Utilizing Social Virtual Reality Robot (V2R) for Music Education to Children with High-Functioning Autism

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Abstract

Virtual Reality (VR) technology is a growing technology that has been used in various fields of psychology, education, and therapy. One group of potential users of VR are children with autism who need education and have poor social interactions; this technology could help them improve their social skills through real-world simulation. In this study, we evaluated the feasibility of conducting virtual music education programs with automatic assessment system for children with autism at treatment/research centers without the need to purchase a robot, resulting in the possibility of offering schedules on a larger scale and at a lower cost. Intervention sessions were conducted for five children with high-functioning autism ranging in age from 6 to 8 years old during twenty weeks which includes a baseline session, a pre-test, training sessions, a post-test, and a follow-up test. Each music education sessions involved teaching different notes and pieces of music according to the child's cooperation, accuracy, and skill level utilizing virtual reality robots and virtual musical instruments. Actually, by analysis of psychological tests, and questionnaires conducted by a psychologist, we observe slight improvements in cognitive skills because of the ceiling effect. Nevertheless, the effectiveness of the proposed method was proved by conducting statistical analysis on the child's performance data during the music education sessions which were obtained by using both video coding and the proposed automatic assessment system. Consequently, a general upward trend in the musical ability of participants was shown to occur in these sessions, which warrants future studies in this field.

Keywords: Social Virtual Reality Robots (V2R), Music Education, Autism Spectrum Disorders (ASD), Imitation, Joint Attention, Cognitive Skills.

1 Introduction

Autism is a neurodevelopmental disorder with deficits in verbal and non-verbal interactions and cognitive intelligence problems that significantly impact communications, social skills, imaginative abilities, as well as the presence of repetitive interests and patterns of behaviors (Robledo and Ham-Kucharski 2005; Puoretemad 2011). Game-therapy is a common method to decrease the behavioral problems of a child with Autism Spectrum Disorder (ASD). These techniques involve focusing on the child's interests (Robledo and Ham-Kucharski 2005; Puoretemad 2011).

Over the past decade, Virtual Reality (VR) has become an emerging technology with the potential of various applications in therapy and rehabilitation. VR is a simulated artificial three-dimensional environment that can be used by individuals with ASD to explore the real world in a controllable artificial environment. Many studies have been performed to investigate the benefits of a VR system (such as adding a sense of reality and enabling content attractiveness) to create various treatments and educational tasks for people with autism (Strickland 1997; Ellis 1991; Kandalaft et al. 2013; Bellani et al. 2011). In a study by Parsons et al. (2006), they designed a bus environment and a virtual café as a gathering place for individuals, including two adolescent boys with ASD. The results of the study indicated the significant potential of Virtual Environments (VE) as a promising tool to improve social skills in individuals with autism. Additionally, a safe experimental environment can be created with the help of virtual reality technology to prepare individuals to experience different tasks and social situations before approaching them in their real lives. A primary study done by Josman et al. (2008) designed a virtual road for children with ASD to test their ability to cross the road. The researchers indicated significant progress in the children's ability to make the right decisions when crossing a virtual street and found that these street-crossing skills learned in the virtual environment could be transferred to their real-life situations. In another study conducted by Fornasari et al. (2013), they designed a virtual environment where children with and without autism could freely explore and navigate an unfamiliar urban environment. Their findings showed stereotyped behaviors in children with ASD compared with children with typical development. Liu et al. (2018) designed virtual scenes (such as a shopping mall, hospital, and classroom) for individuals with ASD and required them to communicate with virtual avatars and finish some training tasks. The results of the Autism Behavior Scale (ABS) and the Childhood Autism Rating Scale (CARS) tables before and after the training tasks demonstrated some relief in the symptoms of ASD patients. The authors concluded virtual reality systems could be helpful in adjuvant therapy for autism. In another study, Bernardes et al. (2015) designed a VR serious game simulating the process of taking a bus in a virtual environment for individuals with ASD. The results showed the acceptance and viability of the experiment and proved a VR setup could help individuals with ASD to live more independently, thus showing great potential as a learning tool. Various studies have used VR technology to enhance the skills of children with ASD by focusing on simulating other cognitive activities (such as listening skills, recognition/memory skills, decision making, etc.) and using different places such as classroom, car, toilet, airport, etc.(Ramachandiran et al. 2015; Zhang et al. 2015). Patsadu et al. (2019) designed a serious game to develop and assess the listening and memory skills of children with ASD. The results indicated the overall satisfaction of ASD individuals and caregivers with the game-therapy program, allowing the authors to conclude that the realistic and attractive features of virtual reality encourage the learning process in these individuals. According to similar studies

(Bellani et al. 2011; Parsons 2016; Mesa-Gresa et al. 2018), virtual reality appears to be a good instrument for improving the social and cognitive skills of children and teenage ASD sufferers. However, there is a serious gap in VR studies for younger participants in the literature.

Several studies have indicated that using technologies like virtual and augmented reality, computer software, and robots are effective in helping individuals with ASD to improve their social/cognitive skills (Reed et al. 2011; Scassellati et al. 2012). The features of social/cognitive skills that can be aided by technology-based studies for children with autism spectrum disorders were briefly reviewed by Reed et al. (2011). Initiating conversation has been the most commonly reported skill in the literature. Scassellati et al. (2012) mentioned that socially assistive robots seem to have a positive effect on encouraging people with autism to enhance their social skills. Further studies have shown that using technology-based interventions often seems to be both appealing and useful in the treatment and education of children with autism (Robins et al. 2005; Goldsmith and LeBlanc 2004). Alemi et al. (2016) reported the effectiveness using of the NAO social robot as a therapy assistant in the reduction of pediatric distress and suffering in children with cancer. Taheri et al. (2015) reported progress in the reduction of stereotyped behaviors and social skills in a pair of seven-year-old twin brothers with autism as a positive response to the presence of a social robot (the NAO robot) in therapy sessions.

Moreover, research has indicated that music therapy is not only an effective way to engage children with ASD in non-verbal and rhythmic communications but is also a well-known method in the education/rehabilitation of these children (Kim et al. 2009). In the literature, music teaching/therapy has been demonstrated as an effective means to acquire social/cognitive skills and to improve communicative behaviors in children with ASD (Edgerton 1994; Kim et al. 2008). Almost twelve percent of all treatments and interventions for autism involves music-based games (Bhat and Srinivasan 2013). Alternatively, research shows that social robots can have a promising effect on children more effectively involving them in therapy sessions. In a study by Taheri et al. (2016), the effect of using a social robot to teach the fundamentals of music to children with ASD has been studied. They reported that using a robot in music-based intervention sessions positively affected not only fine motor imitations and communication skills of children with autism spectrum disorders, but also influenced the severity of their autism.

In our previous study (Shahab et al. 2017), we combined social/cognitive robots (NAO robots), a virtual reality system, and music instrument training (a virtual xylophone and drum) and designed a novel virtual reality game to teach music to children with ASD using Virtual Reality Robots (V2R). Then by the help of a phycologist as a video coder, we assess the child's behaviors and performance to study the acceptability of the game for typically developed children and children with autism. Our findings demonstrated the high acceptance of virtual reality devices for the improvement of social skills. Moreover, it was indicated that V2R could be a promising and appropriate tool to improve the social skills of individuals with ASD in cases where a real robot is not accessible.

In this paper, we have inspired from the intereting results of the previous study to design the scenarios for the innovative V2R-assisted music-based intervention sessions for children with high-functioning autism. To the best of our knowledge, using virtual reality systems to systematically teach music to children with autism is among the first works in the literature in the autism area. Three main research questions of this study are: 1) Does the virtual reality system help children with autism learn music, systematically? 2) Does music teaching by virtual reality technology improve the cognitive skills of children with autism?, and 3) How good is the automatic assessment as a proper method for evaluating the performance of children during virtual reality tasks? To this end, we conducted interventional therapy sessions including baseline, pre-test, music training, post-test, and follow-up sessions in a virtual environment using V2R by implementing novel programs that had not been observed to be used in virtual reality systems so far. Different music notes and melodies (ranging from easy to difficult) were practiced by individuals with high-functioning autism. Finally, we would like to observe the potentials of practical virtual reality games, such as V2R, in musical education and a supplementary method in intervention sessions for children with autism.

