; Garfinkle & Schwartz, 2002), interventions based on contingent imitation (Heimann, Laberg, & Nordøen, 2006), and video-modeling interventions (Charlop-Christy, Le, & Freeman, 2000). Naturalistic and developmental interventions aim to teach imitation within natural ongoing developmentally-appropriate social interactions (Ingersoll & Schreibman, 2006; Landa et al., 2011). For example, in reciprocal imitation therapy, the clinician or parent uses techniques such as contingent imitation, linguistic mapping, modeling, prompting, and contingent natural reinforcement to promote imitation of familiar actions, which gradually progresses to imitation of unfamiliar actions (Ingersoll, 2008). A 10-week randomized controlled trial using RIT techniques in 21 children with ASDs to train spontaneous and elicited object-related and gestural imitation skills led to an increase in imitation skills in the treatment group but not in the control group that received treatment as usual (Ingersoll, 2010). In contrast to clinician/CG-mediated approaches, peer-mediated training is an instructional procedure where adults prompt children with disabilities to imitate the behaviors of their TD peers, and accurate imitation is followed by contingent reinforcement (Garfinkle & Schwartz, 2002). For example, when children with ASDs were prompted to imitate actions on objects modeled by their TD peers, they learned to imitate their peers and also demonstrated

generalization of peer imitation skills to a new set of actions on different objects within novel environments (Carr & Darcy, 1990). Recently, video-modeling, a cost- and time- effective yet motivating strategy has been used to teach children with ASDs imitation skills (Charlop-Christy et al., 2000). Children are asked to watch a video clip of the target behavior and then given an opportunity to imitate the modeled behavior. It is suggested that the television helps to restrict the child's field of vision and allows the child to focus on restricted stimuli (Charlop-Christy et al., 2000). A comparison of video to live modeling to teach imitation skills such as brushing, toy play, and greeting suggested that children with ASDs learned skills faster and generalized learned skills to novel contexts following video modeling (Charlop-Christy et al., 2000). Although several contemporary interventions target imitation skills, to the best of our knowledge, there is a lack of evidence on holistic interventions that focus on improving motor performance. In the current study, we explored the effects of two novel, whole-body movement-based interventions, music and robotic, on the overall motor performance and imitation skills of children with ASDs.

7.1.4. Novel interventions for motor impairments in ASDs

There is a growing body of literature on the use of novel interventions, specifically, music and robotic therapies in children with ASDs. Music-based interventions have been used as a means to promote communication skills and social interactions in ASDs (Simpson & Keen, 2011; Whipple, 2004). Children with ASDs have a predisposition for musical stimuli and find musical experiences very enjoyable (Simpson & Keen, 2011). In fact, in contrast to their impaired language skills, children with autism have intact musical perception skills (Bonnell et al., 2003; Heaton et al., 1999). Music-based contexts have been used to enhance verbal and non-verbal communication skills as well as behavioral skills in ASDs (Gold et al., 2006; Simpson & Keen, 2011; Srinivasan & Bhat, 2013; Whipple, 2004). For example, a meta-analysis based on 3 studies and 24 individuals with ASDs suggested that short-term music therapy led to improvements in verbal and gestural communication skills (effect sizes: verbal skills = 0.36, gestural skills = 0.50) (Gold et al., 2006). Few studies have used music-based contexts to facilitate motor skills

including imitation in children with ASDs (Buday, 1995; Stephens, 2008). For example, a child-led music-based context that created a social routine between the child and the experimenter using reciprocal imitation strategies led to an increase in spontaneous word and action imitation of the adult's actions in 3 out of 4 children with ASDs. However, carry-over effects were observed in only 2 of the 4 participants (Stephens, 2008). Similarly, Buday examined the effects of music and speech conditions, where children were taught manual signs and associated words using either a song or spoken words, on children's memory of signed words. Compared to a condition in which signs were taught in association with spoken words, the music condition led to greater imitation of signs and words (Buday, 1995). Although the current literature on using music-based experiences to promote motor skills in autism is limited, there is evidence from TD children that rhythmic accompaniment using music can promote gross and fine motor skills in children (Costa-Giomi, 2005; Derri et al., 2001; Forgeard et al., 2008; Zachopoulou et al., 2004; Zachopoulou et al., 2006). For example, a 10-week music and movement program in 4-6 year old preschoolers led to greater improvements in locomotor skills including galloping, leaping, horizontal jumping, and skipping, as assessed on the standardized Test of Gross Motor Development (TGMD) compared to a control group that engaged in free play activities (Derri et al., 2001). Given children's musical strengths and the anecdotal literature from children with ASDs and TD children, music-based contexts seem to be a promising tool to facilitate gross and fine motor skills in children with ASDs (Srinivasan & Bhat, 2013). In the current study, we wanted to systematically examine the effects of a prolonged music and movement intervention on the motor performance of children with ASDs using a randomized controlled trial design.

Similar to music, children's intrinsic interest in technology has sparked a line of research that investigates the use of technology, especially robotics, for children with ASDs (Diehl et al., 2011; Scassellati et al., 2012). Robots are considered to be extremely engaging for children with ASDs, and given their simplicity and predictable nature, even children with ASDs, who are unwilling to engage in social interactions with their human partners, can be motivated to engage with robots (Robins et al., 2005; Scassellati, 2007).

Robots have been conceived of as a “social crutch” where children learn and practice skills such as imitation, turn-taking, verbal responses, or joint attention during interactions with the robot, and then transfer learned skills to interactions with humans (Diehl et al., 2011; Scassellati, 2007; Tapus et al., 2007). Given the importance of imitation skills over development, robot-child interactions have been used to encourage imitation skills in children with ASDs. Interactions were either structured by the adult who prompted the child to imitate the robot (Duquette et al., 2008; Fujimoto, Matsumoto, De Silva, Ravindra, Kobayashi, & Higashi, 2011; Robins et al., 2004; Robins et al., 2005), or were more spontaneous, where imitation emerged naturally within turn taking games between the child and the robot (Kozima et al., 2007; Robins et al., 2009; Scassellati et al., 2012). For example, Duquette and colleagues compared the effects of repeated interactions over 7 weeks with a human compared to a robot mediator on 4 low-functioning children with ASDs (Duquette et al., 2008). They found that children paired with the robot mediator demonstrated greater shared attention and greater imitation of facial expressions of the robot compared to children paired with the human; however, in terms of imitation of body movements and familiar actions, the human mediator elicited greater imitation than the robot. The authors attributed these findings to the level of functioning of the children involved in the study and the limitations of their robot (Duquette et al., 2008). In a different study, a creature-like robot, Keepon, was introduced into the play room of children, and spontaneous interactions of children with the robot were observed (Kozima et al., 2007). Across 39 sessions that lasted over 17 months, it was seen that a 3-year old girl with autism and moderate intellectual disability gradually increased her engagement with the robot and eventually initiated an imitation game with the robot, where the robot copied the child’s actions during turn-taking games (Kozima et al., 2007). Although the above mentioned studies encouraged imitation within the context of robot-adult-child interactions, none of the studies systematically assessed changes in imitation errors following training. Moreover, studies have not used standardized tests to assess overall motor performance following prolonged training with robots. In a previous study by our research group, we assessed the effects of 4 weeks of robot-adult-child interactions using a 7-inch humanoid robot, I-sobot, on the imitation and praxis abilities of 15 TD children and 1 child with autism. We developed a

customized coding scheme to assess imitation and praxis errors. Both TD children and the child with autism improved their performance on the imitation and praxis tests (Srinivasan et al., 2013). In the current study, we extended our work to a larger sample of children with ASDs using a humanoid robot, Nao, and systematically coded for training-related changes in imitation accuracy within the training context and overall motor performance on a standardized motor test.

7.1.5. Rationale for current study and specific aims and hypothesis for motor skills

Based on the previous discussion, it is evident that in spite of the growing recognition of motor impairments in ASDs, there is currently little evidence on comprehensive intervention programs that target gross and fine motor performance in ASDs. Moreover, the evidence on novel therapies such as music and robotic interventions is anecdotal and is limited in its application due to small sample sizes, limited training durations, and lack of methodological rigor and experimental controls. Current literature on music and robotic therapies has also not systematically evaluated the effects of prolonged interventions on children's motor performance using standardized assessments and detailed coding schemes. In the current study, we aimed to address the gaps in the current literature by comparing the effects of prolonged music and robotic interventions delivered over 8 weeks on the motor and social communication skills of children with ASDs. We also compared the effects of the novel, movement-based interventions to those of a standard-of-care academic intervention that was designed to mimic the therapy settings that children with autism typically receive in schools. In terms of motor skills, we assessed the effects of the interventions on the gross and fine motor performance, imitation and praxis skills, as well as rhythmic synchrony abilities of children with ASDs. In the current paper, we restrict our discussion to the training-related changes in motor performance as well as imitation and praxis skills (effects on rhythmic synchrony are reported in a separate publication). All three groups engaged in imitation-based activities within group contexts. The music and robot groups engaged in whole-body gross motor and fine motor imitation games to the beat of music. The academic group engaged in table-top fine motor activities. We assessed motor skills within a task-specific test of imitation and within a standardized test of motor

performance, namely the gross and fine motor subtests of the Bruininks-Oseretsky Test of Motor Proficiency (BOT-2) (Bruininks & Bruininks, 2005). Specifically, we used the fine motor precision, fine motor integration, manual dexterity, bilateral coordination, and balance subtests of the BOT-2. Given the heavy focus on imitation-based games in all groups, we hypothesized that all 3 groups would demonstrate improvements in the task-specific test of imitation. In terms of the standardized test, we hypothesized that consistent with training demands, the movement groups, music and robotic, would show improvements on the gross motor subtests (balance and bilateral coordination) of the BOT-2, whereas the academic group would demonstrate improvements on the fine motor subtests (fine motor precision and fine motor integration) of the BOT-2.

