An Interactive Tangram Game For Children With Autism

Beatriz Bernardo[1], Patrícia Alves-Oliveira[2], Maria Graça Santos[3], Francisco S. Melo[1], and Ana Paiva[1]

[1] INESC-ID and Instituto Superior Técnico, Universidade de Lisboa
[2] INESC-ID and Instituto Universitário de Lisboa (ISCTE-IUL), CIS-IUL, Lisboa
[3] Centro de Desenvolvimento da Criança, Hospital Garcia de Orta, Almada, Portugal

Abstract. This work explores the use of a social robot as an assistive agent during therapy sessions, in order to assist children with Autism Spectrum Disorder (ASD), through a Tangram puzzle game. Our aim was to develop a tablet game, so that children with ASD could play with a humanoid robot - NAO. This experiment has two conditions: the Tutor Mode - the robot gives help whenever the child needs; and the Peer Mode - the robot plays with the child in turn-taking. Eight children with autism participated in this study. The results showed that, in the Tutor Mode, the robot was capable of stimulating children's attention towards the game and to assist them most of the times. In the Peer Mode, the robot also stimulated children's attention to the game. Moreover, in this mode, the robot was able to establish turns for the majority of the participants.

Keywords: Social Robot, Autism, Children, Human-Robot Interaction

1 Introduction

Autism is a complex behavioral disorder that is characterized by behavioral impairment in social interaction and communication, and the presence of repetitive patterns of behavior or interests [1]. However, people with autism may present difficulties at other levels, such as cognitive disabilities, avoiding eye contact with others, diminished attention, and deficits in pragmatic skills (e.g., turn taking).

The interest in robots by children with ASD has instigated the majority of the research work in this area. The Aurora Research Project is an excellent example of how robots can be integrated into therapy sessions for improving communication and social interaction skills in these children, through collaborative and turn-taking games with different robots [12]. The use of robots in these cases induced a predictable and controlled environment, favoring a less frightening situation. Furthermore, some studies such as ECHOES [3] and Join-In Suite [13] showed that children with autism are fascinated by computers, tablets, and other electronic devices and also that screen-based games can be adopted in therapy sessions, in order to enhance children's abilities.

Turn-taking is one of the most important social skills required in everyday life (e.g., for developing friendships, communicating with others and playing games).

Children with ASD have difficulties in taking turns as they are described to interrupt a speaker improperly and having difficulties conducting conversations [2]. Nadel [10] concluded that imitation, turn-taking, and recognition of conventional social patterns are a basis for developing social skills and understanding others' intentions. Thereafter, the turn-taking skill is crucial for these children so that their social skills are improved. Thus, part of our work focuses on improving this ability.

The puzzle developed in this work was the Tangram, that consists of seven pieces with different geometric shapes with the goal of creating numerous silhouettes. It is a puzzle usually played during therapy sessions by children with autism. This led us to choose this game. The Tangram has the capacity to improve several skills, such as imagination, visuospatial, logical, concentration, geometric spatial thinking, and mathematics knowledge [7]. However, it is not an engaging game and children's enthusiasm has to be stimulated. Clements [4] stated that recreational devices such as computers may increase the children's level of engagement in learning. Thus, we decided to use a tablet version of the Tangram puzzle, together with a social robot - *NAO*[4]. The robot was programmed to function as a Tutor - helping the children through the game, or as a Peer - engaging the children in a turn-taking game. Our aim was not to use the robot to substitute the therapist within therapy, but to serve as an assistive tool.

Finally, we conducted a single-subject study at three institutions. We evaluated eight participants individually during a number of sessions which varied for each participant and compared with the baseline and final results.

2 A Robot Peer for Tangram

Some researchers have discussed that the presence of an excess of details can be over appealing, becoming a factor of distraction, since it leads the children to concentrate on them instead of in the interaction [8]. Thus, it was important to have a simple and distractions-free interface. For this reason, the game interface consists of only three components: (1) the solution area, (2) the pieces, and (3) a home button (Figure 1). During the game, the players have to drag the pieces with their finger to the right places. When all the pieces are in their places, the puzzle is completed. In order for this game to be playable by most children of the spectrum, some settings were added: difficulty levels, rotation modes, distance threshold, and number of pieces. So that children do not lose curiosity about the game over time and to avoid stress, the difficulty must be gradually increased [13]. Thus, a Difficulty Manager was developed to manage all the game settings. The game was developed in *Unity 5*[5] for Android tablets.

