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The Effect Of A Semi-Autonomous Robot On Children

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Abstract—**This research focuses on designing the behavior of an semi-autonomous robot that supports the researcher while still being in control of the interaction. We present a study on behavioral intervention design in which elements of Pivotal Response Treatment elements are embedded into a game played by a robot and a child. The introduction of more autonomy in robot behavior and interaction increases the time that a researcher can focus on the child. In order to understand whether children perceive an autonomous robot differently than a remotely controlled robot, we examined the preferences of children. Using a within-subject design, fourteen typically developed children played with a robot that performed behavior either autonomously or through remote control. The results show that both robots were evaluated as equally engaging for the children. Thus, autonomous robots allow the operator to focus less on remotely controlling the robot and more on the interaction.**

Keywords: Social robots, child-robot interaction, educational robots, autonomous robots

I. INTRODUCTION

Increasing attention has been given to the use of robot in educational settings, and behavioral training for individuals with Autism Spectrum Disorder (ASD) [1]–[6]. The use of robots within education and therapy is one of the most promising areas of robots, although a tremendous amount of work is required to make it come true.

Research has employed social robots to enhance social interaction and communication in children with ASD [2]. This has been attributed to the fact that social robots are easier to interact with; due to their simpler facial and gestural features that do not overwhelm the child. Moreover, it has been shown that question-asking training was as effective performed by a robot or a human [1], [7]. However, the therapist has to divide his or her attention between operating the robot and the treatment of the child. A therapist is still needed in the same room as the robot and child because he or she can help the child to develop a more detailed conversation or give meaning to the robot's, otherwise, mechanical actions [4], [8].

The challenge of operating the robot and dividing the attention between robot and child can also be applied to educational settings. Moreover, operating the robot can increase the workload, not only during the therapy sessions, but also before it, e.g. by having to learn how to control the robot.

One of the greatest robotic challenges is autonomy of a social robot. Autonomy of robots would help to create richer communication with people. However, a social autonomous robot has it difficulties [9]. The system has to rely on the rules set by human and make decisions based on the conventions that are familiar for all humans. Besides that, people overestimate the capabilities a robot has. Social robots should be able to deal with unexpected situations and respond in the right way, especially in situations with children, in which more unexpected actions can happen. Nevertheless, an autonomous reduces the workload of the operator. A recent investigation of Senft et al. [10] found that participants rated the workload lighter when interacting with an autonomous robot that is programmed to learn from the guidance of the supervisor than with the remotely controlled robot. Another result was that the autonomous robot required fewer interventions of the therapist, which will release time for the therapist to focus on the child. The time required to learn how to operate the robot would also be reduced by a semi-autonomous robot.

Important for the use of an autonomous robot in therapy with children with ASD, is how children perceive an autonomous robot. In the experiment of Senft et al. no children were included in the intervention; therefore, an effect on children could not be measured. This also implies that the therapist was not in realistic training environment, so his/her training load and the perception of the therapy did not include paying attention to the child and its reactions. To make the therapy with the autonomous robot as effective as the therapy with a remotely controlled robot, the children's interactions with the robot and their expectations of playing with the robot should be the same with both the autonomous and remotely controlled robot.

In our current study we investigate the effect of an autonomous robot on the interaction between robot and typical developed children and how typically developed children perceive this autonomous behavior of the robot. To accomplish this goal the children's preferences for playing with a robot that performs behavior either autonomously or through remote control will be tested, and the children's interaction with the robot will be observed. With this study one game, designed to be tested with children with ASD, is analyzed. We aim to improve the overall design of autonomous robots within the interaction, and specifically with the operator still being in control of the game flow.

II. METHOD

Our experiment was designed to test how children would react to the robot with 2 different degrees of autonomy in a standard training intervention scenario. The children played the interactive card game Quartet with the robot. During this game two players play against each other to collect 4 cards that belong to the same category and form a Quartet. In each turn, a player will ask the other player for a card that would help to gather a Quartet. The second player is obliged to hand the requested card over. The purpose of the game is to collect as many Quartets as possible.