7.2. Methods

7.2.1. Study Procedure

Our randomized controlled trial (RCT) lasted for a total of 10 weeks. The pretest and posttest sessions were conducted during the first and last weeks of the study, respectively. The training sessions were provided during the intermediate 8 weeks of the study. Children in all three groups – music, robotic, and academic – were provided a total of 16 sessions with 2 sessions provided by expert trainers each week. Each session lasted for around 45 minutes. In addition to the two expert trainer-delivered sessions, we provided in-person training to caregivers to provide 2 additional home sessions each week to promote repetition and reinforce learning. Out of the 36 children, 15 children missed one session each due to scheduling conflicts.

We recruited 36 children (32 Males, 4 Females) with ASDs in our RCT. Children were between 5 and 12 years of age ($M (SD) = 7.63(2.24)$). We recruited children through online announcements and by posting fliers in local autism schools, early intervention centers, and autism advocacy groups. During enrollment in the study, parents were asked to provide medical or school records confirming their child's diagnosis. In addition, we asked parents to fill out the Social Communication Questionnaire, which is a 40-item

questionnaire that screens for autism-specific social communication impairments in individuals between 4 and 40 years of age (Rutter et al., 2003). Eligibility of the participating children was confirmed using the Autism Diagnostic Observation Schedule, 2nd edition (ADOS-2) (Lord et al., 2012), which is the gold standard assessment for autism diagnosis. All children were enrolled in the study following written parental consent as approved by the Institutional Review Board at the University of Connecticut. Our exclusion criteria included children with additional orthopedic, cardiovascular, neurological, hearing, or visual impairments. Participating families fell within the upper-middle to upper socioeconomic classification as described by the Hollingshead scale of socioeconomic status ($M(SD) = 49.18(10.03)$) (Hollingshead, 1975). Out of the thirty-six participating families, twenty were Caucasian, six were African American, four were Asian, three were Hispanic, and three were of mixed ethnicity (two children of mixed Caucasian and Hispanic ethnicity and one of mixed Caucasian and African American ethnicity).

Following enrollment in the study, we matched children on several criteria prior to randomly assigning them to the music, robot, or academic groups. Specifically, we matched children on age bands, level of functioning, and amount of services received. We used a subjective rating of children's social communication (language, attention, and compliance with testing activities) and motor (imitation, praxis, gross, and fine motor) skills to estimate their level of functioning. Expert testers rated children's social communication and motor skills based on their pretest session on a scale of 1-4, where 1 indicated extremely low abilities and 4 indicated high abilities. For a matched triad of children, we assigned MS Excel-generated random numbers and then randomly assigned children to one of the three groups – music, robotic, or academic. We further confirmed baseline similarity by conducting post-hoc comparisons between groups on age, gender, level of functioning, and the total motor scores on the caregiver checklist of the Movement Assessment Battery for Children -2 (MABC-2) (Henderson, Sugden, & Barnett, 2007). The three groups did not differ significantly on age (Music: $M(SD) = 7.88(2.56)$; Robot: $M(SD) = 7.52(2.22)$; Academic: $M(SD) = 7.36(2.02)$, $p > 0.05$), gender (Music: 10 Males, 2 Females; Robot: 11 Males, 1 Female; Academic: 11 Males, 1 Female, $\chi^2 p > 0.05$), and level of

functioning (based on subjective expert ratings as outlined above) (Music: $M(SD) = 2.49 (0.78)$; Robot: $M(SD) = 2.57(0.81)$; Academic: $M (SD) = 2.90 (0.43)$, $ps > 0.05$). We asked parents to fill out the MABC-2 checklist, which assesses the motor competence of children between 5 and 12 years of age on a variety of tasks requiring movements in static and dynamic environments (Henderson et al., 2007). The scale consists of 30 items that caregivers score on a scale of 0 to 3 (0 = child does the activity “very well”, 1 = child does the activity “just ok”, 2 = child “almost” does the activity, 3 = child is “not close” to completing the activity), where lower scores indicate better performance. There were no significant group differences on the total motor scores of the MABC-2 checklist (Music: $M (SD) = 28 (16.47)$, Robot: $M (SD) = 37.5 (13.06)$, Academic: $M (SD) = 30.5 (14.50)$, p values > 0.05).

7.2.2. Training protocol

In the music and robot groups, children engaged in socially embedded whole-body movement games (see Figures 7-1A & 7-1B). In contrast, children in the academic group engaged in table-top activities promoting fine motor and academic skills within a group setting (see Figure 7-1C). The academic group was structured to mimic the types of activities that children with autism typically practice in special education settings. In all three groups, children engaged in training activities within a triadic context involving interactions with an expert trainer and an adult model (see Figures 7-1A, 7-1B, & 7-1C). The expert trainer played the role of an instructor and guided the child through the activities of each session. The adult model served as a buddy and a visual model for the child and provided hand-on-hand assistance, if needed, to the child during the session. In all three groups, efforts were made to facilitate social communication skills across training sessions. We encouraged social skills such as eye contact, turn taking, ready response, and greeting/farewell. Similarly, we also promoted verbal and nonverbal communication skills such as responding to questions, commenting, asking for help, and use of gestures for communication in all groups. Our training was based on principles derived from current mainstream autism interventions including Applied Behavioral Analysis (ABA) (Lovaas, 1987), Teaching and Education of Autistic and Related Communication Handicapped Children (TEACHH) (Mesibov et al.,

2004), and Picture Exchange Communication System (PECS) (Bondy & Frost, 2003). All trainers involved in the study were pediatric physical therapists or physical therapy/ kinesiology graduate students who received intensive training from the last author prior to the training sessions. Similarly, models involved in the study were undergraduate students with experience working with children with special needs, and they were required to undergo 6-hour in-person and video training prior to participation in the study. To ensure training fidelity, we provided trainers and models of all groups with instruction booklets specific to each group outlining their roles and the details of all activities practiced. Further, we asked an unbiased undergraduate student to code any three randomly-picked sessions for each child, in order to assess trainer and model behavior for fidelity during the sessions.



Figure 7-1: Experimental set-up for training sessions - (A) Music group, (B) Robot group, (C) Academic group

Commonalities existed within the session structure across groups: initial greeting, group-specific activity, and farewell. While the session structure remained consistent throughout the entirety of the training, activities were varied to stimulate the child's interest with general progression from simple to more complex tasks. The three groups differed from each other based on the nature of the activities practiced during training sessions. In the music group, children engaged in whole-body discrete imitation and rhythmic synchrony-based joint action games with the expert trainer and the adult model to the beat of music. Children practiced both upper- and lower-body simple and complex motor sequences requiring

dual and multilimb coordination. Specifically, children practiced activities within the following conditions during each session – action songs, beat keeping routines, improvisational music making games, and moving games. The beat keeping and moving game conditions facilitated rhythmic synchrony between the children and their social partners. In contrast, the action song condition involving whole body actions and finger play, and the music making condition involving the practice of unilateral as well as bilateral symmetrical, asymmetrical, and cross-over xylophone patterns, encouraged discrete imitation and praxis skills. We progressed from simple movement patterns involving 2-note sequences played with one hand to complex patterns involving multiple notes played with both hands.

In the robot group, children imitated a 23-inch humanoid robot, Nao, which performed a variety of dual and multilimb actions to the beat of music. The trainer controlled the robot using a laptop and custom software. The child and the adult model copied the actions of the robot within a variety of imitation and synchrony-based games. Children practiced the following movement conditions each session – warm-up game, action game, drumming game, and walking game. The warm-up and walking games involved synchronous activities during which children tried to match their movements to the movements of the robot and the adult model. During the action game, children imitated the discrete movements of the robot during action songs such as, “The wheels on the bus” and “If you are happy and you know it”. Similarly, during the drumming game, children imitated simple and complex drumming patterns initiated by the robot within turn taking games. We progressed from simple unilateral drumming patterns to complex bilateral patterns involving quarter and eighth notes.

In the academic group, children engaged in several activities that promoted academic and fine motor skills. Children engaged in book reading, building, and art-craft activities. In the building condition, children played with supplies such as Play-Doh®, Duplos®/ Legos®, and Zoob (Infinitoy®) to build creations every session. We encouraged fine motor skills including symmetrical and asymmetrical hand movements such as rolling, pressing, pulling apart, pushing together and different types of grips and pinches, as children engaged in imitation games involving different building supplies with the expert

trainer and the adult model. In the art-craft condition, children made theme-based creations by using skills such as drawing, coloring, cutting, and pasting. All sessions were videotaped for further behavioral coding. In terms of adherence to treatment, 15 out of the 36 children missed an expert training session each, due to scheduling conflicts.

7.2.3. Testing protocol

We wanted to assess changes in children's motor skills including bilateral coordination, balance, gross and fine motor imitation, and praxis skills following training. We used task-specific measures of imitation and praxis within the training context and a standardized test conducted during the pretest and posttest sessions to assess for changes in motor performance following training. In terms of task-specific measures, we coded training sessions to assess for changes in gross and fine motor discrete imitation and praxis across training weeks. In terms of the standardized test, we used the fine motor precision, fine motor integration, manual dexterity, balance, and bilateral coordination subtests of the Bruininks-Oseretsky Test of Motor Proficiency (BOT-2) (Bruininks & Bruininks, 2005) to assess for generalized changes in gross and fine motor performance in all groups.

To assess task-specific training-related changes, we used video data of test activities performed during an early and a late training session in each group to code changes in gross and fine motor imitation and praxis skills. Specifically, in each group, we assessed children's imitation skills with the expert trainer during a set of test activities that were repeated during an early and a late session. In the music group, imitation was assessed during 2 conditions – an action song that required children to imitate whole body movements and finger play of the adult trainer, and xylophone patterns during which children copied unilateral, bilateral symmetrical, bilateral alternating, and cross-over musical sequences played by the trainer. Similarly, in the robot group, we assessed children's ability to imitate the actions of the robot during an action song condition that involved whole-body movements and a drumming condition involving the practice of simple and complex drumming sequences. Lastly, in the academic group, we

assessed children's abilities to imitate the expert trainer during 2 sets of building activities – Play-Doh®, as well as Duplo®/ Lego® and Zoob (Infinitoy®). Specifically, children were asked to roll, flatten, and pinch Play-Doh®, as well as push and pull Duplo®/Lego® blocks and Zoob (Infinitoy®) pieces.