For this project, we decided to use the robot NAO, a social interaction oriented robot, with an anthropomorphic appearance, perfect for interacting with children with ASD as a peer. NAO was our choice for its design, the capacity to

[4] www.aldebaran.com/en/cool-robots/nao
[5] https://unity3d.com/

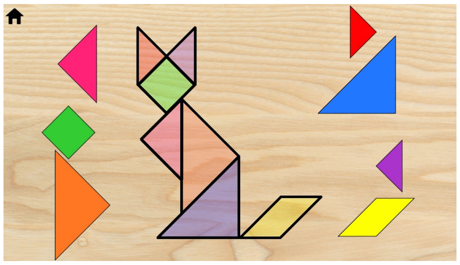

Fig. 1: Game interface easy level and the pieces in the right angle.

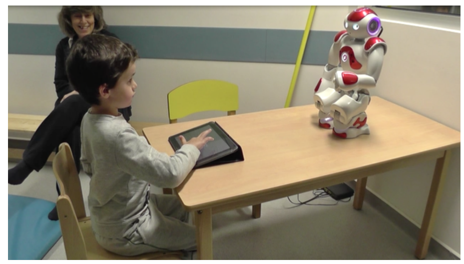

Fig. 2: Child playing Tangram with NAO while the therapist monitors.

provide concrete feedback and the ease of the setup. We used Thalamus [11] as an API to the robot's controls (e.g., dealing with text-to-speech or controlling robot's body), to create a bridge between the robot and the game.

As Bernardini *et al.* [3] discussed, children with autism should receive positive feedback in order to maintain interest and experience a sense of self-efficacy and accomplishment. Besides, visual and auditory feedback make the interaction more appealing and comprehensible. So, whenever the child places a piece in the right spot, the robot gives positive feedback through congratulations and/or other social behaviors (e.g., gestures). Furthermore, children with ASD should not receive overly penalized negative feedback since these children tend to misinterpret this sort of feedback [13]. So, the robot reacts negatively (depending on the number of failed attempts), but only with gestures or a negative word. Once the puzzle is completed, the robot transmits a compliment message towards the child with enthusiastic gestures. Additionally, the tablet evokes a congratulation sound and materializes multiple fireworks upon the completed puzzle. This final reinforcement is mightier than all of the other feedback, to convey the feeling of having reached the final goal. Regarding NAO's utterances, in few of them, the robot mentions the participant's name, in order to act as an acquaintance of the children and to stimulate them when they hear their name. We conducted initial studies in order to analyze the therapist's behavior while children with autism were playing the Tangram tablet game. Thus, NAO's utterances and gestures are based on the behavior of the therapist during these studies.

2.1 Tutor Mode - Prompting

The study has two conditions. The Tutor Mode is the first one and has the purpose of helping and teaching the child during the game. The other is presented in the next subsection. This present condition is adequate for children that have several difficulties playing puzzle games (e.g., motor, reasoning, etc). For this mode we got inspired in the work of Greczek *et al.* [6]. They demonstrated that graded cueing feedback is well suited for most children with ASD. Graded cueing is a method to improve people's skills (e.g., social skills) during therapy by giving them increasingly specific cues or prompts. In our game, if the child insists on placing the piece (1) in the wrong place, or (2) with the wrong angle, the robot begins the prompt system:

- Prompt 0 - no prompts
- Prompt 1 - the agent encourages the child to think about his/her decision;
- Prompt 2(1) - the agent gives a clue about the right spot;
- Prompt 2(2) - the agent gives a clue about the right angle;
- Prompt 3 - the correct spot starts to shine.

