Social Virtual Reality Robot (V2R): A Novel Concept for Education and Rehabilitation of Children with Autism

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***Abstract*—In this paper, we have presented a novel virtual reality setup with the ability to teach music to children with autism as well as perform automatic assessment of their behaviors. This setup contains *Social Virtual Reality Robots* (*V2Rs*) and virtual musical instruments (i.e. xylophone and drum). After conducting a game-session pilot study, we observed that the acceptance rate of the virtual reality headset is about 65% among children with autism, while all of the typically developing children attending the session used the headset. Furthermore, using statistical analysis, it is indicated that the performance of children with autism in music assignments was significantly weaker than their typically developing peers; consequently, the designed V2R music-based game has the potential for autism screening.**

Keywords— Social virtual reality robots (V2R), music education, autism spectrum disorders, imitation, joint attention

I. Introduction

Autism Spectrum Disorders (ASD) are characterized by deficits in social interactions, communications, imaginative abilities and the presence of repetitive behaviors [1, 2]. A common method to decrease the behavioral problems associated with ASD is to use game-therapy techniques. This type of treatment involves focusing on the child's interests [1, 2].

Virtual Reality (VR) is an artificial computer environment that can be used to match the needs of individuals with autism disorder problems like abnormal stimulus-response to the real world. The benefits of using virtual reality appear well matched to the requirements of learning tools for individuals with ASD [3, 4]. A study on two adolescent boys with ASD conducted by Parsons et al. reported the potential of virtual environments (VE) as a promising tool to improve social skills and knowledge in people with autism [5]. They designed a virtual café and a bus environment as a gathering place for individuals. Findings showed that there is a very helpful response to the VE from the users.

By means of virtual reality, a safe environment can be prepared for participants to experience different tasks before approaching them in their real lives. Josman et al. designed a virtual road for children with ASD to test their ability to safely cross the road [6]. Their findings showed significant progress in the children's ability to cross a virtual street during the study. Additionally, a virtual environment was designed by Fornasari et al. to find stereotyped behaviors of children with autism [7]. The results demonstrated that children with ASD have more repetitive movements compared to the control group. According to previous studies, virtual reality has been widely used for teenagers with ASD to improve their social/cognitive skills. However, the lack of VR studies for younger participants is still a serious gap in the literature.

In addition, other studies have shown the effectiveness of using technologies like robots, computer software, and virtual reality to help ASDs improve their social skills [8, 9]. In [8], the authors have attempted to find out the features of social skills in technology-based studies for children with autism. During their review, they have found that initiating conversation is the most common skill addressed in the literature. In [9], it is mentioned that socially assistive robots can seriously encourage individuals with autism to develop social skills. Further studies revealed that technology based interventions are often useful in the treatment and education of children with autism and seems appealing to them [10, 11]. The effectiveness of using a humanoid robot (like the *NAO* robot) as a therapy assistant to reduce the suffering and pediatric distress in children with cancer has been studied by

Alemi and Meghdari et al. [12]. Briefly, positive response to the presence of a social robot in autism research has been reported in detail in [9]. Taheri et al. used the *NAO* robot and found progress in social skills intervention and reduction of stereotyped behaviors in a pair of seven-year-old twin brothers with autism [13].

Alternatively, music teaching/therapy is another common method in education/rehabilitation of children with autism [14]. Several studies indicate that music therapy is helpful at facilitating non-verbal social skills and improving communicative behaviors in children [15, 16]. It appears that using social robots in therapy sessions has a promising effect on involving children to more effectively take part in conversations and the learning process. The relationship between using a social robot in order to teach fundamentals of music to children with ASD has been studied by Taheri et al. [17]. They reported the presence of a robot in intervention sessions positively affected fine motor imitations, communication skills and even the the autism severity of the participants. Nevertheless, to the best of our knowledge, there is no VR study on systematic music teaching/training to subjects with autism.

In this paper, we have presented a novel concept in education/treatment of children with autism by combining the above three mentioned items: virtual reality, social robots, and music training. The main idea behind the contribution of this study is to investigate whether or not *Social Virtual Reality Robots* (*V2R*s) could be appropriate tools for situations where real robots are not available. Therefore, the first challenge is to study the acceptability rate of such VR scenarios for children with ASD. To this end, in this research, a *V2R* music-based game is conducted for two groups of ASDs and typically developing (TDs) children younger than 7 years old. By evaluating the performance of both groups, we wish to explore the potential of using *V2R* as a supplementary method in virtual music classes for children. .