We devised coding schemes to assess for the accuracy of imitated actions within all three groups. In the music and robot groups, we developed an imitation coding scheme based on the error classification proposed by Dewey (Dewey, 1993). Specifically, we assessed for errors in the spatio-temporal aspects of the movement sequences. A score of 0 indicated no error and a score of 1 indicated an error within the specific error category. Spatial errors occurred when the child's positioning and orientation of joints involved in the movement was incorrect relative to the trainer's demonstration. Body part errors occurred when the child used incorrect body parts for the movement. A movement modulation error was scored if the child's movements were either insufficient or exaggerated in terms of effort and range of motion compared to those of the trainer. A movement precision error was scored if the child made errors related to the sequence of movements within a pattern or if the child omitted steps or added extra steps within a movement sequence. A pace error was scored if the child's speed of movement was significantly different, i.e. slower or faster, than that of the trainer. Children were given a movement symmetry/reciprocity error if children incorrectly used the two sides of their body to perform the test movements; for example, if the child used only the right hand to perform an action that involved usage of both sides of the body, or if the child performed a bilateral symmetrical movement instead of a bilateral asymmetrical movement shown by the trainer. A mirroring error was scored if the child failed to mirror the trainer's actions. We also recorded the types of prompts – visual, verbal, or manual hand-on-hand assistance – that children required to complete the actions. We calculated a total error score which was the sum of the scores on all individual error categories for each movement sequence.

In the academic group, we coded for imitation by assessing the type of strategy that children employed for performing test actions compared to those used by the expert trainer. For example, for making a ball of Play-Doh® while holding it off the table, the ideal strategy involved moving the two hands off the table

in an anti-phase manner to roll the dough into a smooth ball. Strategies such as rolling the dough into a tube using 2 hands, or using only 1 hand to roll the dough into a ball while stabilizing it on the table, or rolling the dough into a tube on the table using 1 hand, were all considered as incorrect strategies. Along the same lines, for pushing 2 Lego®/Duplo® blocks or Zoob (Infinitoy®) pieces together, the ideal strategy was to use both hands symmetrically off the table to push the blocks/pieces together. Here, examples of incorrect strategies included the use of only 1 hand to push Legos® together while using table support, or misalignment of Legos®, or use of inappropriate force to push the blocks or pieces together. We assigned a higher imitation error score for strategies that were incorrect and a lower score for correct strategies for all test actions using Play-Doh® as well as Duplo®/Lego® and Zoob (Infinitoy®) supplies within an early and a late session. We also recorded the types of prompts – visual, verbal, or manual hand-on-hand assistance – that children required to complete the actions. Along the lines of the movement groups, we calculated a total imitation error score which was the sum of the strategy scores for all the test actions for each activity (Play-Doh®, Duplos®/Legos® & Zoob (Infinitoy®)).

In addition to task-specific measures, we assessed generalized changes in motor performance using the fine motor precision (FMP), fine motor integration (FMI), manual dexterity (MD), bilateral coordination (BC), and balance (Bal) subtests of the BOT-2. The BOT-2 is a reliable and valid assessment of gross and fine motor performance for individuals between 4 and 11 years of age (Bruininks & Bruininks, 2005). The FMP subtest consists of 7 activities involving drawing, folding, and cutting that require precise control of finger and hand movements. The FMI subtest includes 8 items that assess the child's ability to reproduce drawings of geometric shapes ranging in complexity from a circle to overlapping pencils. The MD subtest consists of 5 items that assess levels of dexterity and accuracy during timed goal-directed actions involving reaching, grasping, and bimanual coordination with small objects. The BC subtest is composed of 8 items that assess children's ability to sequentially and simultaneously synchronize their upper and lower limbs. Lastly, the Bal subtest is made up of 9 items that evaluate postural control skills

during standing and walking. The FMP and FMI subtests together provide a fine manual control composite that measures children's overall ability to control and coordinate their distal small hand musculature for activities such as grasping, drawing, and cutting (Bruininks & Bruininks, 2005). Along the same lines, the BC and Bal subtests together provide a body coordination composite that measures children's overall ability to control and coordinate their large muscles responsible for maintaining posture and balance (Bruininks & Bruininks, 2005). The BOT-2 assessment provides raw total point scores, scale scores, confidence intervals and descriptive categories for all individual subtests as well as standard scores (mean = 50, SD = 10), confidence intervals, percentile ranks, and descriptive categories for all composite scores. A novel tester blinded to the grouping of the child conducted the BOT-2 assessment during the pretest and posttest sessions.

A single undergraduate coder coded the task-specific test of imitation following significant training from the first and last authors and after establishing intra- and inter-rater reliability of over 85% using 20 % of the dataset. Following extensive training from the last author, the first and third authors coded the BOT-2 after establishing inter-rater reliability of > 85% using 20% of the dataset.

7.2.4. Dependent Variables

In terms of the task-specific measure of imitation, we calculated a percent imitation error score for an early and a late session for each activity within the 3 groups. For the standardized test of motor performance, the BOT-2, we used the raw total point scores from the FMP, FMI, MD, BC, and Bal subtests to compare motor performance between the pretest and posttest sessions within each group. We also calculated a fine motor composite, which was the sum of the raw scores on all items of the FMI and FMP subtests, and a gross motor composite, which was the sum of raw scores from all items of the BC and Bal subtests, for the pretest and posttest sessions. In addition, we also used the standard scores of the Fine Manual Control and Body Coordination composites provided by the BOT-2 to assess for changes in gross motor and fine motor performance within groups following training.

7.2.5. Statistical Analysis

We used SPSS Version 16 (SPSS, Inc., Chicago, IL) for statistical analysis of our data. We checked our data for assumptions of normality and homogeneity of variances. Data from our task-specific measure of imitation were not normally distributed and had a moderate number of outliers. Hence, we conducted a square root transformation on these data. We ran 3 ANOVAs, one for each group, on these transformed data, to assess for training-related changes in imitation skills within each group. We used session (early, late) and condition (2 conditions per group) as the within-subjects factors. In case of main effects and interaction effects involving the same factor, we assessed the interaction effects only. Post-hoc testing was done using dependent t -tests. The data from the standardized BOT test satisfied all assumptions of parametric statistics. We used dependent t -tests to compare the raw subtest scores as well as the body coordination and fine manual control composite standard scores within each group. We will report data in the form of means and standard deviations (M (SD)). For the task-specific test of imitation, we will report data in the form of percent imitation error and for the standardized BOT-2 test, we will report data in the form of raw scores and standard scores. We report effect sizes using partial eta-squared (η_p^2) and standardized mean difference (SMD) values (Hedges, 1981). Statistical significance was set at $p \leq 0.05$ and p values < 0.1 were considered statistical trends.

7.3. Results

7.3.1. Training-related changes in the task-specific measure of imitation

We report the results of the 3 within-group ANOVAs below -

- a. Music Group: The repeated measures ANOVA indicated a main effect of session ($F(1, 11) = 93.91, p < 0.001, \eta_p^2 = 0.90$) suggesting that irrespective of condition, children reduced their imitation errors from the early (M (SD) = 35.55(26.85)) to the late (M (SD) = 16.72(18.21), SMD = 0.65) session. Further analysis of the action song (Early: M (SD) = 25.26(19.31), Late: M (SD)

= 12.76(11.86), SMD = 0.60) and xylophone (Early: M (SD) = 45.85(30.06), Late: M (SD) = 20.68(22.77), p values < 0.003, SMD = 0.78) conditions suggested that children showed improvements in imitation performance during both conditions (see Figure 7-2A). Specifically, individual data suggested that 10 out of 12 children improved their performance in the action song condition and all 12 children in the group improved their performance in the xylophone condition following training.

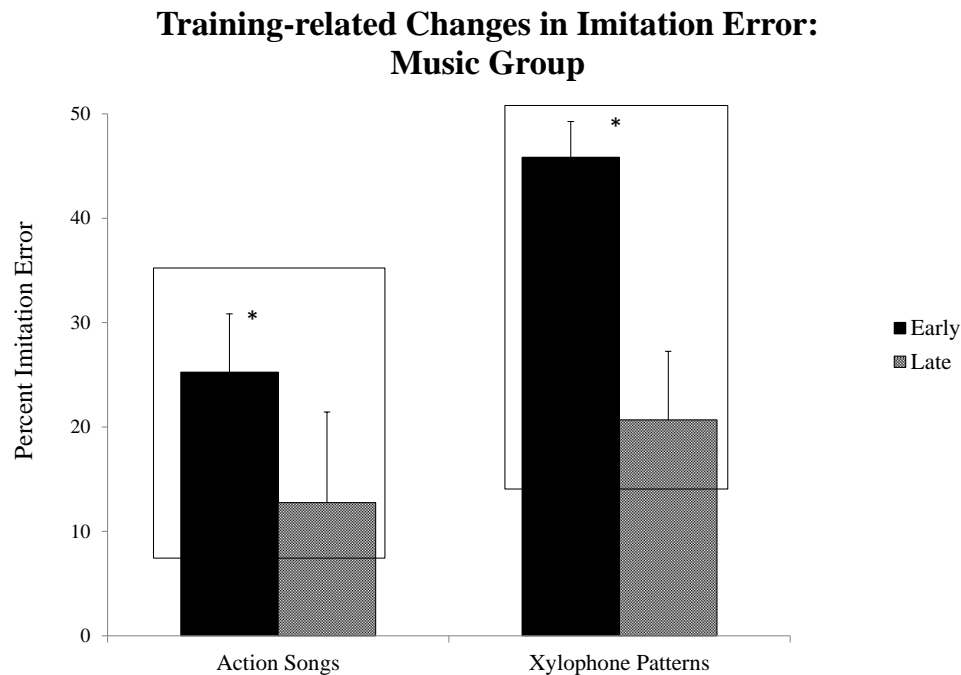


Figure 7-2A: Training-related changes in percent imitation error during the action song and xylophone conditions in the music group. Error bars represent standard errors. $*p \leq 0.05$

- b. Robot group: The repeated measures ANOVA indicated a main effect of session ($F(1, 11) = 6.48, p = 0.03, \eta_p^2 = 0.37$). The results suggested that irrespective of condition, children reduced their imitation errors from the early (M (SD) = 27.91(21.66)) to the late (M (SD) = 22.60(17.59), SMD = 0.23) session. Further, we found that children showed some improvements in their imitation performance during both the action song (Early: M (SD) = 30.01(27.72), Late: M (SD) = 22.27(20.13), SMD = 0.26) and drumming (Early: M (SD) = 25.80(14.24), Late: M (SD) =

22.93(15.54), p values ≤ 0.09 , $SMD = 0.19$) conditions (see Figure 7-2B). Specifically, individual data suggested that with training, 8 out of 12 children improved their performance in the action song condition and 10 out of 12 children improved their performance during the drumming condition.