Also, there is another prompt system in case the child does not move any piece within a few seconds. These prompts have the purpose of stimulating the concentration on the game:

- Prompt 0 - no prompts
- Prompt 1 - random piece shakes and the agent asks where should it go;
- Prompt 2 - the agent gives a clue about the right spot;
- Prompt 3 - the correct spot starts to shine.

The visual stimulation (i.e., piece vibrating) is another form to maintain the child's focus and interest in the game. In both prompt systems, the game starts at P0 level. If any of the three above options arise, the game goes to P1 level. If after some insistence, it still does not take effect on the child, the agent moves to the next prompt level, and so on. After some time on the P3 level, the robot asks if he or she wants to give up on the puzzle and get a new one with a lower difficulty or if he or she wills to give up playing the game. The agent has to decide what action it should perform in both prompt systems, so that it does not deliver an excess of information to the child. For this, NAO considers the previously provided information and also the current game state (e.g., how many mistakes were made or how long without playing). In addition to these two prompt systems, there are also other types of help (e.g., help moving or dropping pieces).

2.2 Peer Mode - Turn-Taking Game

In the second condition of this study - Peer Mode, the robot plays a turn-taking cooperative Tangram game with the child. It has to establish the turns, teach the child to wait for his/her turn and to incentivize the children to help the other even when it is not their turn. Each time they switch shifts, the robot explicitly says *Now I am playing* or *It's your turn to play* followed by a gesture pointing to the child. If the child tries to play in NAO's turn, the piece will not move, and the robot will repeat that it is its turn. Thus, reinforcing the idea that the child should not play in the others' turn. Children with autism are most often observed to be engaged in independent play. To stimulate child's cooperative capacities, occasionally NAO asks for help in its turn. It can ask the child to touch the place where a certain piece fits. Or it can request the child to rotate a particular piece so that the robot could fit it. Since this method is suitable for children who have mastered the game, the aids provided by the robot are not as specific as in the previous condition. Still, NAO gives some help that corresponds to the P1 and P2 levels of the first aforementioned prompt system.

3 Evaluation

We proposed to explore how a humanoid robot could be incorporated as a tutor or as a peer into therapeutic sessions with children with ASD. In order to do so, we conducted experiments during one month and a half in three institutions. The 8 children chosen by the therapists performed sessions that took approximately 15 to 25 minutes. They involved one child, one therapist, the robot and one researcher (Figure 2). The therapist could intervene if necessary. The children played 4 games in each session, but only if not showing signs of discomfort.

Since children in the spectrum can be so different and present distinct characteristics from each other, we decided to base our study on Single-subject Design [5]. This design is normally applied in studies where the sample size is one, or the individuals can be considered as a single group. This incorporates the *baseline logic* principle: the participants serve as their own control. In single-subject design studies, each participant is exposed to a non-treatment condition, the baseline. This condition consists of repeatedly measuring the performance (target behavior) of a participant before experimental phases. Then, the experimental control is introduced and the target's behavior continues to be observed and recorded in the intervention condition. The session with the therapist (A) and intervention sessions (B) are gradually alternated across time, depending on the design used. In our research, we used the A-B-A design.

Before the trials with each child began, the therapist filled out a form with the child description and his or her autism level according to the ADOS [9]. At the end of each session, the therapist answered the questionnaires upon the interaction. Finally, the researcher visualized the video recordings to collect information. Regarding the task performance, we measured the time to complete the puzzle, the time to place the piece, the turn time, the failed attempts to rotate the piece, the failed attempts to drag the piece, the attempts to place the piece in the wrong place, the attempts to place the piece close to the right place, the attempts during others' turn, the responses to help requests, the number of times he/she realizes it is his/her turn, and the number of helps. The affective attributes towards the robot were measured by the gestures and vocalizations. We also measured the gaze and the number of external interventions.