2 Research Methodology

2.1 Participants

Initially, 12 children with autism participated in an acceptance music education session. Seven of the children refused to cooperate in the introductory session and were deemed unsuitable to attend the virtual reality training sessions due either to their young age or being low functioning autistic. For this reason, children with high functioning autism and in the range of 7 years old were selected to conduct the research. The remaining five children (5 boys with a mean age of 7.09, SD: 0.75) consisted of four high-functioning and one low-functioning (Subject V1) individuals. They participated in the training-treatment course voluntarily without receiving any fees. A consent form for the interventions was signed by their parents, and Ethical approval (IR.IUMS.REC.1395.95301469) was obtained as a license to conduct this research.

2.2 The virtual music classroom

In the present study, a virtual reality classroom was designed for musical rehabilitation and treatment of children with autism, similar to the authors' previous study (Shahab et al. 2017). This music class consists of two virtual humanoid robots with the Iranian names Nima and Sina and virtual musical instruments (a xylophone and a drum). The Nima robot was used to teach and play different notes and rhythms on the xylophone, Sina was programmed to play/teach music notes on a drum in the virtual environment (Fig. 1). The player/participant needed to use a headset and two controllers, as mallets, to play these instruments in the virtual class. Different music-based scenarios were designed in this virtual class to improve the joint attention, (fine) imitation, and social skills of ASDs (Kalas 2012; LaGasse 2014).

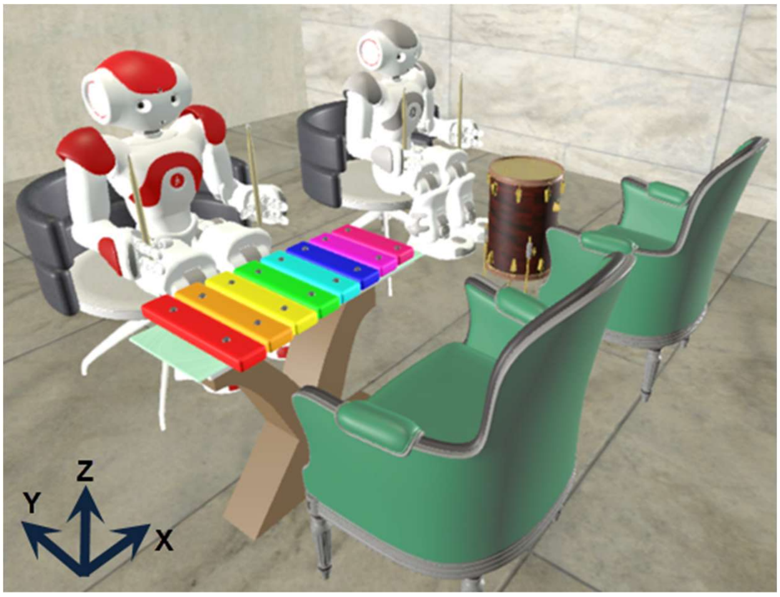


Fig. 1. Snapshot of the VR room, a perspective view of the virtual room, robots, and instruments.

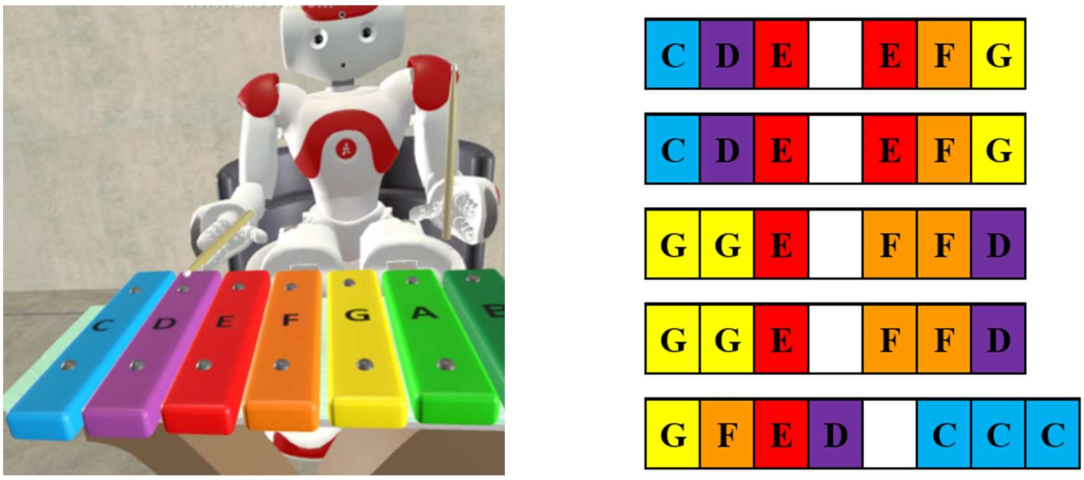
2.3 Experimental Setup and Intervention Protocol

This study was conducted at the Social and Cognitive Robotics Lab at SUT using an HTC VIVE virtual reality headset in the presence of the child, one human teacher, and an operator in a Wizard of Oz style control. The single-subject design method was used to perform the clinical music education interventions, including baseline, pre-test, post-test, and follow-up sessions. The program included 8-10 clinical intervention sessions (about 15-20 minutes each week), and a post-test session followed the last music session. A follow-up session was held two months after the last session to assess the persistence of the training. The performance of the children during the sessions were recorded by a video camera and screen recorder software. After holding the training sessions, the next step was to analyze the results of the children's performance during the treatment sessions.

Because the children participating in the baseline sessions were able to properly imitate the virtual robot and showed a suitable ability to play single, double, and triple notes as well as were able to recognize the colors of the xylophone bar, a higher-level musical instruction was provided for the intervention sessions. In this regard, musical notes, and playing simple pieces of music and melodies were selected as the main scenarios for clinical intervention sessions in the music education section (Fig. 2).

Fig. 2. Snapshots of the VR music education intervention session: the subjects trying to play a piece of music.

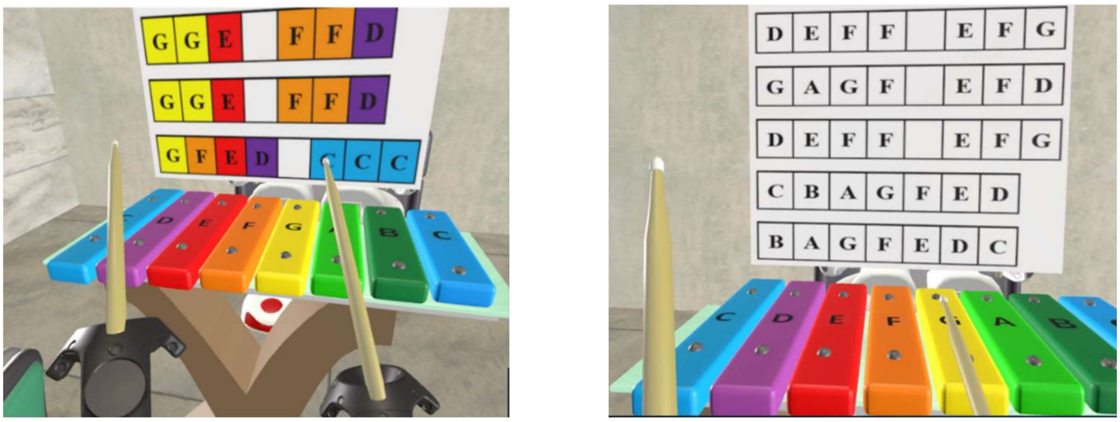
The music training intervention sessions started by teaching seven main notes (Do (C), Re (D), Mi (E), Fa (F), So (G), La (A), Si (B)) to the child using a virtual robot (Nima). The robot taught these notes to the child by playing them meticulously and then ask the child to accompany and imitate him carefully to learn and play the notes in order, using the mallet and also saying the corresponding sound simultaneously to make memorization easier (Fig. 3-a). The child's accuracy in performing the notes was automatically measured and evaluated by the robot.



(a) (b)

Fig. 3. a) The Nima robot teaching the note D (Re) to the child. b) An example of the sheet music of the song "Shab shode" selected for a test melody.