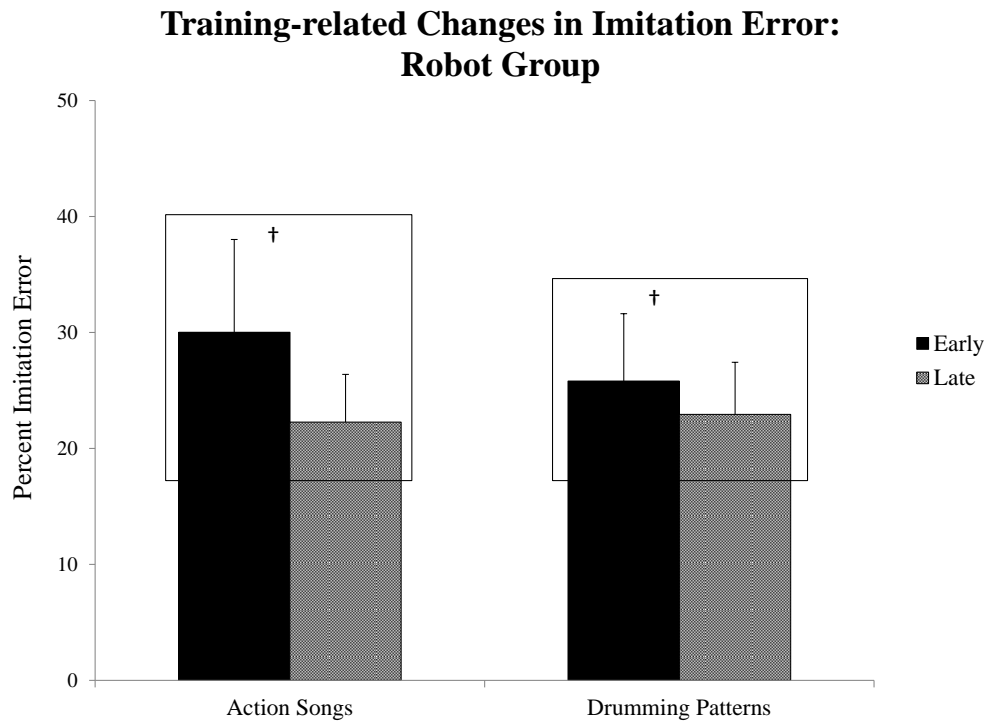


Figure 7-2B: Training-related changes in percent imitation error during the action song and drumming game conditions in the robot group. Error bars represent standard errors. † $p \leq 0.1$

- c. Academic group: The repeated measures ANOVA indicated a main effect of session ($F(1, 11) = 18.87$, $p = 0.001$, $\eta_p^2 = 0.63$) and a condition x session interaction ($F(1, 11) = 6.17$, $p = 0.03$, $\eta_p^2 = 0.36$). Post-hoc analysis of the condition x session interaction suggested that children significantly reduced their imitation error scores during the Duplo®/Lego® and Zoob (Infinitoy®) test activities from the early ($M(SD) = 25(18.80)$) to the late ($M(SD) = 6.25(8.04)$), $p = 0.003$, $SMD = 0.93$) session (see Figure 7-2C). Specifically, 10 out of the 12 children followed the group trends for improvements in imitation performance with training. However, for the Play-Doh®

activity, there was only a trend for improvement in imitation performance following training (Early: $M (SD) = 24.70(23.27)$, Late: $M (SD) = 12.5(8.94)$, $p = 0.06$, $SMD = 0.49$) (see Figure 7-2C). Individual data suggested that only 6 out of 12 children showed improvements in imitation skills within the Play-Doh® activity.

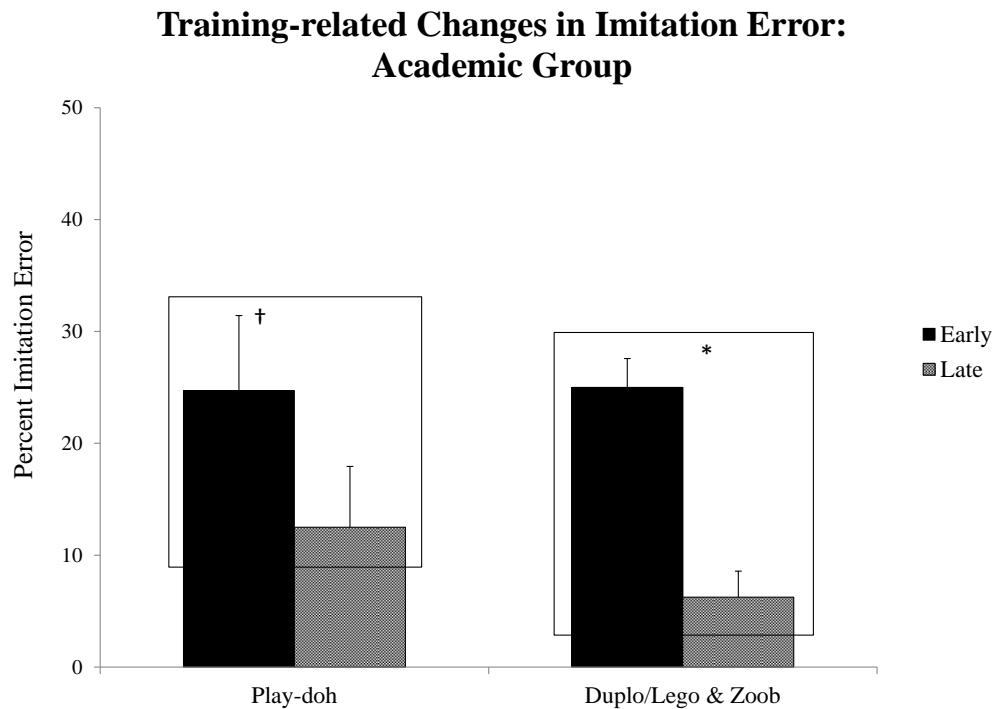


Figure 7-2C: Training-related changes in percent imitation error during the Play-Doh® and Duplos®/Legos® & Zoob (Infinity®) conditions in the academic group. Error bars represent standard errors. * $p \leq 0.05$, † $p \leq 0.1$

7.3.2. Training-related changes in the standardized test of motor performance

We report on the generalized changes in motor performance on the BOT-2 from the pretest to the posttest session. Three children out of the total 36 children were excluded from the analysis of the standardized test since they were very low-functioning and could not perform a majority of the test actions of the BOT-2, both in the pretest and the posttest sessions. The final analysis for the standardized BOT-2 test was based on 11 children in each group. We report results within each group below.

- a. **Music Group:** Dependent *t*-tests suggested that children improved their performance on the raw scores of the BC subtest of the BOT-2 in the posttest ($M (SD) = 13(8.17)$) compared to the pretest ($M (SD) = 9.73(7.38)$, $p = 0.004$, $SMD = 0.41$). Children also demonstrated significantly greater scores on the Bal subtest of the BOT-2 in the posttest ($M (SD) = 22.36(5.70)$) compared to the pretest ($M (SD) = 19.27(8.55)$, $p = 0.02$, $SMD = 0.33$) (Figure 7-3A shows changes in the gross motor composite with training). Along the same lines, children demonstrated improvements on the standard scores of the body coordination composite in the posttest ($M (SD) = 36.36(6.90)$) compared to the pretest ($M (SD) = 32.91(5.34)$, $p = 0.01$, $SMD = 0.60$). Specifically, 9 out of the 11 children in the group followed these trends. Children did not demonstrate any training-related improvements in the raw scores of the MD, FMI, and FMP subtests (Figure 7-3B shows changes in the fine motor composite with training). The music group also did not demonstrate any changes in the standard scores of the fine manual control composite of the BOT-2 from the pretest to the posttest.

