Social Robots and Teaching Music to Autistic Children: Myth or Reality?

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Abstract. Music-based therapy is an appropriate tool to facilitate multisystem development in children with autism. The focus of this study is to implement a systematic and hierarchical music-based scenario in order to teach the fundamentals of music to children with autism through a social robot. To this end, we have programmed a *NAO* robot to play the xylophone and the drum. After running our designed robot-assisted clinical interventions on three high-functioning and one low functioning autistic children, fairly promising results have been observed. We indicated that the high-functioning participants have learned how to play the musical notes, short sentences, and simple rhythms. Moreover, the program affected positively on autism severity, fine movement and communication skills of the autistic subjects. The initial results observed indicate promising potentials for involving social robots in music-based autism therapy.

Keywords: Music-based therapy · Xylophone · Autism spectrum disorders (ASD) · Humanoid social robot · Social and cognitive skills · Imitation

1 Introduction

Music greatly influences humans and in particularly children's emotions, moods, and feelings. Teaching music can help develop new or improve existing social, verbal and non-verbal communication skills in children [1, 2].

Children with autism have stereotyped behaviors and limited verbal communication skills [3]. Music and rhythms are effective methods to involve them in rhythmic and non-verbal communication. Nowadays, at least 12 % of all treatment of individuals with autism consist of music-based therapies [4].

Music has often been used in therapeutic sessions with children with mental and behavioral disabilities [5, 6]. In particular, there is ample evidence that shows either playing music during therapy sessions or teaching music to children with autism spectrum disorders (ASD) can significantly increase the impact of therapy sessions [7]. In such studies or therapy sessions an instrument is either played by a human or recorded

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music is played back in individual and group intervention sessions [4, 8]. The effects of music-based therapy in improving social skills of children with autism (i.e. eye contact and initiating social behaviors) have been reported in [9]. Kim et al. [2] showed improvement in joint attention, turn taking and eye contact of children with autism in active music-making interventions. In [10, 11], the studies showed a decrease in stereotyped behaviors and self-injuries in children with autism after running music-based interventions. Music therapy interventions have been used to increase social [12] and emotional [13] skills, verbal and gestural communication [14], and behaviors [15] of individuals with autism in individual and group modes. It should be noted that the lack of studies on improving gross and fine motor skills of autistic children through music-based interventions is still a gap in this area [4].

Recently, we have designed a comprehensive robot-assisted music-based intervention scenario to improve perceptuo-motor, social, and cognitive skills of ASDs and conducted it in a single subject design study. The purpose of this educational-therapy program is to teach the fundamental concepts of how to play drum and xylophone using a *NAO* humanoid robot as a teacher's assistant to children with autism. Our goal is to find scientific answers for the following research questions: (1) Does a humanoid social robot have the ability to teach music (i.e. notes and rhythms) to children with autism? (b) Can a humanoid robot improve social and cognitive skills in children with autism through music education?

To this end, a drum/xylophone playing humanoid robot in addition to other musical instruments, both of which are loved by children, were used. Although the use of robotics technology in different aspects of education and treatment is increasing [16–25], to the best of our knowledge utilizing a humanoid robot to systematically teaching music to children with autism is still an interesting topic. Tapus [22] has used a social robot in a music-therapy program on individuals with cognitive impairments; however the robot did not play any musical instruments in her study. It should be noted that some researchers have also used music instruments like a drum played by a robot [23] as reinforcement tools (and not necessarily as an education tool) in autism treatment.

This paper presents the results and observations of a robot-assisted therapy in a single subject design study on three high-functioning and one low-functioning children with autism. The study was conducted in eleven music-based intervention sessions in Iran in order to explore the potentials of music-based games on ASDs.

2 Research Methodology

2.1 Participants

Three children with high-functioning and one child with low-functioning autism enrolled in this robot-assisted research study. All of the participants were 6 years old males without any previous music background. The children's details are describe in Table 1.

Table 1. Our participants' details

#	Abbreviation	Autism severity
1	P1	High-Functioning autism, with hyperactivity
2	P2	High-Functioning autism
3	P3	High-Functioning autism, with verbal deficits
4	P4	Low-Functioning autism with poor verbal skills

2.2 Humanoid Robot

The humanoid robot used in this research is the *NAO* H-21 robot made by Aldebaran Company [26]. The capabilities of *NAO* as well as the suitable programming interface of this robot make it a commonly used commercial robot for autism research [27–29]. We have renamed the robot to the Iranian boy's name, "*Nima*", during our studies.

2.3 Musical Instruments

Having noticed that when the instrument sound is simpler and more pleasant the patient will be deeper involved and the interventions will be more effective, we have selected a drum and a xylophone for the robot to play in our intervention sessions.

2.4 Technical Design of the Games

We have designed two general music games to involve children in interventions: (a) playing a real drum/xylophone in Robot-Child or Robot-Child-Therapist/Parent imitation turn taking games and (b) playing a Kinect based virtual xylophone on the screen.