In the baseline of the Tutor Condition (TC), the participant plays one puzzle of the original Tangram with the therapist, then plays the tablet Tangram game, and at the end, the robot is presented. The child is encouraged to touch the robot in order to feel comfortable with it. Then he/she has 4 sessions with the robot that consist of 4 puzzles played exclusively with NAO. The complexity of the games can gradually increase or not, depending on the performance of the child. Finally, the last session is similar to the first. In the Peer Condition (PC), each participant could perform 2 or 3 sessions with the robot, depending on their availability, performance and the will to continue. The design of this experiment is very similar to the TC, with some exceptions. The baseline consists of 4 games played with the therapist in the turn-taking mode. The intervention sessions are also composed of 4 games with the robot in the turn-taking mode. Lastly, in the final session, the child plays four games with the robot and then plays an additional four with the therapist in turn-taking mode.

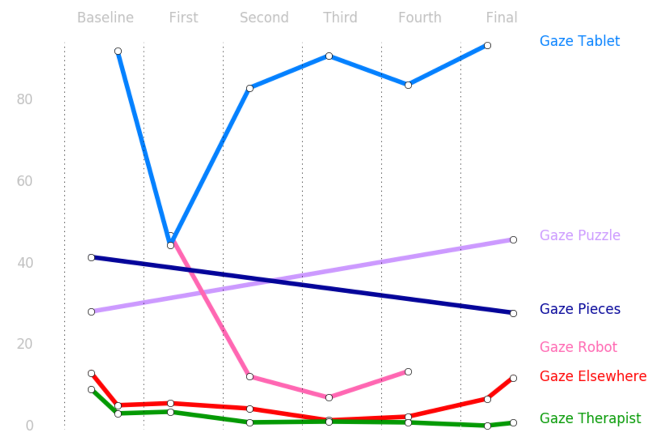

Fig. 3: Participant J.F.: Percentages of eye gaze per session. The baseline and final session have 2 data points each. The first one corresponds to the original game and the last one to the tablet game.

4 Results

This section solely presents the results of 3 participants. The first participant is the only child in the TC and the other two played in the PC. The general results of the 7 children who participated in PC are discussed at the end of this section in order to comprehend if our solution was capable of meeting our objectives.

Participant J.F. J.F. is a 14-year-old boy with severe autism. His linguistic, cognitive, and motor development are strongly underdeveloped. In the **baseline**, J.F. played the original Tangram game. He was not able to finish any puzzle without help from the therapist, especially due to his motor and cognitive impairments. Most of the time he was not concentrated on the game (Figure 3). Then, he played the Tangram tablet game also in the baseline. He has always been very focused on the game and was constantly willing to play another puzzle, even after the end of the session. He laughed and was very excited when he saw the fireworks at the end of each puzzle. Then he met NAO and tried to establish physical contact with it. In the **4 sessions with the robot**, J.F. was always very focused. In the first ones, he seemed to not being able to understand what the robot was saying to him. But throughout the sessions, he seemed more aware to NAO's utterances. An increase in his performance and autonomy was verified over the sessions. In the **final session**, he played 2 Tangram puzzles on the tablet with the therapist almost autonomously. And then played again the original Tangram puzzle. He was able to almost completely finish the original puzzle by himself, which was surprising. Also, he was much more focused on the puzzle than in the baseline (Figure 3). This was tested in just one day, so we can not confirm that this result was due to the games he played on the tablet.

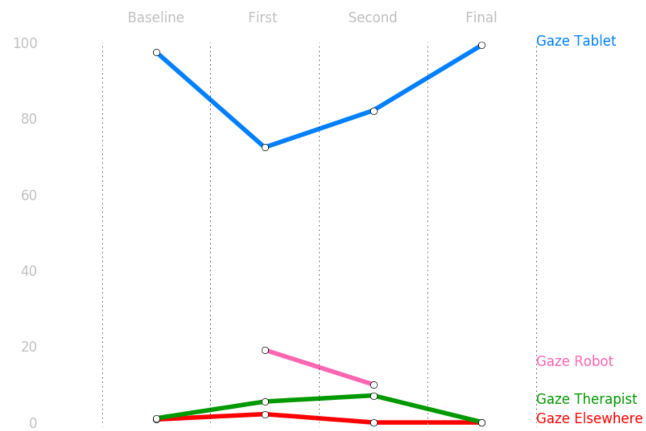

Fig. 4: Participant M.A.: Percentages of eye gaze per session.