II. Research Methodology

A. Participants

Fourteen children with autism (Mean: 4.9, SD: 0.83 year old) and 21 typically developing children (Mean: 5.0, SD: 0.9 year old) between 4-6 years old participated in this study. They were named as ASD-01 to ASD-14, and TD-01 to TD-21, respectively.

B. Designing the Social Virtual Reality Robots (V2R) Environment

We have designed a virtual realty environment for teaching music and rehabilitating children with autism consisting of a room in which one can practice playing xylophone and drum. The ultimate goal in designing such music-based scenarios is to improve joint attention, (fine) imitation, and social skills of ASDs [14-16, 18, 19].

The robot characters (with Iranian names *Nima* and *Sina*) from our previous study on social robots and music education/therapy [17] are presented in this virtual room. Fig. 1-a shows the virtual room environment, robot characters, and virtual musical instruments. We have been careful so that the room decorations used in our virtual environment will not misdirect the attention of the participant.

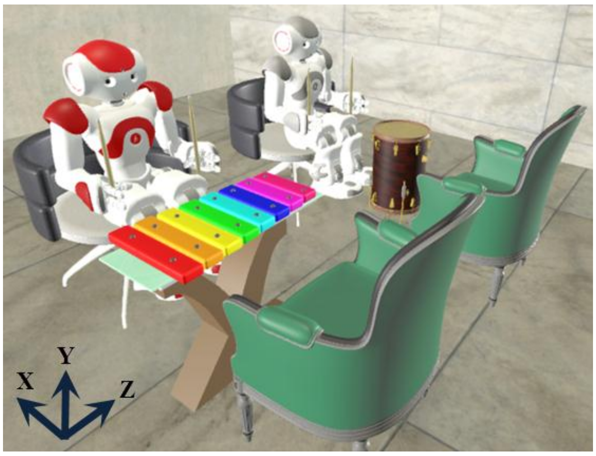
The Virtual Reality Setup used in this study is the VIVE by HTC [20] and the graphics of the environment are designed in UNITY 5 software. The components of our virtual room are presented as follows:

1) *Two virtual humanoid robots (Nima and Sina)*: The *V2R*s have the identical shape and face of the commercial humanoid robot *NAO* [21]. In [17], we successfully used a real *Nima* robot to teach music to children with ASD in Iran *Nima* (the gray robot) and *Sina* (the red robot) are programed to play/teach music notes/rhythms with a xylophone and drum in the virtual environment. They interact with the child during different scenarios while they applaud or help the participants improve their performance. The *V2R*s are able to state a collection of prerecorded voices for better interaction quality.

2) *Virtual Xylophone/Drum*: The virtual xylophone has eight color bars which have the same sound of a standard xylophone. There is also a virtual drum in the room which sounds like a real drum. The virtual musical instruments are placed in front of the *V2R*s. VIVE Controllers are used as mallets by the children to play the xylophone/drum.

3) The *Room Environment and Decorations*: there are four seats in the middle of the room. In addition, four pictures are hung (one on each wall) on the walls. These pictures are of a chick, car, football player and the Azadi Tower (a well-known tower in Tehran, Iran). Similar to the Early Social Communication Scales (ESCS) instructions, these pictures are used to assess the joint attention skills of the participants.

Our application uses the participant's visual-attention tracking of different objects as well as analysis of imitation accuracy/agility during the sessions for behavioral assessment of the children



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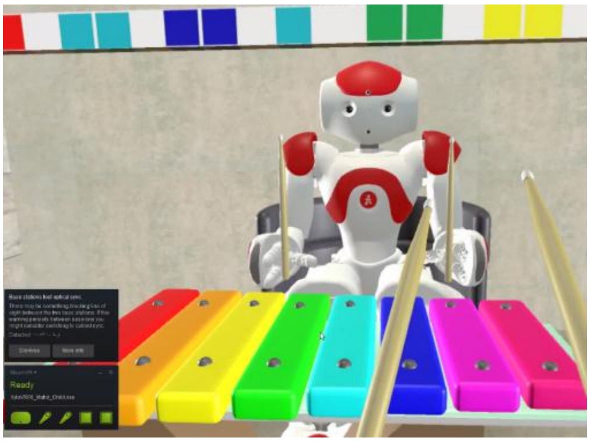


(b)

(c)

Fig. 1. Snapshots of the VR room: a) perspective view of virtual room, robots, and instruments, b) *Sina* robot asks the child to play a music phrase, and c) points to the pictures on the walls.