Play the Drum/Xylophone: Our robot has been programmed to be able to play the drum/xylophone. A configurable user friendly GUI[1] as well as some rhythm patterns by Choregraphe [26] software have been developed in order to enable the robot playing the instruments either manually by operators/psychologists or automatically in a real-time situation. The robot is able to play different rhythms and notes with its right/left arm.

Virtual Xylophone: We have developed a Kinect based virtual xylophone containing 8 colored bars programmed by C# WPF. In this game, the player can see the music bars on the screen. The participant can hit the bars using colored mallets or the palm of their hands. The sounds of one octave from C4 (261.6 Hz) to C5 (523.2 Hz) are heard when hitting these bars. We have used the Toub.Sound.Midi Library in order to generate music notes with the computer.

[1] Graphical User Interface .

2.5 Experimental Setup

Our study was conducted in the Social & Cognitive Robotics Laboratory at Sharif University of Technology with four autistic children during eleven sessions in the presence of a human therapist (and sometimes their parents), a humanoid robot, and a robot operator. Time duration of each session was 20–30 min.

The games' instructions were described by the robot and/or the human therapist before each game. The Wizard of OZ (WOZ) style robot control has been used in this study, and most of the time the robot operator sent appropriate real-time voice/motor commands to the robot after seeing the child's performance. Our single subject design study contains a Baseline, Pre-Test, Post-Test, and Follow-up Test (four weeks after the last session) all in the absence of the *Nima* robot. Because no control group was utilized in this paper, our focus was on comparing each participant's skills/behaviors with his previous behaviors based on the assessment tools (which will be introduced in Subsect. 2.7).

2.6 Interventions Protocol

The purpose of designing a comprehensive music-based robot-assisted intervention scenario is teaching the fundamentals of music, decreasing impairments and improving/generalizing social and cognitive skills as well as fine/gross movement skills of children with autism spectrum disorders. Our music games are based on active music-based therapies which included imitating the robot in playing the drum/xylophone, rhythm perception, working memory games, teaching the notes, involving in turn-taking group games, reading/playing music sentences, and finally generalizing the learned knowledge to another instrument (i.e. the virtual xylophone). The designed therapeutic games have the potentials to improve auditory perception, perceptuo-motor activities, vision skills, mental development, and social and communication skills.

2.7 Assessment Tools

To answer the research questions of this study, two measuring instruments have been used each for four times (on Baseline, Pre-, Post-, and Follow up tests).

(1) Stambak's Rhythmic Structures Reproduction test [30] which is a test containing 21 (easy to hard level) rhythmic tasks that the participant should reproduce the patterns through a drum after hearing (and not seeing) them performed by the therapist.
(2) Gilliam Autism Rating Scale (GARS) [31], a questionnaire for estimating autism severity, with 56 questions which covers four subscales: Stereotyped Behaviors, Communication, Social Interactions, and Developmental Disturbances.

3 Results and Discussion

At the first session, the *Nima* robot was introduced to the participants. The main purpose of this session was to familiarization/desensitization the participants to the class environment as well as observe the child's tendency to start/keep communication with *Nima*. It should be noted that music was not taught during the first session.

After that, following the designed educational protocol, music was taught step-by-step by the robot during the rest of the sessions. The selected snapshot of the intervention sessions is presented in Fig. 1.

Fig. 1. Snapshot of the robot-assisted music-based intervention sessions

Music was a happy and enjoyable activity for all of the participants. The existence of the robot itself considerably increased the motivation of the children to use their capabilities to involve their sensorimotor mechanisms. A short description of observations for the participants are presented in the following.

P1: The psychologists reported noteworthy improvement in his social skills, attention, and the ability to learn. The music learning process occurred for Benyamin and the presence of the robot was the reason for this observation

P2: P2's performance was very similar to typically developing children. Although P2 is very resistance to education classes in his real life, he did not show any maladaptive behaviors in our course. It seemed the child felt secure and relaxed during the sessions

P3: Improvement in Radvin's verbal skills was reported by his mother. In comparison to the other two high-functioning children, Radvin's weakness at the first sessions

was his lack of expressing/identifying some colors; fortunately, this deficit was resolved by the last sessions

P4: He understood none of the instructions at the beginning of the program. Improvement in his instruction perception, attention, and understanding what happened in the class was the positive note occurred for P4 over time. He usually played randomly on the real xylophone bars instead of correctly imitating the robot/parent during the turn-taking games; however he was able to acceptably imitate the robot switching hands in the last four sessions. We observed that P4's stereotyped behaviors (especially his fluttering fingers) decreased and his verbal skills increased. Music is very effective in decreasing the stereotyped behaviors of children with autism [10, 11].

3.1 Stambak Rhythmic Structures Reproduction Test

To investigate the participants' improvement in rhythm perception during this time, the Stambak's Rhythm Reproduction Test has been run on the autistic subjects. The results of this test in the Pre- and Post-Test are presented in Table 2. We indicated that all of the three high-functioning participants show improvement in playing rhythm which means music learning has occurred for these subjects. In [32], the Stambak rhythm test has been used to show the music improvement of typically developing subjects after running a human-based music-therapy program.