In the next sessions, it was time to perform musical melodies. A set of easy-to-difficult hierarchical music assignments (simple melodies and music phrases) found useful by the music teacher was presented by the robot (Fig. 3-b). The Nima robot first played the notes of the music phrase and then asked the child to play the notes in order according to the melody sheet music placed in front of him. The child attempted to play the relevant note correctly by looking at the sheet music and observing the order and intervals specified in it. In the first step, the sheet music contains both English letters and the color of the notes, and after passing this level, the color of the notes was removed from the sheet so that the child could become first more familiar with and then easily remember the musical letters on the xylophone (Fig. 4). The criteria for passing an exercise and moving on to the next harder task was to correctly play that exercise at least 50% of the performed time. The robot interacts with the child during different scenarios to help the participants improve their performance.



(a) (b)

Fig. 4. Using the controllers as mallets to play music phrases. a) Initially, the sheet music contains both English letters and the color of the notes. b) Then, the sheet music contains just the English letters.

2.4 Assessment Tools

In this research, several types of assessment tools were used to study the effectiveness of the education for children with autism spectrum disorders. These tools included psychological tools (questionnaires) and human assessment.

First, human assessments were conducted by psychologists four times at the Baseline, Pre-Test, Post-Test, and Follow-up. These assessments included 1) examining the children's ability to recognize/express colors, 2) performing the Stambak Rhythmic Structures Reproduction Test (Fig. 5) to assess the children's musical skills (Gardner 1971), and 3) a quantitative/qualitative evaluation of the children's social and cognitive skills, focusing on imitation skills and joint attention (extracting items from the Early Social Communication Scales (ESCS) (Pouretemad 2011)).

Fig. 5. Snapshot of the Stambak test in the follow-up session.

Second, four questionnaires, the 1) Autism Social Skills Profile (ASSP) (Bellini and Peters 2008), 2) Gilliam Autism Rating Scale (GARS) (Gilliam 1995), 3) Autism Checklist (Corbett et al. 2008), and 4) Parenting Stress Index-Short Form (PSI-SF) (Abidin 1990), were completed by the parents at several stages (before and after the treatment period).

Due to the small number of the participated children in this study, actually no significant statistical tests (such as T-test or ANOVA test) could be performed on the results of the questionnaires, scientifically; therefore, the Cohen's d effect size (Cohen 2013) between the Pre- and Post-Tests on the questionnaires is calculated and reported. The Cohen's d effect size might not represent the actual improvement of children's abilities; nevertheless, because of the limited number of the data which makes it impossible to conduct statistical significant tests, it could be used for evaluation of the potentials of the designed V2R program's effects (according to the questionnaires) on the participated subjects. In this regard, we would suggest that the reported results of the questionnaires' effect sizes would be considered as the preliminary exploratory findings.

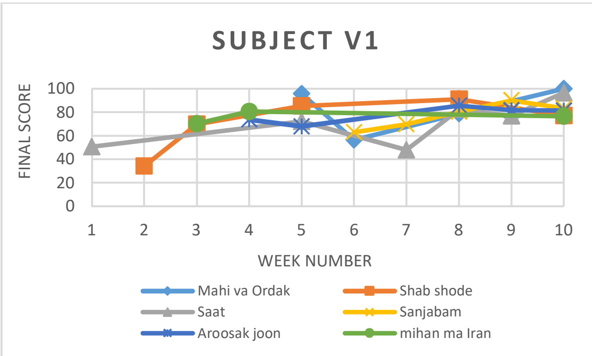
Third, content analysis worksheets of session videos were completed by two therapists to evaluate and quantify the children's behaviors. The qualitative and quantitative criteria for scoring consisted of having a continuous focus on playing the melody, the accuracy of playing the desired bars, using the correct hand to play each note, observing the time interval between playing different notes according to the instructions, observing the continuity and accuracy of the child's performance. By watching a video of the child's performance in the virtual environment, the child's behavioral details in performing the musical tasks were assessed and accurately scored. The final score for each subject is a normalized score indicating his performance and reports the sum of the subject's quantitative and qualitative scores.

Forth, the kinematic data (position and orientation) of the headsets and controllers in the virtual environment were recorded with the aim of automatic evaluation to study the imitation and joint attention of the child during the treatment sessions. These data were recorded during training and clinical intervention sessions, and the child's performance during exercises was monitored by automatic assessment algorithms.

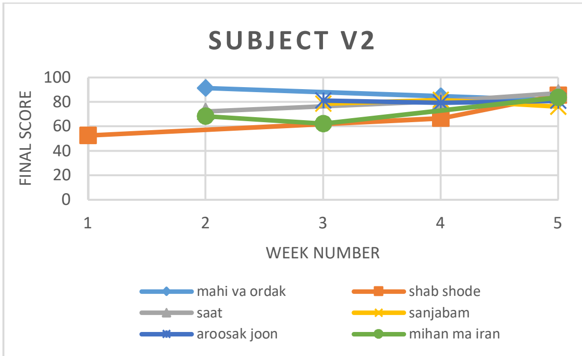
3 Results and Discussion

Clinical intervention sessions of about 20 minutes were held every week. In each session, the previous week's learned melodies were played by the subject, and the melody of that session, according to the schedule, was played by the robot. Thus, at the end of the music training sessions, several scores were recorded for each of the different musical phrases by two therapists as video coders in the different training sessions. These scores indicate the educational progress of the child in the virtual musical exercises in various sessions, including the training and test sessions (Pre-test and Post-test). A selected melody, not taught by the robot, was played by the subject in the pre-test and post-test sessions to measure and validate the subject's performance.

Since the single-subject design method was used for this study, the performance of each subject in the clinical intervention and follow-up sessions and the obtained scores for the different melodies are individually presented in separate graphs (Fig. 6 a-e). Depending on the cooperation of the subjects, two or three melodies were played in each session; therefore, by the end of the sessions, each melody was played between one to six times.



(a)



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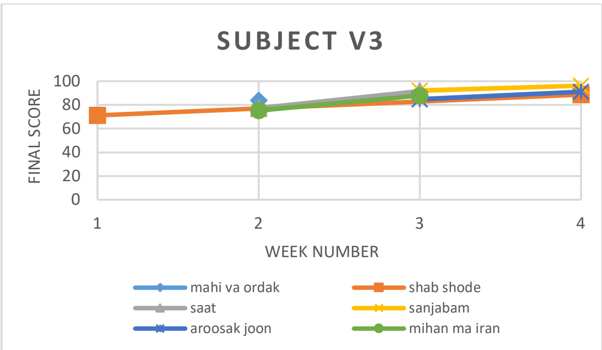

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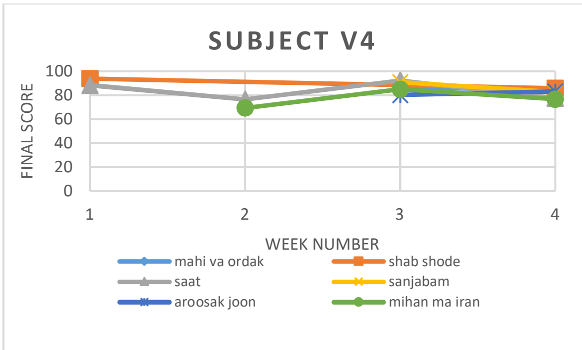

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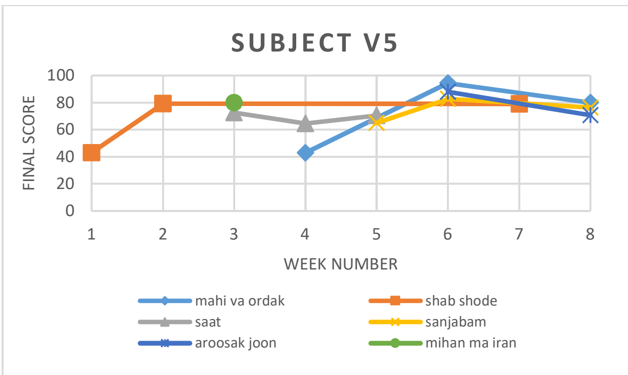


(e)

Fig. 6. The scores were obtained by the subjects (V1 –V5) for the six melodies (shown in different colors) during the intervention sessions. These different melodies were selected at the discretion of the music instructor in a set of music assignments with easy-to-difficult hierarchical levels to teach the way of playing music sentences/phrases, to the children with autism during the program. The scores of each participant in each melody are presented in this figure: a) Subject No. 1 (V1), b) Subject No. 2 (V2), c) Subject No. 3 (V3), d) Subject No. 4 (V4), and e) Subject No. 5 (V5). Participants' cooperation was varied in this study, but the performance of most subjects in playing the taught melodies generally improved during the training sessions. V1 was present in all of the

intervention and follow-up sessions actively and played the most number of phrases in comparison to the other subjects. He played each of the music phrases 5 or 6 times. Subject No. 3 (V3) were not as active as V1, however, he received high scores in the class exercises and showed an increasing trend in his performance during the course of the program. Similar to V1, V5 was also present in all of the intervention sessions. Subject No. 4 (V4) was an exception who received high scores in most of the sessions (in the same level), however it seems that his appropriate performances were because of the ceiling effect and no significant performance improvement had been seen for this participant is reported by the human teacher.