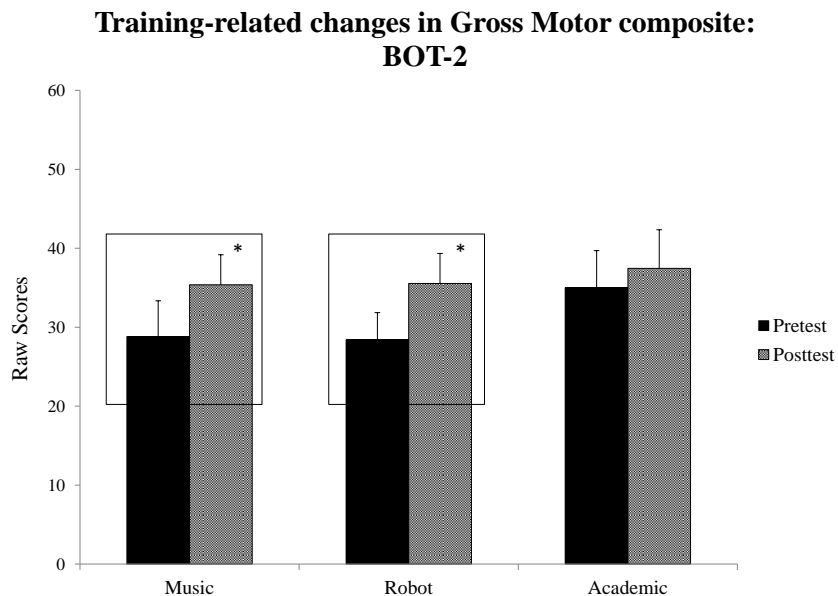


Figure 7-3A: Training-related changes in the gross motor composite of BOT-2. The gross motor composite was calculated by summing the total raw scores of the bilateral coordination and balance subtests of the BOT-2. Error bars represent standard errors. $*p \leq 0.05$

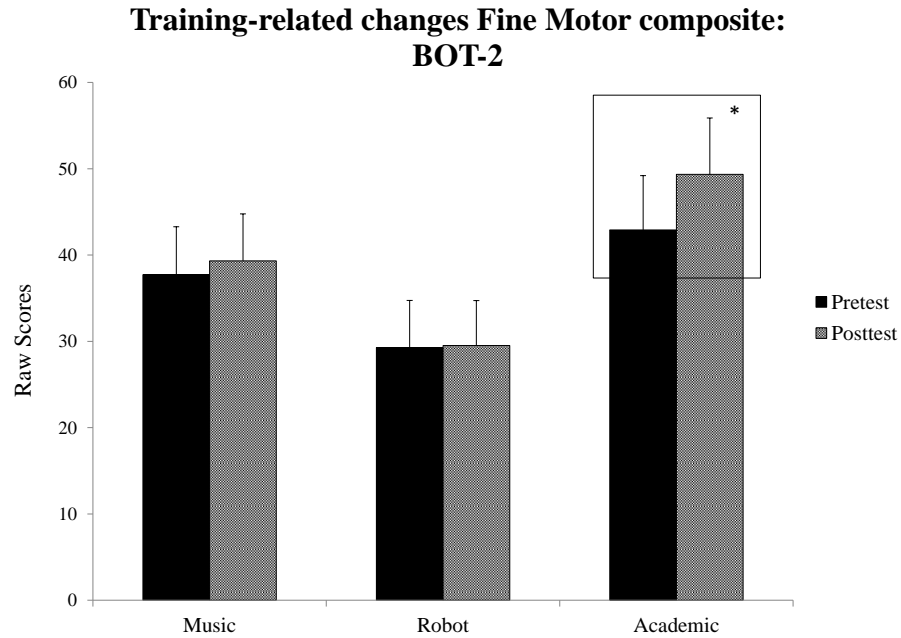


Figure 7-3B: Training-related changes in the fine motor composite of BOT-2. The fine motor composite was calculated by summing the total raw scores of the fine motor precision and fine motor integration subtests of the BOT-2. Error bars represent standard errors. * $p \leq 0.05$

- b. Robot Group: Similar to the music group, children in the robot group improved their performance on the bilateral coordination and balance subtests of the BOT from the pretest (BC subtest: M (SD) = 8.36(6.17), Bal subtest: M (SD) = 19.91(7.03)) to the posttest session (BC subtest: M (SD) = 11.45(8.48), Bal subtest: M (SD) = 23.73(5.82), p values < 0.02, SMD (BC) = 0.46, SMD (Bal) = 0.50) (see Figure 7-3A). Children also showed improvements on the overall body coordination composite following training (Pretest: M (SD) = 37(9.15), Posttest: M (SD) = 41.73(12.02), p = 0.02, SMD = 0.48). Individual data suggested that 8 out of the 11 children in this group improved their gross motor performance following training. In contrast, children did not show any improvements in the FMI, FMP, and MD subtests (see Figure 7-3B). Similarly, there were no changes in the standard scores of the fine manual control composite following training.
- c. Academic Group: Children demonstrated significant improvements in the raw scores of the FMP and FMI subtests from the pretest (FMP: M (SD) = 17.73(9.40), FMI: M (SD) = 25.71(12.12)) to

the posttest sessions (FMP: $M (SD) = 20.91(10.76)$, FMI: $M (SD) = 29.38(12.12)$, p values = 0.03, $SMD (FMP) = 0.31$, $SMD (FMI) = 0.28$) (see Figure 7-3B for fine motor composite scores). Moreover, they showed higher values on the standard scores of the fine manual control composite in the posttest ($M (SD) = 44.52(10.83)$) compared to the pretest ($M (SD) = 41.44(8.72)$, $p = 0.05$, $SMD = 0.33$). Specifically, of all the children in the group, 6 out of the 11 children followed the group trends. Children did not show any changes in performance on the BC, Bal (see Figure 7-3A), and MD subtests and the body coordination composite of the BOT-2 from the pretest to the posttest session.

7.4. Discussion

7.4.1. Summary of results

The overall goal of our project was to systematically evaluate the efficacy of novel, embodied music and robotic interventions on the social communication, motor, and behavioral skills of children with ASDs. In the current paper, we discuss the effects of the movement-based interventions compared to a stationary academic intervention on the imitation skills and overall motor performance of children with ASDs. In each group, we examined training-related changes in imitation accuracy using task-specific tests. We developed detailed coding schemes for assessing spatial and temporal errors in imitation during the performance of the task-specific tests. Moreover, we also evaluated generalized changes in fine and gross motor performance outside the training context with a novel tester using the standardized BOT-2. In the music group, children showed a reduction in imitation error scores on the task-specific test of imitation in the late session compared to the early session. Children improved their accuracy of imitation during the action song and the xylophone conditions (see Figure 7-2A). In terms of the standardized test, the music group demonstrated a significant improvement on the raw scores of the balance and bilateral coordination subtests of the BOT-2 (see Figure 7-3A) as well as on the standard scores of the body coordination composite in the posttest compared to the pretest. Children did not show any improvements on the fine

motor subtests of the BOT -2 (see Figure 7-3B). The robot group showed a reduction in imitation error scores on the task-specific test in the late compared to the early session. Further analysis suggested that children demonstrated trends for improvement in imitation error scores for the action song and the drumming patterns following training (see Figure 7-2B). In terms of the standardized test, similar to the music group, this group also demonstrated improvements in the raw scores of the balance and bilateral coordination subtests as well as on the standard scores of the body coordination composite of the BOT-2 from the pretest to the posttest session (see Figure 7-3A). The robot group did not improve its fine motor performance as assessed on the BOT-2 (see Figure 7-3B). Lastly, the academic group demonstrated an improvement in the task-specific test of fine motor imitation. Specifically, children showed significant improvement on the imitation of actions involving Lego®/Duplo® blocks and Zoob (Infinitoy®) pieces; however, children only showed a trend for improvement in the imitation of actions using Play-Doh® (see Figure 7-2C). Consistent with the nature of the activities practiced in this group, children demonstrated significant improvements in the raw scores of the fine motor precision and fine motor integration subtests as well as on the standard score of the fine manual control composite of the standardized BOT-2 (see Figure 7-3B). There were no improvements on the gross motor subtests of the BOT-2 (see Figure 7-3A). All three groups did not demonstrate any improvements in the MD subtest of the BOT-2. In the subsequent sections, we discuss possible reasons for our findings and also highlight the implications of our study results.

7.4.2. Task-specific and generalized changes in motor skills: Music group

Children reduced their imitation errors on the task-specific test of imitation in the late compared to the early session (see Figure 7-2A). The task-specific test in this group assessed imitation during two conditions, i.e. action song and xylophone patterns. Children were required to imitate whole body actions and finger play of their adult partners during the action song condition. In addition, we examined praxis by assessing children's ability to copy multi-step unilateral as well as bilateral symmetrical, asymmetrical, and cross-over patterns performed by the trainer on the xylophone. During both these

conditions, we assessed spatial and temporal errors in children's imitation performance including errors in spatial location, body part usage, pace, movement precision, movement modulation, movement symmetry/reciprocity, and mirroring. We found that children showed medium effect sizes for improvements in imitation and praxis performance for the action song and xylophone patterns (ES for action songs = 0.60, ES for xylophone patterns = 0.78); however, children demonstrated a larger magnitude of improvement for the xylophone patterns (see Figure 7-2A). In terms of individual data, we found that 10 out of the 12 children in the group improved their performance in the action song condition, whereas 12 out of 12 children reduced imitation errors during the xylophone patterns.

Our findings of task-specific improvements in imitation and praxis skills fit with the limited existing literature on the use of music therapy in children with ASDs and the broader music education literature on the effects of music-based experiences on motor skills of TD children (Costa-Giomi, 2005; Forgeard et al., 2008; Hurwitz, Wolff, Bortnick, & Kokas, 1975; Stephens, 2008). For example, Stephens used the context of one-on-one musical interactions involving dancing, singing, and playing musical instruments to promote reciprocal imitation between the child with autism and the adult experimenter. Specifically, she found that contingent imitation-based games to music served as an engaging and predictable medium for children with ASDs, and in fact led to an increase in spontaneous imitation of actions and words of the experimenter by 3 out of 4 children with ASDs (Stephens, 2008). When TD children learn musical instruments such as piano, guitar, or xylophone, the training leads to an improvement in their ability to coordinate movements of their hands smoothly and flexibly as well as their ability to plan and execute multistep sequences of musical notes. For example, TD children who received prolonged musical instrument training showed more accurate performance on a motor sequencing task that required them to perform sequences of key presses with both hands following a visual cue compared a control group that did not receive musical instruction (Forgeard et al., 2008). In a similar study, following piano training, TD children showed an improvement in motor performance and a specific increase in response speed compared to a control group that did not receive any musical training. The authors suggested that the

repeated practice during musical training led to improvements in visuomotor coordination abilities as well as the speed and accuracy of children's responses (Costa-Giomi, 2005). Similarly, in our study repeated practice might have led to an improvement in children's bilateral and visuomotor coordination abilities, contributing to improved imitation and praxis performance in the late compared to the early session. In addition to imitation and praxis abilities, we think that our training could have impacted children's compliance with the context as well as their social monitoring and turn-taking abilities, which might have also contributed to the improvements observed. In the early session, we noticed that children found the training activities complex, given their impairments in bilateral coordination, imitation, praxis, and dynamic balance, as well as due to the novel and unfamiliar nature of the training context. Children had great difficulty in staying on task and focusing on the task. Over time the activities became more familiar to children and their compliance with the training increased. Their improved compliance with training activities might have made it possible for children to direct sustained attention towards their social partners. Improvements in social monitoring skills might have contributed to better perception of the trainer's movements, leading to better imitation of actions demonstrated by the trainer.