C. Experimental Setup and Study Protocol

In this study, each participant was asked to individually attend a *V2R*-assisted music-based game for one session in a Wizard of Oz (WOZ) control style study. In WOZ experiments, robots' movement and speech are controlled remotely via an operator. A teacher and a game operator were also present in the room. The performance of the children during the sessions were recorded by two video cameras. One of the cameras was used to record the occurrences in the virtual room by filming the computer monitor. The other camera located in front of participants captured children's actions and voices during the sessions. The game included three items: 1) imitating *Nima* in playing the virtual drum, 2) imitating *Sina* in playing the virtual xylophone, and 3) responding to *Sina* pointing to different pictures in the virtual room.

In the first part, each child was seated in front of the monitor without a headset and took the VR controllers (as the mallets); the virtual *Nima* robot greeted the participant and showed him/her how to play the virtual drum. Then five assignments including 2-/3-hit tasks with different arrangements of the leftand right hands were played for the participant (Fig. 2-b). Next, the *Nima* robot asked the child to wear the virtual headset and get engaged in playing the xylophone. If the child resisted using the headset, the game continued in the same manner as the first part.

In the second part, the *Sina* robot introduced himself as well as the musical instrument and taught the child how to make sounds using the mallets. Next, a set of easy-to-difficult hierarchical music assignments were presented by *Sina* in order. We had 16 short music exercises included tapping the desired colors and different 1-/4-hit tasks. Moreover, a music phrase consisting of 14 notes was considered as the long exercise in the xylophone part of the session; the notes' colors were shown on the screen and the child had to play them in order after the robot (Fig. 1-b). The second part of the game could be stopped if the child refused to continue or he/she could not complete four consecutive tasks.

In the third and last part, the *Sina* robot asked the child to describe what he/she could see in the virtual room. As mentioned earlier, in addition to the robots, instruments, and the chairs (which were obviously visible on the headset/monitor), there were four pictures on the walls of the virtual room. It is expected that curiosity will lead some participants to discover these elements. However, if they could not find the pictures the robot points to those images (Fig. 1-c) and the children's response to these joint-attention situations (RJA) is observed

D. Assessments

In this study, we have investigated the acceptance rate of the designed game as well as the time duration of being involved in two conditions of using/not-using the headset for both ASD and TD groups. The scores of the children in the drum/xylophone-based tasks were rated by a video coder. Responding to joint attention scores and the total number of verbal communication with the *V2R*s were also rated for each subject. Each participant gets a predefined score for each of his/her correct task/hit.

III. Result and Disscution

A. Acceptance Rate of the V2R-assisted Game

Based on the protocol design, the *V2R*-assisted game was conducted for all 35 participants. Figs. 2 show some snapshots of these sessions. With regard to the limited amount of head-mounted virtual reality-based studies on ASDs, one of the most interesting finding of our study (which was not anticipated) was the acceptance rate of 64.3% by the ASD group in playing the designed game while using the virtual headset. Regarding the overall acceptance (i.e. using or not-using the headset), 11 out of 14 of the participants with autism took part in the game for more than 3 minutes, which indicates that the game was accepted by 78.6% of the ASD group. In addition, 100% of the subjects in the TD group used the headset for playing the game. Nineteen out of 21 TD subjects claimed that they preferred playing the game in wearing the headset mode; however, due to the lack of verbal skills/perception of the ASDs subjects, their preference mode could not be identified. We could conclude that the game was appealing for the participants. Similar to this observation, da Costa et al. [22] reported high interest of the subjects and considerable acceptance of virtual reality devices for cognitive rehabilitation. The high acceptance rate is a signal that the *V2R*-assisted game does have good potential to be used as a commercial application for children wishing to learn music. Fortunately, with the use of a secure (similar to [6]) and stationary chair there was no danger of the participants falling down, getting injured, etc. during the sessions.