The expected progress trend for each melody was that the performance score would increase during the training sessions and decrease in the follow-up session. This trend can be seen in the diagrams for most of the melodies. For example, as Fig. 6a shows, Subject number one's (V1) score for the melody Shab shode displayed a gradual increase in the training sessions and a slight decrease in the follow-up session in comparison with the post-test session.

Furthermore, we evaluate the performance of children in the music exercises by analyzing the controller's kinematics data that were recorded automatically during the intervention sessions. We designed a machine assessment algorithm in order to assess the quality of playing different notes and music exercises by each participant. In Figure 7 the kinematics data of the right controller for Subject No.3 (V3) is shown which represents the participant's performance while playing different music exercises in the post-test session. The video coding results were positively Pearson's correlated with the proposed automatic assessment in the intervention sessions (r = 0.81, P = 0.04), which illustrates the high potential of automatic assessments for evaluating the performance of participants.

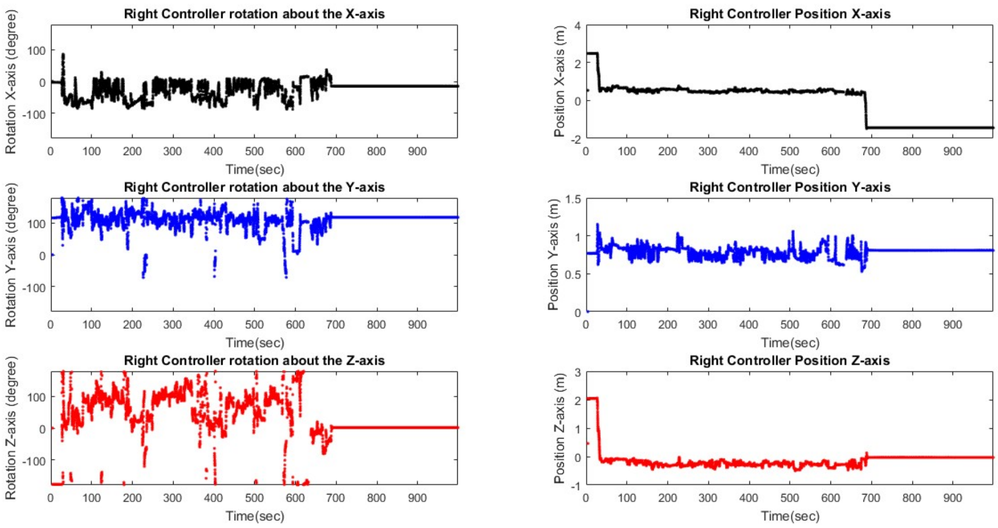


Fig. 7. Right controller rotation angles and positions versus time for Subject V3 in Post-test session.

Although human assessment has higher quality due to the careful focus of by the therapist in studying the participant performance, the automatic assessment would help us to assess more data in lower time with acceptable accuracy and reliability by using advanced artificial intelligence algorithms. Therefore, regarding the third research question, the automatic assessment would be a proper method for evaluating the performance of subjects in a virtual reality environment and these sessions could be handled using such algorithms.

One of the items examined in the pre-test, post-test, and follow-up sessions was the ability to play a test music phrase, the melody ("Shab shode"), which, while not taught in the training sessions, was similar to the other taught melodies.

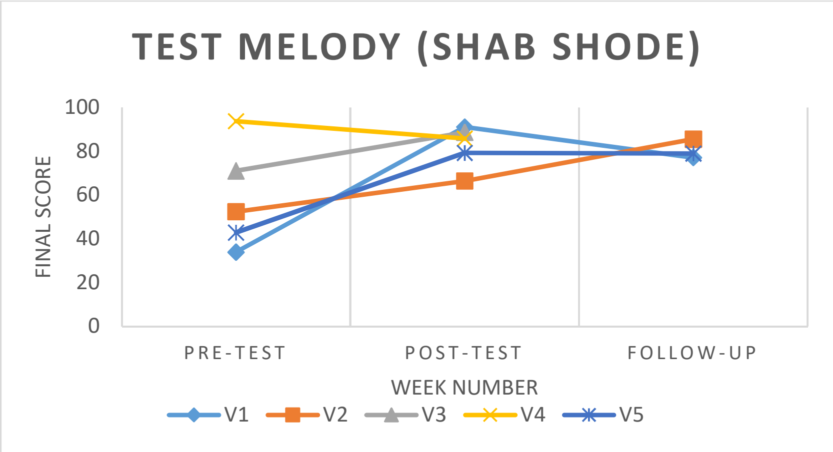


Fig. 8. Score of the test melody for all subjects in the pre-test, post-test, and follow-up sessions.

As shown in Fig. 8, the performances of two subjects (V1 and V5) follow the expected trend, meaning that the score of the post-test is higher than the pre-test, and a score reduction is reported in the follow-up session due to the passage of time. However, we observed a significant increase in the follow-up session score for Subject (V2). The other two participants, (V3 and V4), were absent for the follow-up session. The score of Subject (V3) had improved in the post-test compared to the pre-test, but Subject (V4)'s performance had decreased in the post-test due to his absences and lack of cooperation.

To study the effectiveness of the intervention sessions on each subject separately, we conducted statistical analyzes. Due to the small number of participants, we categorized the available data for the tests in such a way that we could perform the appropriate statistical analyzes. In this way, we had more suitable data in different categories for statistical analysis. The statistical studies performed in this research are explained in the following section.

We considered five methods for data classification to do statistical analysis on the data recorded in the first half and the second half of the training sessions: 1) Dividing musical assignments into difficult and simple groups, 2) Studying the effectiveness for one of the subjects with the most cooperation, 3) Studying the effectiveness for all subjects in all assignments, 4) Studying the effectiveness for a particular melody, and 5) Studying the differences between subjects participating based on their performance in all musical exercises in these sessions.

In the first analysis, the musical phrases were divided into two categories, difficult and easy. This division was done according to the length of the musical phrases and the difficulty of playing consecutive notes in each phrase. Based on this division, the "Fish and Duck" and "Shab shode" melodies were considered simple melodies. According to the music teacher, these two melodies were among the simpler and shorter melodies taught to the children in the first sessions. Other melodies were considered more difficult melodies. Applying this classification, sixty-two difficult melodies and twenty-five simple melodies were obtained from all subjects. Then, we divided the simple and difficult exercises into two categories according to the session number (the first half of the sessions and the last half). In the next step, we performed a Two-Sample T-test analysis using Minitab software (Minitab 2010) to study whether there was a significant difference between the subjects' scores in the first and second halves of the training sessions for difficult and simple tasks.

In the second analysis, we examined the effectiveness of training for one subject (who was the most cooperative during the research) in the second half of the sessions as compared to the first half for both difficult and the total tasks. Twenty-eight data were available on his performance in the music classes, twenty of which were difficult tasks and suitable for statistical analysis. We used a T-test analysis to determine if there was a significant difference in the subject's performance between the first and the second half of the sessions.

The third analysis was done on all of the recorded data for all of the participants. At this stage, we studied the effectiveness of virtual reality training using the scores of all tasks for all subjects done in the second half of the sessions compared to the first half to determine if there were any significant differences. Twenty-eight tasks were performed in the first half and 59 tasks were performed in the second half, which is a suitable amount of data for statistical analysis. In the fourth section, we used a T-test to determine if there was a significant difference between the performances of all subjects in playing a specific melody (which was played more than the others) in the first half of the sessions compared to the second half of the sessions.

In the last analysis, the differences between different subjects participating in the music education sessions were studied to answer our research question of if there is a significant difference between the subjects' performance, participating in this research. The analysis method was the One-Way ANOVA analysis performed in Minitab software (Minitab 2010) to figure out whether the difference between the average performance of different subjects was significant or not. The results of the statistical analysis are shown in Table 1.