In addition to improvements on the task-specific test within the training context, we were interested in assessing children's ability to generalize learned motor skills to a standardized test of motor performance, the BOT-2. We found that the music group demonstrated an improvement of medium effect size ($ES = 0.60$) in the standard scores of the body coordination composite of the BOT-2. Nine children followed the group trends. Specifically, children improved their performance on both the bilateral coordination and the balance subtests of the BOT-2 (see Figure 7-3A). The activities in the music group focused heavily on dual and multilimb coordination by encouraging the practice of movements involving symmetrical and asymmetrical use of hands and legs. Similarly, practiced activities required good dynamic balance skills as children engaged in jumping, hopping, galloping, and skipping actions. All activities were done to the beat of music, and since rhythm is an element common to both music and limb movements, music-based training might have improved children's rhythmic abilities and their ability to coordinate body segments

to a beat. Overall, the rhythmic nature of the training activities might have led to sustained improvements in coordination and balance that generalized to the standardized test of motor performance. Our findings fit with music education literature, where music is frequently used as an accompaniment in physical education programs for TD children (Brown, Sherrill, & Gench, 1981; Derri et al., 2001; Zachopoulou et al., 2004; Zachopoulou et al., 2006). For example, a 24-session integrated physical education/music instruction program that combined Kodaly and Dalcroze ideas which focused on rhythm and movement, led to greater improvements in the perceptuo-motor performance on a standardized test in 4-6 year old TD children compared to a control group that received a motor exploration program. The authors suggested that age-appropriate rhythmic exercises to music that could improve the accuracy and precision of movement control have the potential to enhance fundamental perceptuo-motor skills in children (Brown et al., 1981). Similarly, a developmentally-appropriate music and movement program led to greater improvements in jumping and dynamic balance skills of 50 preschool children as assessed on the standardized *Motoriktest fuer vier-bis sechsjaehtidge kinder* (MOT 4-6) test compared to a control group that engaged in physical education activities that were not based on music (Zachopoulou et al., 2004). Music improved children's rhythmic abilities, which translated to improvements in children's abilities to perform coordinated movements and to adjust to changing motor demands in unpredictable environments (Zachopoulou et al., 2004). Overall, in line with other literature in children with ASDs and TD children, our music and movement-based training led to improvements in the task-specific and generalized measures of motor performance.

7.4.3. Task-specific and generalized changes in motor skills: Robot group

The robot group showed small improvements on the task-specific test of imitation and the generalized test of motor performance (see Figures 2B & 3A). The activities practiced in the robot group were similar to those in the music group except that children interacted with a robot instructor in the robot group compared to a human instructor in the music group. In the task-specific test of imitation and praxis, we assessed children's ability to accurately imitate the movements of the humanoid robot, Nao, within the

action song and drumming conditions. The action song involved whole-body imitation, whereas the drumming condition required children to copy simple and complex drumming sequences involving unilateral, bilateral symmetrical, and bilateral asymmetrical hand usage. In terms of individual data, 8 out of 12 children showed small improvements in imitation during the action song condition and 10 out of 12 children demonstrated small improvements (ES action songs = 0.26 , ES drumming patterns = 0.19) in their ability to accurately copy drumming patterns.

A few other previous studies have assessed the efficacy of robots in promoting imitation of actions, facial expressions, and gestures in children with ASDs (Duquette et al., 2008; Fujimoto et al., 2011; Hanson et al., 2012; Pioggia et al., 2008; Robins et al., 2004). However, only a handful of studies have systematically provided prolonged robot-delivered imitation training for children with ASDs (Duquette et al., 2008; Robins et al., 2009; Robins et al., 2004). It is important to note that none of the studies conducted to date have assessed imitation accuracy and changes in spatial and temporal errors associated with imitation performance following robot training. For example, Robins and colleagues used a humanoid doll robot, Robota, for repeated short bouts of interactions with 4 children with ASDs over 101 days. They found that towards the end of the training children demonstrated a trend for imitation of the simple actions of the robot (Robins et al., 2004). Similarly, in a different study by the same group using a child-sized humanoid robot, KASPAR, with a minimally expressive 16-year-old teenager with autism, it was found that across repeated unconstrained interactions with KASPAR conducted over several months, the teenager gradually learned to engage in imitation games with the therapist, mediated by the robot. The therapist and the adolescent took turns in controlling the robot while the other imitated the actions of the robot. The adolescent learned this game and then went on to play a similar game during interactions with the robot in the presence of another child (Robins et al., 2009). Our findings agree with this literature, but importantly add to the current body of knowledge by systematically coding imitation and praxis accuracy using custom-developed coding schemes. Children might have improved their imitation and praxis skills as a result of the training. In addition, children might have also improved their perception of the

anthropomorphic characteristics of the robot, which could have contributed to the improved imitation of actions in the late session compared to the early session. However, we would like to highlight that the improvements in the task-specific tests were small in magnitude (see Figure 7-2B), and we think that several characteristics of the current robot might have limited the amount of improvement observed. Although the Nao robot has 25 degrees of freedom, its movement repertoire is limited and impoverished compared to the rich variety of movements that the human body affords. Hence, the robotic context could not provide children with a variety of movement experiences similar to those provided within the human-delivered music context. Moreover, the robot's movements were not very smooth and precise, and they were also slower than the natural rhythm of children's movements, making it difficult for children to accurately copy the movement pattern and pace of the robot's movements. Lastly, we observed that during the drumming game, which involved children practicing quarter and eighth patterns, many children found it difficult to accurately imitate the robot's movements. The amplitude of the robot's movements was small and the timing of the movements not very accurate. Hence, children found it difficult to decipher the robot's movement sequences and the trainer had to frequently intervene to demonstrate the pattern. Overall, several technology-related factors might have limited the variety and complexity of movement experiences provided to this group, thereby restricting the improvements observed in imitation performance.

Similar to the results in the music group, children in the robot group also demonstrated an improvement in standard scores of the body coordination composite of the BOT-2 (see Figure 7-3A). However, the magnitude of improvement was small ($ES = 0.48$) in the robot group. In terms of individual data, 8 children in the group followed the group trends. Specifically, children demonstrated small improvements in the bilateral coordination and balance subtests of the BOT-2 in the posttest compared to the pretest. The only other study in the robotics literature that examined changes in motor performance was conducted by Pierno and colleagues (Pierno, Mari, Lusher, & Castiello, 2008). In this study, the performances of 12 high-functioning children with autism and 12 TD children between 10 and 13 years

were compared on a visuomotor priming task that required children to perform a reach-to-grasp action towards an object following observation of either a human or a robotic arm model performing the same action. They assessed kinematic measures of motor performance and found that children with ASDs were better at imitating the robot compared to the human model, as suggested by faster movement duration and peak velocity, whereas the reverse pattern was observed in TD children (Pierno et al., 2008). In contrast to the Pierno study that assessed the effects of a single session of robotic interactions, in the current study, we assessed the effects of prolonged robot-child interactions on overall gross motor performance. We found small improvements in motor skills that generalized to the standardized test of motor performance.

7.4.4. Task-specific and generalized changes in motor skills: Academic group

The academic group demonstrated improvements in the task-specific test of imitation (see Figure 7-2C) as well as on the fine manual control composite of the generalized test of motor performance. In the task-specific test of imitation, we assessed children's ability to use their hands in a coordinated manner and the strategies that children used while manipulating building supplies such as Play-Doh®, Duplos®/Legos®, and Zoob (Infinitoy®). Children demonstrated a small effect size for improvement in imitation accuracy for Play-Doh® actions ($ES = 0.49$); in contrast, children demonstrated a large magnitude of improvement for imitation of actions involving Duplo®/Lego® blocks and Zoob (Infinitoy®) pieces ($ES = 0.93$) (see Figure 7-2C). In terms of individual data, 6 out of 12 children improved imitation on the task-specific test of Play-Doh® and 10 out of 12 children improved imitation on Duplo®/Lego® and Zoob (Infinitoy®) actions. In terms of the generalized test, consistent with the training demands, children showed small improvements on the fine motor subtests (see Figure 7-3B) and the fine manual control composite ($ES = 0.33$) of the BOT-2. The fine motor subtests assessed children's fine motor control during activities such as coloring shapes while staying inside lines, copying shapes, folding paper, and using scissors. Individual data suggest that 6 children followed the group trend of improvements on the generalized test of motor performance.

The improvements in imitation skills seen in the academic group were consistent with the training activities practiced. Children practiced fine motor skills such as object manipulation during the building condition. For example, we encouraged children to practice rolling, flattening, and pinching of the Play-Doh®, as well as manual skills such as pulling, pushing, and stacking of the Lego®/Duplo® blocks and Zoob (Infintoy®) pieces. Our results suggested that children showed large improvements on imitation of test actions involving Duplo®/Lego® and Zoob (Infintoy®) pieces, but relatively smaller improvements for the imitation of actions on Play-Doh®. Our Play-Doh® test actions involved making a ball of the Play-Doh® using both hands, flattening it using thumbs, palms, and fingers, rolling it into a tube using two fingers, and lastly, pinching the Play-Doh® using two fingers of one hand as the other hand held the tube in the air. In contrast to the structured predictable assembly toys, Legos®/ Duplos® and Zoob (Infintoy®), Play-doh® is more free-form which might have made this activity more challenging for children. We observed that a majority of the children found these actions very difficult to begin with, and continued to encounter difficulties in certain steps even during the last session. Although there were large improvements in the simpler tasks involving the blocks and Zoob (Infintoy®) pieces, it is possible that our training intensity was not enough to lead to substantial changes in the more complex fine motor skills involving manipulation of Play-Doh®.