(a)

(b)

Fig. 2. Snapshots of the game session: a) a child is playing the xylophone using the headset, and b) a subject is playing the drum without the headset.

B. Performance Comparison of ASD and TD Groups

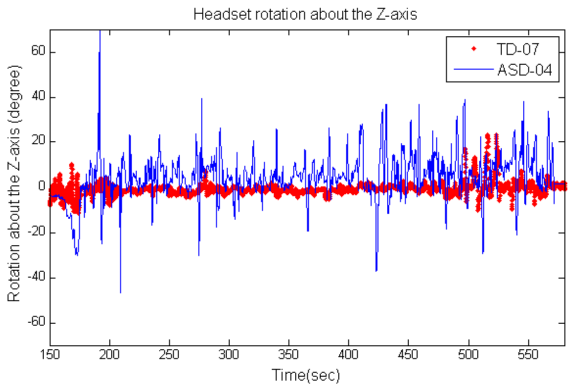
Applying 2-sample t-test statistical analysis using Minitab software [23], we observed significant difference between the scores of the ASD and TD groups in the drum imitation tasks, xylophone imitation assignments, RJA behaviors, verbal communication scores, and the time of using the headset, respectively (see Table I). The observations of this section could be a sign of our games' potential in assessing/screening of children with autism among their typically developing peers. In the current study, the maximum score of the overall tasks was 89; therefore, according to the mean values of each group, it is expected that a *V2R*-assisted music-based scenario has the potential to teach music to both ASD and TD groups. This assumption was investigated/confirmed during our previous study in using real social robots to teach music to children with autism [17]. Although the positive effects of having real robots in autism treatment cannot be ignored [9], the designed *V2R*-assisted game could be an appropriate, low-cost, safe, and user-friendly educational/treatment tool for the situations where real robots are unavailable (such as homes). To now, we are still unable to answer whether the probable learnt music knowledge by children through such *V2R* games could be generalized to real musical instruments. It could be mentioned that the designed music tasks' difficulty level was hierarchical and even the TD participants (with no music background) faced challenges in getting very high scores.

TABLE I. THE MEAN AND STANDARD DEVIATION SCORES OF THE ASD AND TD GROUPS IN DIFFERENT ITEMS OF THE CONDUCTED GAME AND THE P-VALUES ASSOCIATED WITH THE T-TESTS; P-VALUE <0.05 SHOWS THE 95% CONFIDENCE INTERVAL.

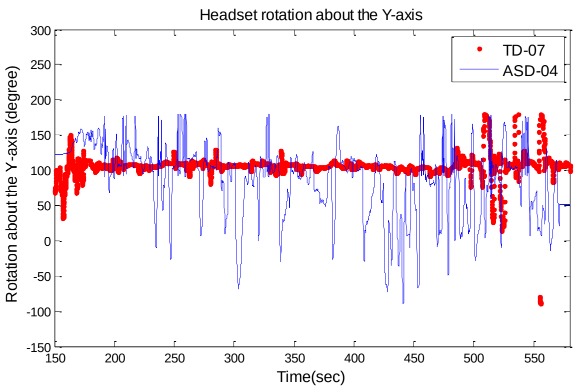
No.	Item	Scores' Mean (SD)		P-value
		ASD group	*TD group*	
1	Drum Score (out of 11)	2.93 (3.58)	5.86 (3.42)	0.023
2	Xylophone Score (out of 66)	5.57 (8.16)	33.8 (14.1)	0.000
3	Total Music Score (out of 81)	10.4 (13.4)	45.2 (16.0)	0.000
4	Curiosity and RJA Score (out of 4)	0.64 (1.01)	2.905 (0.301)	0.000
5	Verbal Communication with Robots Score (out of 4)	1.29 (1.64)	2.619 (0.921)	0.013
6	Total time of the game (in second)	464 (266)	654 (109)	0.023
7	Time duration of wearing the headset (in second)	231 (238)	525.5 (83.7)	0.000

A close look into the positions/orientations data of the virtual headset/controllers shows us an interesting difference in the dynamic performance of ASDs and TDs. In the following, some performance samples of the participants in gaze-shifting, performance in playing the music assignments, and responding to the robot's pointing are presented.