Table 1. The results of the statistical analysis of the subject's scores.

Numb	Research Topic	First half Avg	Last half Avg	T-value	P-value
1	Difficult tasks for all subjects	68.8 (±15.5)	81.5 (±8.3)	3.27	**0.004**
2	Easy tasks for all subjects	74.3 (±12.9)	82.0 (±9.3)	1.62	0.125
3	Difficult tasks for subject (V1)	64.8 (±17.0)	80.1 (±9.7)	2.22	**0.058**
4	All tasks for the subject (V1)	69.1 (±16.0)	80.3(±10.0)	1.99	0.068
5	All tasks for all subjects	70.8 (±14.0)	81.6 (±8.5)	3.63	**0.001**
6	"Shab shode" melody for all subjects	66.1(±21.0)	82.0 (±8.4)	1.97	0.081

P-values greater than 0.05 show significant difference between the two groups of the scores. The P-value of 0.058 could be considered marginally significant.

From the results of the statistical analysis presented in Table1, it can be concluded that there is a significant difference between the performance of the subjects for difficult melodies in the first and second half of the sessions (for example, subject V1's p-value is 0.004). However, for simple melodies, there is no significant difference between the score's average. This is most probably due to the ceiling effect. Due to the simplicity of simple melodies, the subject was able to play an acceptable percentage of the melody without any problems in the initial sessions, but the children had essentially the same performance in the final session, showing little progress, so no significant difference was observed.

However, the difference between Subject V1's melodies scores performed in the first half of the sessions compared to the second half was in the meaningful boundary. The p-value was 0.058 for difficult tasks and 0.068 for total tasks, and both were in the significant boundary. As a result, with a little approximation, it could be concluded that the performance in difficult tasks in the first half of the class was significantly different from the second half for Subject V1, indicating the effectiveness of the training sessions with virtual reality technology.

The p-value for all of the exercise scores obtained by the participants was equal to 0.001, which illustrates that the difference between the average scores of the first half and the second half for all subjects was quite significant, and as a result, we can conclude that the training conducted by virtual reality technology was effective. By reviewing the results of the statistical analysis, regarding the first research question, we indicated that VR can be effective for children with high-functioning autism to learn the music systematically and improve their musical abilities.

Furthermore, the difference between the performances of the subjects in playing a particular melody (Shab shode) during both halves of the training sessions was studied, and the results (see Table 2) showed no significant difference, with a p-value of 0.08. Since this melody was considered a simple melody which was played more than the other music phrases, we also expected there not to be a significant difference.

Table 2. The results of the statistical analysis of all exercises for all subjects.

Avg for V1 score	Avg for V2 score	Avg for V3 score	Avg for V4 score	Avg for V5 score	T-value	*P*-value
76.3(±13.5)	77.1 (±9.3)	85.4(±7.9)	83.6 (±6.6)	71.9 (±14.2)	3.36	0.014

In the next step, one-way ANOVA analysis was performed to determine if there was a significant difference between the performances of all subjects participating in this research. Table 2 shows that the p-value of the one-way ANOVA test was equal to 0.014, showing a significant difference was observed between the performances of the subjects participating in this study. This significant difference between their performances was predicted since the subjects differed in terms of the severity of their autism spectrum, their cooperation in performing tasks, and their patience and tolerance in playing musical phrases. Fig. 9 graphically compares the subjects' performances with each other, and the average score and standard deviation for each subject are shown.

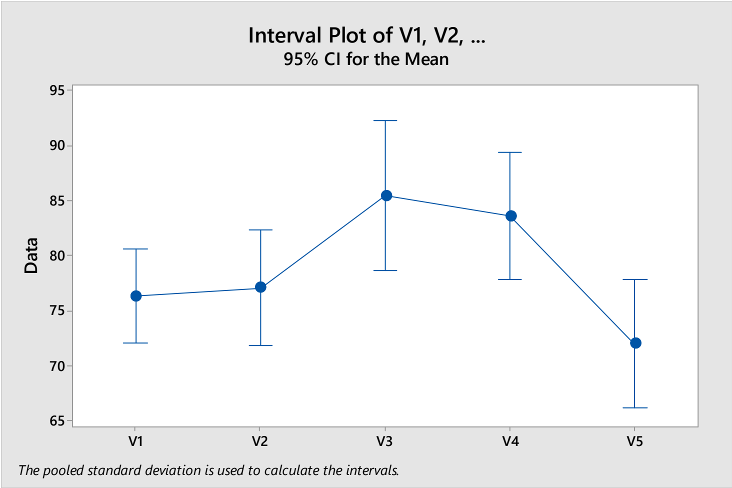


Fig. 9. The subjects' performance for all music exercises during the intervention sessions.

3.1 Human assessment

3.1.1 The Stambak Rhythm test

To investigate the differences between the subjects over time in the temporal structure, the test of Stambak auditory rhythm structures was taken. This test contains twenty-one easy to hard level musical rhythmic actions and the results of this test were presented in three stages: baseline, pre-test, and post-test (Fig. 10).

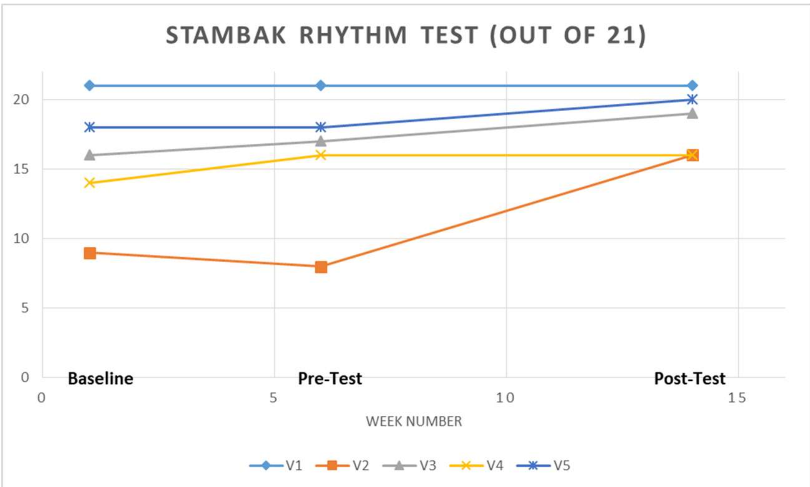
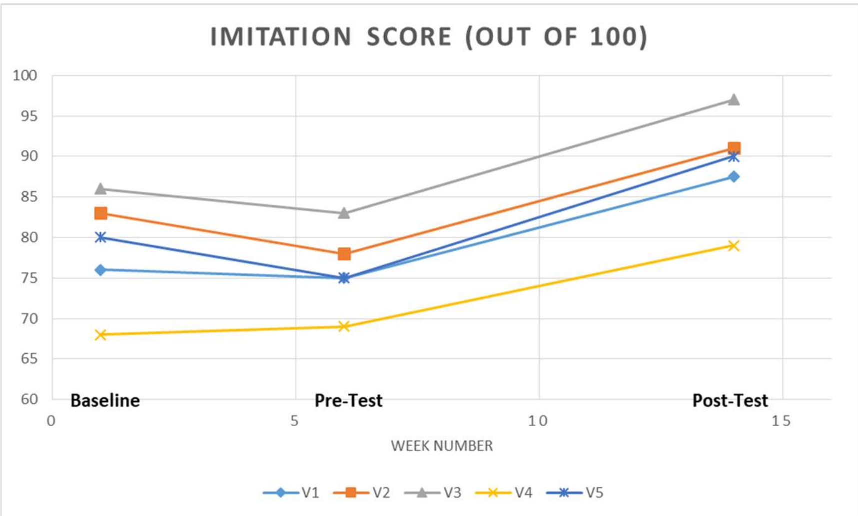


Fig. 10. The results of the Stambak Rhythm Test for the subjects at the baseline, pre-test, and post-test.