Children in this group improved their scores on the fine manual control composite of the BOT-2. We had designed our standard-of-care academic group to mimic the kind of fine motor activities that children engage in within occupational therapy sessions in school settings (Case-Smith & Miller, 1999). Typically, occupational therapy services directed towards fine motor problems in children frequently address issues related to handwriting skills (such as illegible writing, inability to stay on the line, letter reversals, etc.), desk skills (such as using scissors, folding, cutting, rolling Play-Doh®, manipulating small objects, etc.), and organization skills (such as keeping materials in order, completing homework, remembering sequence of tasks, etc.) (Case-Smith, 2002; McHale & Cermak, 1992; Reid, Chiu, Sinclair, Wehrmann, & Naseer, 2006). Similarly, during the art-craft condition in our study, children made theme-based creations that

focused on desk skills such as drawing, coloring, copying, cutting, and pasting. Our findings are in line with other studies from the occupational therapy literature suggesting improvements in fine motor and visuomotor skills following prolonged intervention programs in children with fine motor problems (Case-Smith, 2000; Dankert, Davies, & Gavin, 2003; Reid et al., 2006; Wehrmann, Chiu, Reid, & Sinclair, 2006). For example, following an 8-month intervention targeting fine motor problems in 44 preschool children, improvements were observed on standardized tests assessing in-hand manipulation, eye-hand coordination, fine motor skills, and visuomotor skills, as well as on measures of functional performance. Moreover, the amount of improvement observed was associated with the intensity of training (Case-Smith, 2000). Similarly, Dankert and colleagues assessed the effects of a 1-year occupational therapy intervention on the visuomotor skills of children with developmental disabilities using standardized tests. The training activities included fine motor activities such as art-craft, finger play, and object manipulation, visuomotor activities such as drawing, cutting, and assembling, as well as gross motor activities involving dancing and an obstacle course. They found that children with disabilities showed significant gains in visuomotor skills, and the rate of gain was greater than that seen in control TD children (Dankert et al., 2003). Along the same lines, in our study, it was encouraging to see that a relatively short duration of fine motor training led to gains in task-specific and generalized measures of fine motor skills. However, it would be important to replicate these results with studies involving longer training durations to produce more substantial and robust improvements in fine motor skills.

7.5. Clinical Implications

We assessed the effects of novel, embodied, movement interventions - music and robotic - compared to a standard-of-care academic intervention on the imitation skills and motor performance of children with ASDs between 5 and 12 years of age. It was encouraging to see that a short, intense protocol led to improvements in gross and fine motor skills in children with ASDs. In line with our hypotheses, all three groups demonstrated improvements in task-specific tests of imitation. Moreover, consistent with the training demands, the movement groups, which engaged in whole-body imitation and rhythmic,

synchrony-based games, demonstrated an improvement on the body coordination composite of the BOT-2. In contrast, the academic group, which engaged in table-top fine motor activities, demonstrated improvements in the fine manual control composite of the BOT-2. As discussed previously, there is evidence to suggest that gross and fine motor impairments in ASDs are associated with the core symptoms of the disorder (Dziuk et al., 2007; Hilton et al., 2012; Hilton et al., 2007). For example, motor impairments in children with ASDs as measured on the BOT-2 were associated with autism symptom severity measured on the social responsiveness scale (Hilton et al., 2012). Given the association between motor difficulties and autism symptoms, it is critical to assess and include gross and fine motor goals in the treatment plan of children with ASDs. In the present study, movement-based rhythmic activities involving whole-body imitation and synchrony games led to improvements in imitation and praxis skills as well as overall motor performance. Between the two movement groups, we found medium-to-large effect sizes for improvements on the task-specific and generalized tests of motor skills in the music group. In contrast, children showed small improvements in both task-specific and generalized measures in the robot group. Our observations suggest that the current robotic technology is limited in its application as a feasible and valuable tool to promote movement skills in children with ASDs for several reasons. The robot has a limited movement repertoire and cannot train children for complex actions such as running, jumping, galloping, hopping, skipping, or even walking at different speeds. Secondly, the robot's movements are slower than those of a human, and are not as precise and smooth as those of a human. Lastly, the robot cannot train fine motor skills such as cutting, coloring, drawing, etc. In the academic group, there were promising small-to-large effect size improvements in imitation skills and fine motor performance. Overall, we think that there is great value in promoting gross and fine motor skills in ASDs. In addition to the existing emphasis on remediating the fine motor issues in children with ASDs within occupational therapy sessions, gross motor activities involving music and movement within socially-embedded contexts must also be introduced in the school curriculum of children with ASDs. In fact, other data from our research group suggest that these movement-based activities to music within group settings

can also promote social communication skills such as social monitoring and verbal communication between children and their social partners.

7.6. Limitations and Future directions

In the current study, although we observed improvements in motor performance following training, we did not use any functional measures to assess the implications of these improvements during activities of daily living within naturalistic environments. Since we did not conduct follow-up sessions, we are also unsure of the extent of sustenance of gains in motor skills observed following training. Compared to conventional behavioral and occupational therapy interventions that last for prolonged durations, our intervention was provided for a relatively short duration. In terms of participants, we had a relatively small sample of 12 subjects per group. Since we included both high- and low-functioning children in the study, there was considerable variability in our sample. Future studies should replicate our results using larger, more homogeneous samples and prolonged training durations.

7.7. Conclusions

In the current study, we assessed the effects of novel movement-based interventions – music and robotic – and a standard-of-care academic intervention on the imitation skills and overall gross and fine motor performance of children with ASDs. To the best of our knowledge, ours is the first study to systematically assess the effects of music and robotic interventions on motor skills using standardized motor tests and custom-developed coding schemes to evaluate imitation. In line with our hypotheses, we found that all groups demonstrated improvements on the task-specific test of imitation. Further, consistent with the training demands of the contexts, the movement groups demonstrated improvements in gross motor performance, whereas the academic group demonstrated improvements in fine motor performance on the standardized BOT-2. Overall, we argue that given the significant perceptuo-motor impairments in this population, goals promoting gross and fine motor proficiency should be included within the treatment

plan of children with ASDs. Our data suggest that embodied rhythmic music and movement activities are a motivating and enjoyable context to promote motor and social skills in children with ASDs.

Chapter 8

Conclusions and clinical implications

8.1. Conclusions

The randomized controlled trial compared the effects of novel, embodied, movement-based music and robotic rhythm interventions to those of a standard-of-care, stationary, academic intervention on the social communication, behavioral, and motor skills of 36 children with ASDs between 5 and 12 years of age. The study was conducted over 10 weeks, with the pretest and posttest sessions conducted in the first and last weeks of the study, respectively, and the training sessions provided over the intermediate 8 weeks. Two training sessions were provided each week for a total of 16 sessions, with each session lasting for around 45 minutes. Children engaged in training activities within a triadic setting involving the child, the trainer, and the adult model. In the music group, children engaged in human trainer-delivered sessions that focused on whole-body games involving discrete imitation and synchrony to the beat of music. In the robot group, children engaged in robot-delivered sessions which involved children copying the whole-body actions of the robot within imitation and rhythmic synchrony-based games. In the academic group, children engaged in table-top academic and fine motor activities that mimicked the interventions that children receive within school-based settings. We assessed the effects of the three interventions on children's social communication, behavioral, and motor skills using task-specific measures within the training context, as well as during standardized tests in the pretest and posttest sessions. Specifically, we assessed task-specific changes in the duration of social attention, duration of social verbalization, frequency of repetitive/problem behaviors, and percent imitation error scores across training sessions. In terms of generalized tests, we assessed training-related changes in the standardized test for joint attention, the JTAT, and the standardized test of motor performance, the BOT-2. We were interested in assessing (1) context-related differences in the dependent variables between groups, (2) training-related changes in all variables within each group, and (3) condition-related differences in variables within each group.

The music-based context afforded greater social monitoring compared to the other groups, since children were required to attend to their social partners and synchronize their movements with those of their social partners. Specifically, movement-based conditions that encouraged social synchrony afforded greater social attention compared to conditions that facilitated object engagement. Children also engaged in a greater amount of socially-directed compared to self-directed vocalization/verbalization in this group. Moreover, across training sessions, children increased their verbalization with the trainer. Conditions that involved singing and encouraged social interactions without concurrent motor demands promoted greater verbalization compared to movement conditions that required children to synchronize with their social partners. The improvements in social communication skills observed with training also generalized to the standardized test of responsive joint attention in the posttest compared to the pretest. In addition, we found that given the novel and challenging nature of the activities practiced in the music group, children engaged in greater frequencies of negative/self-injurious behaviors in the early session compared to the academic group. In fact children engaged in greatest negative behaviors during the music-making condition which required the practice of complex motor sequences. The music-making condition also afforded greater sensory exploration with objects, given the easy access to objects during this condition compared to other conditions. However, over training sessions, children reduced the frequencies of negative/self-injurious behaviors, probably due to increased familiarity with the context and improvement in imitation skills. Accordingly, children improved their imitation and praxis performance as suggested by reduction in imitation errors during the task-specific test of imitation involving action songs and xylophone patterns. Moreover, following music and movement training, children also demonstrated improvement in gross motor skills, specifically in the body coordination composite as well as the balance and bilateral coordination subtests of the standardized test of motor performance, the BOT-2.