Figs. 3 represents the different patterns of the children's gaze toward the objects in the virtual room for ASD-07 and TD-04 (two subjects with moderate total scores). The head pitch and yaw angles of the headset is recorded during the sessions to investigate the gaze-direction and joint attention skills of the participants. TD-04 mostly looked at *Sina* and the xylophone to do his tasks; and after the robot's pointing, he turned his head to see the pictures on the wall according to the game schedule (between t=500 to t=550 (s)). However, ASD-07 did not pay enough attention to the robot and its instructions, and he showed a variety of head movements (looking at the ground, walls, and roof). Significant differences between the temporo-spatial gaze patterns of ASDs and TDs in dynamic situations have been widely reported (such as [24]).



(a)



(b)

Fig. 3. The head angles of participants' TD-07 and ASD-04 versus time; high attention of the TD subject toward the assignments versus low-attention of the ASD subject, a) head pitch angles, and b) head yaw angles.

After analyzing the controller's kinematics data, we found that some ASDs stereotyped behaviors could be extracted from the recorded data. As an example, Fig. 4 shows that the hands' fluttering behavior of an ASD subject throughout the captured kinematics data. ASD-09 did not actually cooperate and showed no interest in the game.

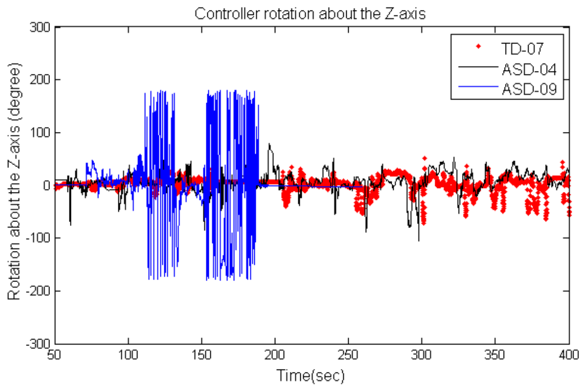


Fig. 4. Controller rotation angles versus time; meaningless stereotyped behavior of ASD-09.

The recorded data of the controllers and headset illustrates the high potential of the designed virtual reality setup in the field of automatic assessment of cognitive parameters (such as imitation and joint attention) for autism screening. It should be noted that in our analysis, the kinematics data has been omitted in case the participants removed the headset.

C. *Limitations and Future Works*

Due to the small number of our participants, the limitations of this study were neglecting the autism severe heterogeneity of the ASD subjects as well as the unbalanced sample size of the male/female participants in ASD and TD groups.

Now knowing the considerable acceptance rate of the designed game, the next step of this study is to conduct step-by-step/systematic music teaching interventions [17] during (at least) 10 sessions on a group of children with autism to investigate the effectiveness of the *V2R*-based treatment on their music ability and social/cognitive skills. Thanks to the game's behavioral assessment feature, the music tasks' difficulty can be automatically adapted to the children's performance over the duration of the music education lessons. Based on Table 1, the time duration of the sessions can be set to ~15 minutes. Moreover, (as an estimation of their 3-D gaze dynamics) the head direction/orientation of ASDs and TDs' could be investigated/compared more completely in dynamic interactions of the designed *V2R* environment.

IV. Conclusion

Nowadays, virtual reality has found various applications in a growing number of fields in different branches of science. In this paper, we have introduced a novel application of this technology called *Social Virtual Reality Robots* (*V2Rs*) for music education/therapy and rehabilitation of children with autism. In this game, two virtual robots were used to play music-based assignments by interacting with children in an attractively safe virtual room. One of the advantages of this game is that the music class can be held without using a real robot, thereby saving crucial time, cost and energy. It is indicated that the designed *V2R*-assisted game was accepted by all of the typically developing children, whereas, more than 60% of children with autism agreed to use the virtual headset. Therefore, through this preliminary exploratory study, one can conclude that virtual reality is a viable instrument for educating and rehabilitation of children with autism (especially for high-functioning subjects). Moreover, using this game the children's performance can automatically be recorded for online/offline behavioral assessment. This kinematics' data can be used to assess imitation and joint attention skills of children with autism. Since the performance of the ASDs is highly distinguished from the TDs, the *V2R* setup can be used as a helpful tool for screening of children with autism.

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