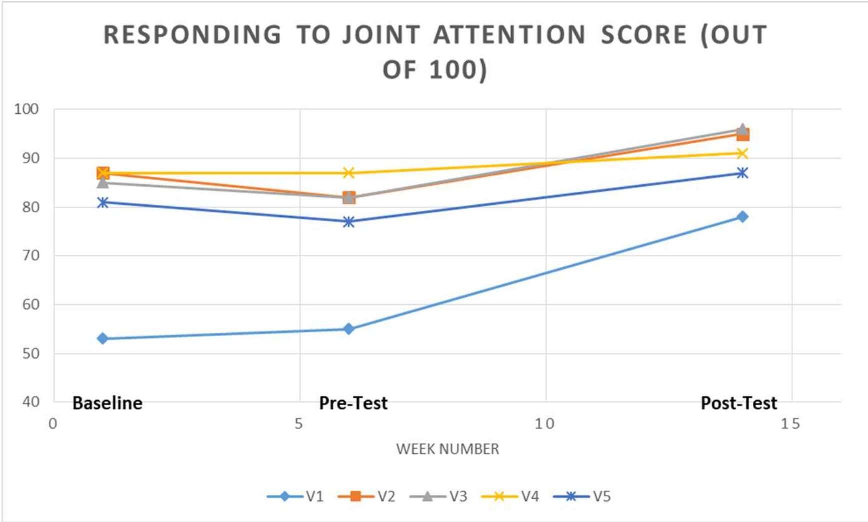
Except for Subject V1, who achieved a perfect score on the baseline test with an outstanding performance, all four other participants, albeit to a small extent, showed progress in playing the rhythm. At the end of the sessions, the children were able to use both hands consecutively in playing the correct notes in the motor imitations section; they used only their superior hand in the initial sessions. Improvement in children's rhythmology can regulate the body's internal rhythm and have a positive effect on walking, speaking, and even writing (Cordell 2000). As a result, we can conclude that virtual robots have the ability to teach musical notes to children with autism.

3.1.2. Assessment of socio-cognitive skills

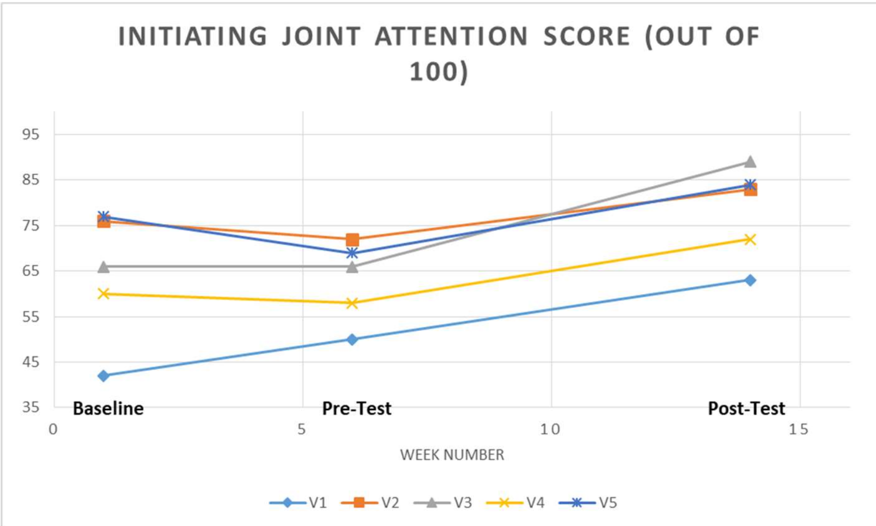
Using the example of the ESCS test and imitation assessment tests in Applied Behavioral Analysis (ABA) classes, 30 tasks for each subject were selected from the three stages (baseline test, pre-test, and post-test) to assess the social and cognitive skills of the participants. The presented items were used to study the children's skills in understanding instructions, turn-taking, social reciprocity, gaze-shifting, joint attention, and gross and fine imitations. Each task was performed 2 or 3 times by each child. Finally, after coding and analyzing the videos of the human assessment sessions, the percentage of the child's success was calculated as his / her performance score for all the imitation situations or the joint attention that was placed in the assessment session. Figs. 11a to11c show the subjects' imitation scores, response to joint attention (RJA), and initiation of joint attention (IJA). According to Figs. 11a to 11c, the performance process of all five children participating in the imitation and joint attention tasks improved from the pre-test to post-test (at an interval of 8 weeks), while the baseline and pre-test scores (5 weeks apart) are reported at almost the same level.



(a)



(b)



(c)

Fig. 11. Different scores for the subjects at the baseline, pre-test, and post-test: a) imitation scores, b) RJA scores, and c) IJA scores.

3.2. Questionnaires

As mentioned in the previous sections, this study was single-subject design research and we focused on each child's progress separately. All questionnaires were completed four times during the 22 weeks (including first baseline, pre-test, post-test, and follow-up test) by parents to assess changes in the children's socio-cognitive skills.

3.2.1. The Gars questionnaire

The Gars questionnaire (autism syndrome) was completed four times by the children's parents, and the results are shown in Fig. 12. It should be noted that higher scores on this questionnaire indicate greater severity of autism. According to the parents, the subjects had a mean score of 73 in the pre-test. After clinical interventions, four children showed a decrease in autism syndrome from the pre-test to post-test; however, the rate of reduction in the Gars scores varied for the subjects.

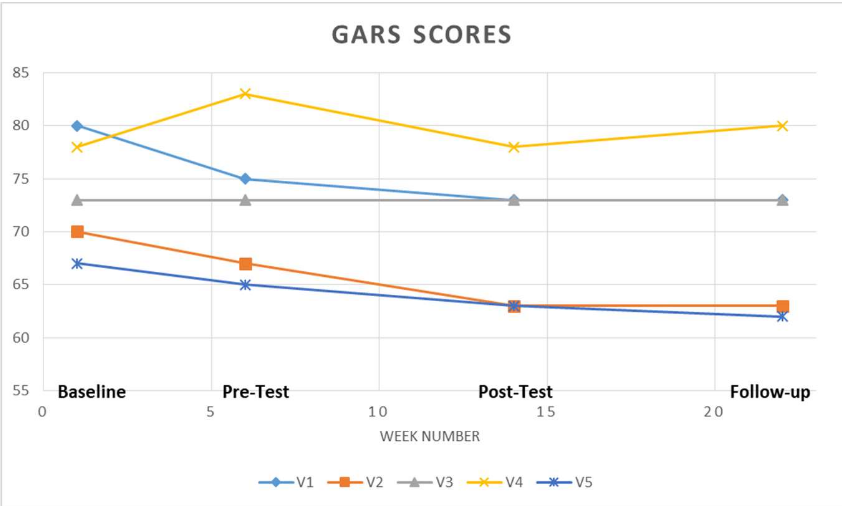


Fig. 12. The Gars scores as filled in by parents for the subjects at the baseline, pre-test, and post-test.

According to the result, a total of three children showed an upgrade in scores from the pre-test to the post-test on the social interaction subscale. Clinical sessions based on virtual robots seem to have a promising effect on the socio-cognitive skills of the participating children, resulting in a reduction of their autism. The protocol implemented in this educational-therapeutic program contained various imitation and joint attention tasks; it has been shown that the development of imitation skills and an increase in the joint attention of children with autism can significantly affect their social and communication skills. A comparison of the participant's result in the post-test with the follow-up test showed the persistence of the results of technology-based clinical interventions for 4 out of 5 children after two months.

3.2.2 The ASSP questionnaire

The results of the ASSP questionnaire are presented in Fig. 13. All the children's social skills improved from the pre-test to the post-test. Of course, the rate of each child's development varied from the others. This finding is consistent with the results in other music-based research (Werry et al. 2001; Robins et al. 2005; Taheri et al. 2019; Taheri et al. 2018).