In the robot group, children spent maximum time attending to the robot. This was consistent across all conditions within training, and this might have restricted their opportunities to interact with their social partners. However, although the time spent in attending to social partners was lower than that seen in the

music group, this group engaged in overall social attention levels greater than those seen in the academic group. Over time, children reduced the attention directed to the robot with a concurrent increase in attention to elsewhere in the room, suggesting progressive boredom with the context. In terms of verbalization, children engaged in greater self-directed compared to socially-directed verbalization. One possible reason for this was that children chose to spontaneously use verbal labels such as “Pal-Buddy” as they practiced the quarter and eighth patterns during the drumming condition. But, in addition, we noticed that children engaged in greater scripting, echolalia, and self-directed vocalizations including whining, squealing, and giggling in this group. Our observations suggest that the context could not sustain children’s engagement and therefore children engaged in scripting or negative behaviors such as tantrums, whining, etc. during training sessions. Nevertheless, we found that across training sessions children increased the amount of verbalization with the model, although these improvements did not generalize to the standardized test of social communication skills. In line with the finding in the music group, the social interaction phase that focused on verbal communication without simultaneous motor demands promoted greater verbalization compared to other conditions. In terms of repetitive behaviors, children demonstrated greater negative/self-injurious behaviors compared to children in the academic group. These results are similar to those observed in the music group and are possibly because activities practiced in this group were also highly novel and difficult for children. These behaviors were prominent during the action game and drumming conditions, which placed the greatest motor demands on children. However, unlike the music group, children did not show a reduction in negative behaviors across training sessions. Lastly, in terms of motor skills, children demonstrated small improvements on the task-specific test of imitation as well as on the bilateral coordination composite and the bilateral coordination and balance subtests of the standardized test of motor performance.

In the academic group, children directed maximum attention to objects at the cost of attention to their social partners. This was seen during all the conditions, but especially in the reading, building, and art-craft conditions. However, in terms of verbal communication skills, children demonstrated high levels of

socially-directed verbalization from the first session and maintained this trend across sessions. Specifically, the social interaction phase and the reading conditions promoted greater verbalization compared to other conditions. Children also demonstrated an improvement in their ability to respond to the verbal bids for joint attention initiated by the novel tester in the posttest compared to the pretest. In terms of repetitive/problem behaviors, children engaged in greater frequencies of sensory behaviors with objects compared to all other types of behaviors. Given the familiarity of the practiced activities, children engaged in the lowest levels of negative/self-injurious behaviors in this group. Moreover, the frequencies of sensory behaviors were greater during the building and art-craft conditions compared to other conditions. In terms of motor skills, children showed a reduction in errors associated with fine motor imitation performance during the late compared to the early session, especially for the Duplo®/Lego® and Zoob (Infinitoy®) activities. Consistent with the training demands in the group, children demonstrated an improvement in the fine manual control composite as well as the fine motor precision and fine motor integration subtests of the BOT-2.

8.2. Clinical Implications

Overall, our randomized controlled trial provided valuable insights that suggest the need for changes in the standard-of-care treatments conventionally used for children with ASDs. Rhythm interventions that involved movement-based activities to music promoted spontaneous engagement and social monitoring. Although children initially found these activities challenging, over training they improved their compliance with training and their motor imitation skills. Music-based contexts were enjoyable for children; these experiences promoted singing and also led to an increase in spontaneously-initiated social interactions. Although similar to the music context in terms of the motor activities practiced, the robotic context could not sustain children's engagement across sessions. The robot was a salient object that attracted children's attention towards itself, but instead of acting as a mediator in promoting triadic interactions between children and their social partners, it led to children persistently visually fixating on it. Over time, children were bored with the robotic context; they started looking elsewhere in the room

and engaged in self-directed vocalizations and scripting. We think that the limitations of the current robotic technology contributed to these trends. The Nao robot had a limited movement repertoire compared to that of the children, was slow in its movements, had limited and unclear pre-programmed verbiage, and was not autonomous in nature, thereby limiting its ability to dynamically and contingently adapt to the movements of the child. These limitations severely restricted children's sustained engagement with the context. Unless these limitations are addressed, we do not think that robotic technology can be used as a feasible and effective treatment tool in autism. Contrary to expectations, standard-of-care academic activities, which required engagement with objects, did not promote social attention in children with ASDs. Children are typically used to academic and fine motor activities in school, and hence the academic context afforded greater compliance with training activities, lower levels of negative behaviors, and greater responsive communication with social partners. But our study suggests that table-top contexts promote predominantly object engagement and repetitive sensory behaviors with objects. To summarize, our study underscores the need for including enjoyable and engaging music and movement activities within the treatment plan of children with ASDs. Given the pervasive nature of motor impairments in autism, rhythmic movement-based music interventions seem to be promising tools to promote motor as well as social communication and behavioral skills in children with ASDs.

Chapter 9

Limitations and future directions

9.1. Limitations

As their name implies, Autism Spectrum Disorders encompass a variety of symptoms and a broad range of levels of functioning. Research that attempts to understand the effects of novel interventions on such a diverse population must of necessity contend with several inevitable issues related to variability and study design. In terms of sample characteristics, we had a relatively small sample size of 12 subjects per group. Moreover, our sample was quite heterogeneous, since we included both high- and low-functioning children in a wide age range of 5 to 12 years. In spite of matching each triad of children on age, level of functioning, and services received, prior to random assignment to one of the three groups, we observed considerable variation in symptoms of children in our study. In terms of testing measures, although we used both task-specific and standardized tests to assess training-related changes, we observed that the improvements in the standardized tests were small to moderate in magnitude. Given previous evidence that children with ASDs find it hard to generalize learned skills to novel contexts involving novel people, it was not surprising that we did not obtain large effect sizes for training-related improvements on the standardized tests. It is possible that the short duration of the training limited the amount of improvement observed. Moreover, we do not know what improvements within task-specific and standardized tests amount to in functional terms. We did not use functional measures to assess carry-over of learned skills to activities of daily living, which limits our ability to draw conclusions about generalization following training. In terms of training characteristics, compared to conventional autism treatments that last for at least several months, our training lasted for a relatively short duration of only 2 months. Moreover, we did not conduct follow-up sessions to assess for maintenance of training effects. In terms of the training content, for each group, we developed a high-functioning and a low-functioning protocol; however, treatment was not individualized to the needs of each child. For example, we observed that our existing

music protocol might have been more suitable for younger and low-to-moderate functioning children. For high-functioning older children, singing and rhythmic synchrony-based games might not be very engaging; instead, choir training or musical instrument training might be more age-appropriate as well as engaging and enjoyable. In the current study, we tried to involve parents in the training to promote generalization of skills to naturalistic interactions. However, there was significant variability in the adherence levels of parents with the home program with the home training sessions, which might have influenced the study results. Finally, the current study design only allowed us to conclude that a music and movement-based rhythm intervention might be a promising tool to remediate the impairments in autism; however, our study did not allow us to tease apart the specific training-related factors within the context, i.e. the “active ingredients” – music, movement, traidic setting, etc. - that might have contributed to our results.

9.2. Future Directions

The current study is a stepping stone to further investigations on music and movement-based rhythm interventions for children with ASDs. Prior to the inclusion of embodied rhythm interventions in the treatment of autism, it would be important to understand the critical factors that contribute to the positive effects following music and movement interventions. Our individual data suggest that not all children uniformly demonstrated improvements on all variables. To explain the observed variability in the treatment effects, it would be important to study the associations between the effects of therapy and various patient characteristics such as age, IQ, and baseline levels of social communication and motor skill scores, as well as those between therapy effects and parent adherence to the home program. In other words, music therapies might be beneficial to a specific sub-set of children with ASDs, for example, for younger and low-functioning children with ASDs. To address these issues empirically, our results need to be replicated using larger RCTs with homogeneous sample pools. More research is needed to develop the training content to ensure that children sustain engagement in the training activities across training weeks. For example, as mentioned above, some of our training activities might not have been appropriate for

older high-functioning children with ASDs. Hence, future research should aim at developing modules of age-appropriate and meaningful activities for children in the pre-school, elementary school, middle school, and high school age groups. Although our current therapy goals emphasized age-appropriate social communication and motor skills, we would like to train functional activities using music-based contexts in the future. For example, Kern and colleagues used custom-composed songs embedded in the daily classroom curriculum of children with ASDs, to teach children self-care activities such as hand-washing, toileting, and cleaning-up (Kern, Wakeford, & Aldridge, 2007). Development of interventions targeting daily-living skills which could be easily embedded into the routine classroom or home environments would be very valuable for this population. The next step would be to involve teachers, parents, and peers in the training process to ensure that therapy settings mimic the naturalistic environments of children with ASDs, allowing for easy generalization of learned skills. To this end, we are trying to develop ways in which our current protocol could be made available to clinicians involved in the care of children with ASDs. We are also developing training protocols and instructional videos that could be used to train peers and parents of children with ASDs.

In addition to improving the current protocol for music-based rhythm interventions for children with ASDs, there are several other promising treatment avenues that remain to be explored. We would like to examine the effects of other movement-based interventions such as creative yoga, dance, and active play on impairments of children with ASDs. Although much work still needs to be done, we conceive of a socially-embedded movement-based curriculum involving elements of music, yoga, dance, and play that can be integrated into the daily routine of children with ASDs. Our recent review of the literature suggests that physical inactivity, unhealthy eating habits, and lack of awareness about health-related issues might increase the likelihood of obesity and overweight in individuals with ASDs (Srinivasan, Pescatello, & Bhat, 2014). Currently, there is limited evidence on exercise interventions that are targeted towards reducing obesity and improving physical fitness in this population (Srinivasan et al., 2014). There is a need to develop comprehensive programs that include components of aerobic and resistance exercise,

dietary changes, and lifestyle modification to effectively target issues related to obesity in individuals with ASDs. These interventions would require the collaborative efforts of physical therapists, special educators, dieticians, and the family of the child to ensure adherence and long-term benefits. Although all the suggestions discussed so far regarding future research on interventions for ASDs have focused on motor goals, we acknowledge that around 70-90% of individuals with ASDs have atypical sensory responses, including hypo- or hyper-responsiveness to sensory stimuli, which might adversely influence their adaptive functioning (Baranek et al., 2013; Ben-Sasson et al., 2009). In the current study, we capitalized predominantly on the auditory and visual modalities during training activities. Future intervention programs should also involve activities relying on the tactile-proprioceptive and vestibular systems. In our own work, we will be investigating the effects of contact games involving the tactile system within a creative yoga protocol in children with ASDs.

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