Participant M.A. This participant is six years and has moderate autism according to ADOS. M.A. presents a very good cognitive development and also a good linguistic development for his age. In the **baseline**, he was able to complete the puzzles without difficulty. M.A. was focused on the game (Figure 4) and noticed whenever it was his turn. Then, the robot was introduced to the participant. At first, he was not comfortable with its presence, but rapidly got used to it. In the **intervention sessions**, M.A. understood the concept of turn-taking. There was a large number of vocalizations because this participant answered the majority of robot's questions. Interestingly, he began to imitate the robot's requests for help. Since the robot did not respond to his requests, he continued to play. He repeated this behavior over all games, even in the **final session**.

Participant D.B. The last participant is five years old and his cognitive development is below the normal level for his age. He has difficulty in concentrating, taking turns, and focusing on communication. At **baseline**, he did not present many difficulties realizing when he should play. In the **first games with the robot**, he was very concentrated and followed all of its instructions. However, with the advance of the game, he was losing focus on the robot and concentrated

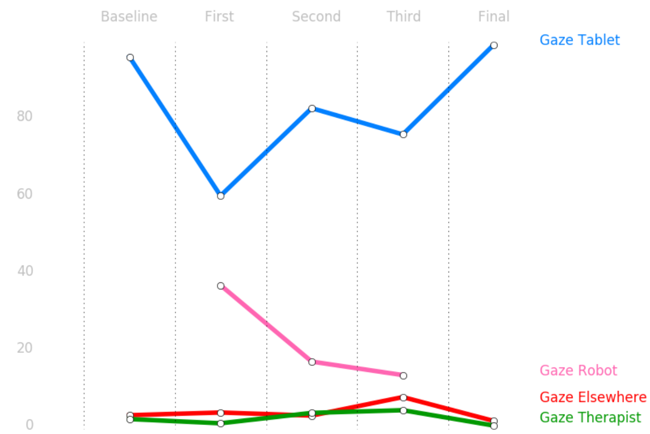

Fig. 5: Participant D.B.: Percentages of eye gaze per session.

only in the game (Figure 5). So he started to play more out of turn and sometimes he did not help NAO (requiring therapist intervention). According to the therapist, this was due to to the fact he did not realize how the robot played (i.e., NAO did not need to touch the tablet to play). But in the **final session** with the therapist, he was more focused and interested again in the game. This was due to the therapist being able to provide more frequent and enthusiastic feedback. It was easier for the participant to realize when it was his turn to play.

Discussion of the Results For most participants in PC, the robot was able to stipulate the turns to play. The two children (one of them was D.B.) who did not have such positive results are also the youngest participants, and so had more difficulty on the turn-taking. Almost all participants processed robot's help requests and promptly helped him, with the few exceptions being due to lack of attention. Over time, all participants improved their performance, as they played increasingly harder games and were able to solve them almost independently in most cases. There was a huge interest in the robot by almost all participants at the first session. However, this interest noticeably decreased over the sessions due to habituation to NAO (Figure 3,4,5). Also, it was surprising to see that all children responded to questions asked by the robot, and some participants (e.g., M.A.) spontaneously imitated NAO's lines. It was really a challenge to transform an uninteresting game into something appealing that could engage all children with ASD. We think this has been achieved, because although none of the participants particularly liked the Tangram, everyone was excited and engaged while playing. However, throughout the sessions, there was a gradual growing disinterest by some of the most experienced participants. This was due in part to the fact that the game always had the same flow and it became monotonous.

5 Conclusion

The purpose of this project was to analyze how engaging a social robot can be to children with ASD during a therapy session. Therefore, we developed a tablet game and programmed a social robot to play with the children as a tutor and as a peer. Two experimental studies were conducted to test the viability of this approach. Overall, the participants in the PC showed little difficulty in taking turns with the robot. Our goal in this condition was to study if the children are as or more autonomous with the robot as with the therapist. Given the decreased number of external interventions and help in the majority, the aforementioned goal was verified. All the participants showed a great interest in the robot and the game. However, the following sessions registered a drastic decrement in the enthusiasm towards NAO. Given the heterogeneity of the autism spectrum, it was not expected that a single methodology would be adequate to all subjects.