Table 2. Stambak's Rhythm Test results in Pre-Test and Post-Test

#	Abbreviation	Scores of the Stambak's Rhythm Test	
		Pre-Test	Post Test
1	P1	18	19
2	P2	6	13
3	P3	11	14
4	P4	0	4

Meanwhile, P4 was unable to do any of the rhythm tasks in Pre-Test; however, in the Post-Test he was able to play tasks #1 to #4, each in his second try with the help of counting (the number of played hits) and saying "Baam-Baam".

For the high-functioning autistic children, our main goal was observing the trend of their music learning pace. Rhythm perception for the three high functioning subject have been improved. From our observations, we hypothesized that there is no obvious difference between the music learning process/progress rate of high-functioning ASDs and TDs[2]; they can read/play the notes and simple musical sentences and the progress rate for the spent three months was really promising. Moreover, we observed noticeable progress in all four children's fine hands imitation as well as using two hands consecutively, which they all had problems with in the first sessions.

[2] Typically Developing.

One of the promising observations from the high-functioning subjects' performance in this study was their following, curiosity, and questioning increased in the presence of the robot. The children used as many opportunities as they could to push Nima to speak and ask him questions.

3.2 GARS Questionnaire

The results of GARS are presented in Fig. 2. We observed a decrease in the autism severity of all four participants from Pre-Test to Post-Test. A detailed assessment of the GARS questionnaire showed us improvement occurred in 3 subscales: stereotyped behaviors, communication, and social interaction for two of the participants, P1 and P4 from Pre-Test to Post-Test. P3 progressed in stereotyped behaviors and communication, while P2 showed improvement in communication and social interaction. The interesting point of the GARS results is the progress of all of the subjects in subscale "communication". This finding is in line with our therapists' reports during the intervention sessions. The existence of *Nima*, as an attractive communication tool, positively affected the communication skills of the children. Comparison of GARS overall scores between the Post-Test and Follow up-Test shows the retention as well as the stability of the sessions' impact on autistic children. Similarly, improvement of autistic children in different social and communication skills after music-based therapies or robot-assisted clinical interventions have also been confirmed in [12–15, 20, 21, 29].

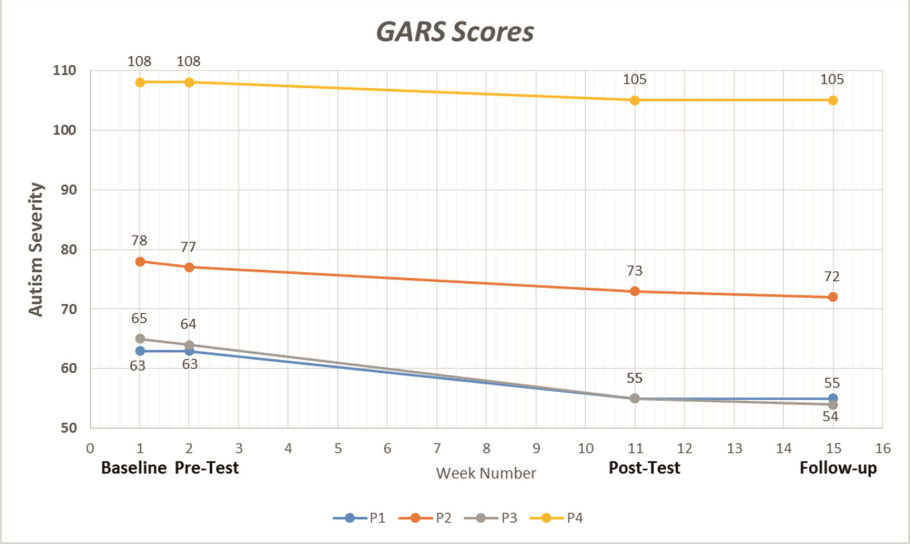

Fig. 2. GARS overall scores (autism severity) of the participants in Baseline, Pre-Test, Post-Test, and Follow up Tests.

3.3 Limitations and Future Works

In order to check for the effectiveness of the treatment, a larger sample size is needed, ideally with male and female children and a control group. Moreover, one of the greatest limitations in these kinds of studies is accessing valid tools which have the potential to accurately measure/assess children's behavior. Unfortunately, because of small number of the autistic participants in this study, no scientific statistical analysis could be applied on the data. To generalize the mentioned findings in robot-assisted music-based therapy, further research with more autistic subjects is needed.

4 Conclusion

Through the designed music-based scenario package, we wanted to explore the potential of music-based intervention on ASD's improvement in motor, communication skills as well as learning music. The robot does have the ability to teach the fundamentals of music to children with autism. We also saw improvement in fine hands imitation, using both hands in order, and rhythm identification for all of the participants. The high-functioning subjects can now read/play the notes and simple musical sentences and their progress was quite acceptable during the three months interventions. In the case of the low-functioning subject, improvement in verbal skills and a decrease in stereotyped behaviors have been indicated. Additionally, the GARS showed that the autism severity of all of the participants were reduced after the robot-assisted intervention sessions.

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