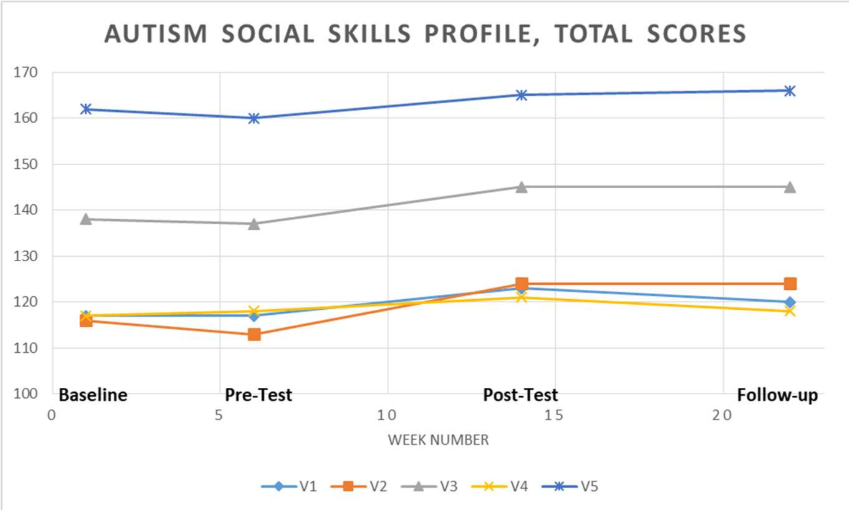


Fig. 13. The ASSP scores as filled in by parents for the subjects at the baseline, pre-test, post-test, and the follow-up test. According to the graph, it is illustrated that the ASSP scores have been improved from the pre-test to the post-test session for all of the subjects. It should be noted that the participants' scores remained in the same level from the base-line to the pre-test sessions. Moreover, no significant difference has been shown between the results of the follow-up sessions with the post-test sessions. This finding is in line with the expected trend in such studies which states that the performance score would increase in the training sessions and remain in the same level (or somewhat decrease) in the follow-up session. For better interpretation of the results, the scores are studied in the three main subscales of the questionnaire (i.e. Social Reciprocity score, Social Participation/Avoidance score, and Detrimental Social Behaviors score) and the effectiveness could be investigated by calculating the Cohen's d effect size. The overall results illustrate slight improvement in the social skills of the subjects.

A review of the subscales of the questionnaire shows that: 1) the Social Reciprocity scores increased for all participants with a mean of 2.0 and an SD of 3.5 except one of the subjects (Subject V3) . 2) The Social Participation/Avoidance score had a slight upward trend (mean 1.8 with a standard deviation of 2.2), and the Cohen-d calculation in this subscale showed that the effect size of this subscale was lower than average. This probably indicates the lack of significant effects of the educational-therapeutic protocol designed on this subscale; and 3) the score of Detrimental Social Behaviors, which had the most change (in particular for Subject V3). As can be seen in Table 3, we observed that this educational-therapeutic program decreases socially harmful behaviors in the children, this would be denoted with a high effect size (Cohen-d value 0.68).

A systematic overview of the basic principles of reciprocal imitation programs has shown that putting children with autism in imitative situations can lead to higher participation in activities and games and increased social responsibility and joint attention (Moghim Eslam et al. 2013). It was observed that the scenarios based on imitation and joint attention in this training course had a positive effect on the social interactions of the children in this study.

Also, comparing the total scores of the ASSP test from the post-test to the follow-up test showed the persistence of the effect of a virtual robot-based educational program on the social skills of the participating children.

3.2.3 The Autism checklist questionnaire

The results of the Autism Checklist questionnaire are given in Fig. 14. The total score of this questionnaire for all children participating in this study increased (slightly) during this rehabilitation period (mean change was 1.8). The highest improvement was recorded for the low-functioning child (V1). The lack of major changes in the high function participants is due to the ceiling effect, and also having only three options for questions in this questionnaire.

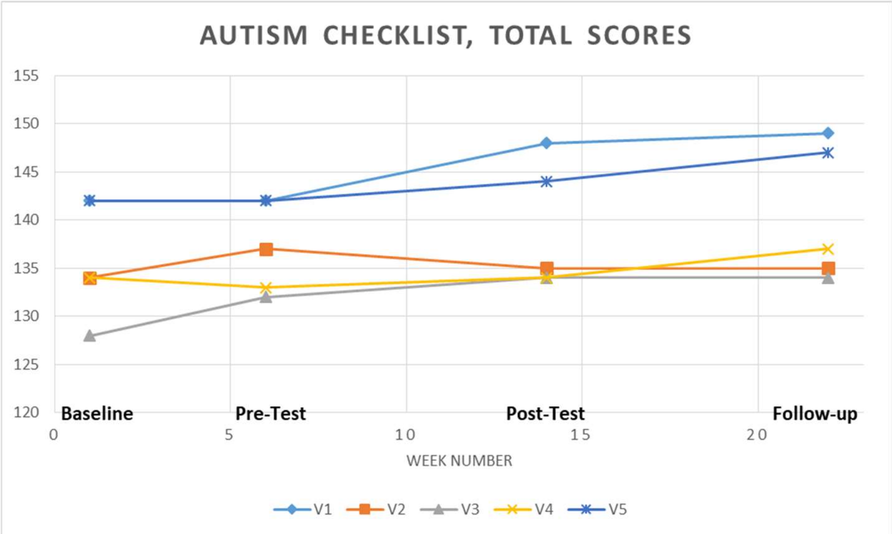


Fig. 14. The Autism Checklist scores as filled in by parents for the subjects at the baseline, pre-test, post-test, and the follow-up test. The Autism Checklist scores have been increased from the pre-test to the post-test session for all of the subjects except subject V2 and the highest improvement was recorded for the participant with low functioning autism (i.e. V1). The ceiling effect is the main reason for the minor changes in the performance of the high functioning participants. Furthermore, having only three options for questions in this questionnaire could be another cause for the slight progress. By studying the scores in the four main subscales of the questionnaire (i.e Verbal, Language, and Communication score Socializing score, Sensory or Cognitive Awareness score, and Physical and Behavioral Health score), the results were interpreted in more details and it was illustrated that no significant improvement had been obtained by the subjects in these subscales.

A closer look at the scores of the Autism Checklist Questionnaire provides the following additional information:

1) The score of the “Verbal, Language, and Communication” subscale did not change for any of the high-performance children in this study. In other words, on this subscale, we encountered the ceiling effect, the mean and standard deviation of the changes in the scores of this subscale are 0.2, and the effect size is low (Table 3).

2) The scores of the subscale “Socializing” for three subjects increased by a not so significant average (the mean and standard deviation of the scores of this subscale was 0.6).

3) In the score reported by the parents on the scale of “Sensory or Cognitive Awareness ", only the low function child has shown improvement and other children haven’t progressed because of the ceiling effect.

4) The scores of the subscale “Physical and Behavioral Health" had the least change among all subjects in this study. In other words, the designed educational-therapeutic program did not affect this subscale and probably does not have the capacity to improve this field. The Cohen-d values for this section were also low.

3.2.4. PSI-SF

A shortened questionnaire, consisting of 36 questions, was completed four times by the mothers to evaluate the effect of clinical interventions with virtual robots on their stress level (Fig. 15). It showed that from the pre-test to the post-test, the major stress of the mothers of the children undergoing the educational-therapeutic technologies was reduced. The highest stress reduction during the training period was reported by the mother of Subject No. 5 (V5).

Since the participants were in kindergarten or elementary schools, the mothers had expected them to learn the music alphabet easily, and each child's minor improvements during music education had little effect on parental stress. Hence, Cohen’s d effect size of this questionnaire was small. It should be noted that the nature of the results of this questionnaire also depends on the mother’s mood at the time of filling in the questions, and the increase in the mothers' stress score was probably due to other issues in her life or an unfamiliarity with the questions in the first place.

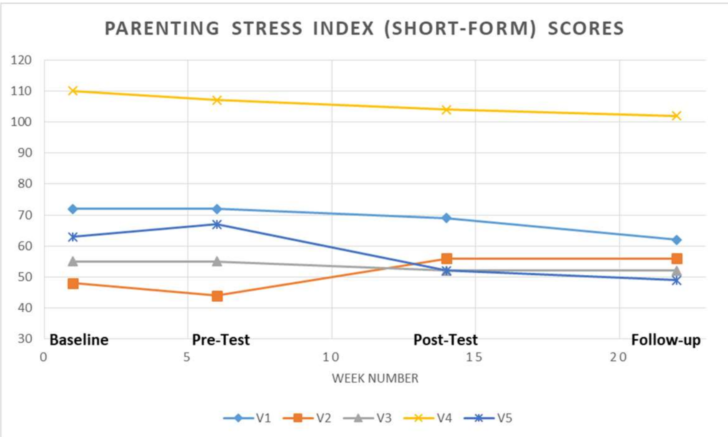


Fig. 15. The PSI-SF scores for the subjects at the baseline, pre-test, and post-test filled in by parents.

In summarizing the topic of the questionnaires, it is necessary to pay attention to the fact that during the relatively short period of four months of clinical interventions, one should not expect miraculous changes in these children. For this reason, as observed, the change in performance scores of autistic children and their parents in the four questionnaires presented was mostly small, although this small amount is valuable.