With our study, we realized that a few details could be addressed in subsequent work. Regarding the study, a long-term experiment should be done more systematic and replicated with a larger number of participants. These exposures repeated over multiple sessions would allow us to analyze the generalizability and repeatability of our observations. The baseline and the final sessions should also be conducted for several days until results are stable. Regarding the game, there should be a negotiation between the child and the robot in Peer Condition to decide who plays first. Also, NAO's utterances and gestures in the PC should be improved in order to be clearer when the robot is playing and when it is the child's turn. Moreover, so the interest in the game and the robot does not diminish, children non-verbal behavior should be detected (through the camera or sensors), so that NAO could act optimally.

Acknowledgments

This work was partially supported by the Portuguese Fundação para a Ciência e a Tecnologia and the Carnegie Mellon Portugal Program and its Information and Communications Technologies Institute, under project CMUP-ERI/HCI/0051/2013. P. Alves-Oliveira acknowledges a FCT grant ref. SFRH/BD/110223/2015.

References

1. American Psychiatric Association: Diagnostic and Statistical Manual of Mental Disorders (DSM-5®). American Psychiatric Pub, Arlington, VA (2013)
2. Baron-Cohen, S.: Social and pragmatic deficits in autism: cognitive or affective? Journal of autism and developmental disorders 18(3), 379–402 (1988)
3. Bernardini, S., Porayska-Pomsta, K., Smith, T.J.: ECHOES: An intelligent serious game for fostering social communication in children with autism. Information Sciences 264, 41–60 (2014)
4. Clements, D.H.: "Concrete" manipulatives, concrete ideas. Contemporary Issues in Early Childhood 1(1), 45–60 (2000)

5. Gast, D.L., Ledford, J.R.: Single subject research methodology in behavioral sciences. Routledge (2009)
6. Greczek, J., Kaszubski, E., Atrash, A., Matarić, M.J.: Graded cueing feedback in robot-mediated imitation practice for children with autism spectrum disorders. In: Proceedings of the IEEE International Symposium on Robot and Human Interactive Communication. pp. 561–566 (2014)
7. Kohanová, I., Ochodničanová, I.: Development of geometric imagination in lower secondary education. In: Proceedings of the International Conference on Mathematical Conference in Nitra. pp. 75–80 (2014)
8. Kozima, H., Nakagawa, C., Kawai, N., Kosugi, D., Yano, Y.: A humanoid in company with children. In: Proceedings of the IEEE/RAS International Conference on Humanoid Robots. vol. 1, pp. 470–477 (2004)
9. Lord, C., Rutter, M., DiLavore, P.C., Risi, S., Gotham, K., Bishop, S.: Autism diagnostic observation schedule: ADOS-2. Western Psychological Services Los Angeles, CA (2012)
10. Nadel, J.: Early imitation and the emergence of a sense of agency. In: Proceedings of the International Workshop on Epigenetic Robotics. pp. 15–16. Lund University Cognitive Studies (2004)
11. Ribeiro, T., Vala, M., Paiva, A.: Thalamus: Closing the mind-body loop in interactive embodied characters. In: Intelligent Virtual Agents. pp. 189–195. Springer (2012)
12. Robins, B., Dautenhahn, K., Dickerson, P.: From isolation to communication: A case study evaluation of robot assisted play for children with autism with a minimally expressive humanoid robot. In: Proceedings of the International Conference on Advances in Computer-Human Interactions. pp. 205–211. IEEE (2009)
13. Zancanaro, M., Giusti, L., Gal, E., Weiss, P.T.: Three Around a Table: the facilitator role in a co-located interface for social competence training of children with autism spectrum disorder. In: Proceedings of IFIP Conference on Human-Computer Interaction. pp. 123–140. Springer (2011)