Based on the result of the video coding and the proposed automatic assessment system, we concluded that our virtual music teaching setup using virtual reality robots has a high potential of teaching musical notes to children with ASD. Our findings indicated that the virtual robot-assisted music classes can potentially improve participant’s rhythmology and can teach them music rhythms recognition and reproduction. Several studies indicate that this improvement could have a positive effect on an individual's body movements, body language, and speaking during their interactions (Srinivasan et al. 2016).

Cohen’s d effect size was calculated in order to evaluate the results of the used questionnaires (Table 3). Because of the small number of subjects participated in this study, no significant statistical tests could be conducted; consequently, the Cohen’s d effect size (which is independent of the study’s sample size) between the Pre- and Post-Tests on the questionnaires were calculated which represent the effect size by comparison of the two means and standard deviation (i.e. between the Pre- and Post-test scores). Cohen suggested that d = 0.2 (or less than this value) be considers as a "small" effect size, 0.5 represents a "medium" effect size, and 0.8 (or more than this value) shows "large" effect size (Cohen 2013).

Table 3. Cohen's d effect size between the Pre-Test and Post-Test scores of the questionnaires.

Questionnaire	Subscale	Participants Score
Autism Social Skills Profile (ASSP)	Overall Score	0.34
	Social Interaction	0.18
	Social Participation/Avoidance	0.32
	Detrimental Social Behaviors	**0.68**
Autism Checklist	Overall Score	0.31
	Verbal, Language, and Communication	0.16
	Socializing	0.20
	Sensory or Cognitive Awareness	0.06
	Physical and Behavioral Health	0.27
GARS	Overall Score	0.38
	Stereotyped Behaviors	0.39
	Communication	0.16
	Social Interaction	0.33
PSI-SF	Overall Score	0.10

It should be noted that Cohen's d = 0.2 (or less) is considered as a "small" effect size, Cohen's d = 0.5 (or around) represents a "medium" effect size, and Cohen's d = 0.8 (or more) shows "large" effect size. The Cohen's d value of more than 0.65 which shows approximately the effect size of "close to being large" is shown in bold.

According to our observations in this study, musical education classes using virtual reality robots can potentially improve the musical ability and performance of children in playing melodies, but we detected slight improvement in the social and cognitive skills of children with autism in this research due to the low Cohen's d effect size in the questionnaire's items. Based on the Cohen's d effect size in Table 3, only the Detrimental Social Behaviors subscale in the ASSP questionnaire has a medium Cohen's d effect size and other subscales have small effect sizes. Conducting this research for a small number of children with high-functioning autism and high cognitive ability in comparison with low-functioning autism, a small number of training sessions, designing simple musical interventions which involves just simple social and cognitive skills, and the ceiling effect for the presented education in the intervention sessions are just some of the actual reasons for the minor improvement of participants' cognitive skills in this research. However, it is important to be noted that none of the participant's performances have been decreased during these intervention sessions and harmful effects hadn't been reported.

Shahab et al. (2017) reported that their music-based virtual reality environment was only acceptable and applicable for the participants with high functioning autism and their subjects with low functioning autism were not got engaged systematically in their program. On the other hand, the music tasks designed in this study are similar to the clinical interventions of social robots for children with autism by Taheri et al. (2019) with various music-based tasks and high potentials for cognitive rehabilitation of children with cognitive impairments (especially for children between 5 to 7 years old). However, due to the ceiling effects regarding the participants' initial cognitive levels in this study, the children's social and cognitive performances have improved slightly during the course of this program based on the Cohen's d effect size calculated in the questionnaire's items. The participants with high functioning autism learned the musical tasks easily and got high scores for the musical assignments during the intervention sessions. Consequently, it can be concluded that the use of the virtual reality robots for children with high functioning autism can be socially and cognitively effective if the tasks and exercises' design become more complex regarding social and cognitive skills. As a result, we can conclude that with appropriate design of V2R games based on the proper cognitive and social skills in more time periods of education, not only the educational ability of the participants improve, but also these games have the ability to be used for social and cognitive rehabilitation of children with high (or even middle) functioning autism. As a summary, in this study, by considering the potentials of music education and virtual robot-assisted intervention sessions for participants with autism, we combined the mentioned two paradigms to propose a virtual educational and therapeutic environment to present variety of cognitive and educational tasks and situations for subjects with ASD and to explore the preliminary exploratory impacts of the designed systematic virtual educational environment on our participants with autism.

4 Limitations and future works

The main limitation of this study was the small number of participants. There were some limitations in the selection of proper subjects for this research. First, the subjects needed to have high-functioning autism, and secondly, he/she should be about seven or eight years old to be able to cooperate properly with the virtual reality system. Furthermore, we had an unbalanced sample size of male/female participants in the subject group (all participants were male). In addition, the lack of similar papers in the literature was a limitation to compare the outcomes of this study with other related researches. Moreover, the children were sometimes less cooperative during certain exercises due to the length of some of the melodies or because the participant became impatient during a session, resulting in fatigue, and they achieved lower grades. Also, the short time of each intervention session (maximum of twenty minutes) was another limitation of this study. In addition, in this research, it is concentrated on the effects of the overall VR robot-assisted music-based education on the subjects with ASD and in this stage, it is impossible to determine the ratio of positive findings (especially regarding the music education of the participants) regarding the V2R's attendance and the music tasks, separately. Having no control group in this research was another limitation of our study.

In future work, the effect of this technology on cognitive rehabilitation of children with autism would be studying more systematically. We would like to design our next research to overcome as much as the problems and limitations we faced/mentioned in the current study so as to have a more comprehensive conclusion on the designed program's impacts on children with autism. After conducting this study, we believe that the direction of the engineering activities in using virtual reality technologies in education and rehabilitation should seriously tend towards empowering educational virtual robots in the following two categories: "automatic/self assessments" and "adaptive teaching".

Future educational virtual reality robots should have more robust an reliable ability to assess the child's performances automatically and report it to the teacher/human therapist during the sessions, as well as adapting the treatment protocol according to the child's condition and performances' history. Such next clinical intervention studies would be conducted by considering more intervention sessions with a higher number of participants (e.g. with at least twelve subjects) including children with high functioning autism with a balanced sample size of males/females. The scenarios and assignments which would be designed for the games conducted in the intervention sessions should be more socially and cognitively complex to have the potentials to improve the high level skills of the participants (even have positive impacts on children' theory of mind). In addition, these interactive games in the VR simulation environment should have an attractive and entertaining design with engaging audio-visual appearances, so that the child does not get bored and impatient during the assignment. Also, we would suggest that if the participant would not be in the desired situation (based on his/her parents or teacher's report), the data of that session is excluded in the study. All in all, the results of such proposed future researches would help the autism community to study the effectiveness of VR technology for children with autism more accurately.

5 Conclusion

This study aimed to evaluate the idea of using virtual robots in active music education sessions and study the effectiveness of using virtual reality robot in intervention sessions. The positive results observed in this initial study promise that virtual reality technology would be effective in the rehabilitation of children with autism spectrum disorders. The results of this study showed that the ability of children to play musical phrases during the second half of the sessions was significantly different from the first half of the sessions. Also, by dividing the tasks into difficult and simple tasks, we found that there was a significant difference in the subject's performance of difficult tasks between the first half of the sessions and the last half of the sessions. However, there was not a significant difference in the simple tasks because of the ceiling effect. This significant difference and the evaluation of the children's performance during the sessions by both video coding and automatic assessment method indicates the effectiveness of the virtual reality technology in increasing the ability to play musical phrases of children with autism spectrum. Nevertheless, we didn't observe any significant improvement in the cognitive skills of the children who participated in this research since a ceiling effect occurred during the educational program. Additionally, we observed that each child's performance was significantly different from the other. This means that we were able to determine the differences between participants with different degrees of autism, another important achievement of this study.

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Conflict of interest Author Alireza Taheri and Ali Meghdari have received research support from Sharif University of Technology and the "Cognitive Sciences and Technology Council" (CSTC) of Iran, respectively. The authors Mojtaba Shahab, Mohammad Mokhtari, Azadeh Shariati, Rozita Heidari, and Minoo Alemi declare that they have no conflict of interest that is relevant to the content of this article.

Ethical approval Ethical approval for the protocol of this study was provided by the Iran University of Medical Sciences (#IR.IUMS.REC.1395.95301469).

Availability of data and material All data from this project (results of questionnaires, scores of performances, videos of sessions, etc.) are available in the archive of the Social & Cognitive Robotics Laboratory.

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