A. Participants

Twenty typically developed children, from the elementary school De Lindt in Helmond, the Netherlands, took part of the experiment. For all children both parents signed a consent form. The participants were between 7 and 8 years old (mean=7.75, SD=0.65). Four children were excluded due to software difficulties during the first day of the tests and two children were excluded because the voice of the robot changed during the experiments. Eventually, fourteen children participated in this study.

B. Game protocol

The game was performed by one robot and one child. First, the robot greeted the child and asked who would start. If the child responded, the experimenter entered the answer in the computer and the game continued with the turn of the child or the robot. In the case that the robot started, the robot looked at its cards and requested a card from the child (either autonomously or with the help of the researcher). After the child showed the card to the robot and after the autonomous robot or the researcher (depending on the condition) recognized the card, it was the child's turn.

During the child's turn the child asked the robot for a card and the researcher pressed a button so the robot pointed at that card while the robot asked the child to grab it. Each time the robot or the child had four cards of the same kind, the robot cheered and in the case of the child said "well done". This repeated until there were no more cards in the game. At the end of the game, the robot said "Congratulations" while it cheered if the child won the game or "Thank you for playing this game" if the child lost the game.

C. Hypotheses

Our main research question explores whether children perceive a robot that plays autonomously the same as a remotely controlled robot. Akerkar [11] argued that an autonomous machine will appear more intelligent, therefore, we hypothesized that the children find the robot displaying autonomous behavior more intelligent than the robot that is remotely controlled (H1). We also hypothesized that children interact less with the researcher (H2) and that they find the game more enjoyable and are more motivated to play the game (H3) when playing with the robot that is autonomous than with the robot that is controlled by the researcher.

To explore these hypotheses, we decided to use a within-subject design, consisting of two conditions: the robot that was completely remotely controlled by the experimenter and the robot that uses its vision to recognize the cards. During the first condition, the remotely controlled condition, the experimenter had to choose all the behaviors of the robot. The robot was remotely controlled by the experimenter with a laptop. The participant interacted with the robot but was able to notice that the robot was remotely controlled. The robot interacted with the child only when a button was pressed on the laptop for a certain behavior.

In the second condition, the semi-autonomous condition, the experimenter only chose a behavior in case the child was talking. The robot used its sensory information to notice whether the child had finished his/her turn and decide on its own card. Both conditions did not differ in the output of the robot, only the input and operation of the behaviors was different.

D. Implementation

To implement the autonomous behavior of the robot, the graphical software TiViPE [5] was used. Every card had an individual marker for the robot to identify the card. For the markers the ArUco markers were used [12]. The robot can identify the cards with these markers and decide which cards belong together.

The robot's strategy was to let the children win. Each time it was the robot's turn, it would ask a random card from the cards that the robot did not possess. In order to let the children win, the robot had a bigger chance (twice as big) to ask a card from a category of which the robot had only two cards. This decreases the chance of the robot to complete a Quartet, but increases the chance of the child to assemble a Quartet.

The speech recognition of the robot is too unreliable to be used autonomously, because of that this part of the scenario was remotely controlled by the therapist. All possible robot behaviors can be activated by a simple keyboard press. During the game the therapist could prompt the child when necessary, by using a text-to-speech interface [7].

E. *Experimental settings and materials*

The experiment was conducted in an empty class room in the school. Before the experiment all children were introduced to the robot in a group demonstration. Each participating child was called twice out of the class room to play with the robot. During those sessions, the child and the robot sat in front of each other at a table and the experimenter at another table but within sight of the child (see Figure 1a and 1b.). A digital video camera was placed between the robot and the experimenter, to record the child's behavior. A laptop was used to control the robot. After the child had interacted with the robot in both conditions he/she filled in a questionnaire to reflect on the game with the robot. In the end of both games the experimenter asked the child to fill a questionnaire to reflect on the game with the robot.

The robotic platform used for this study is the NAO humanoid robot, with 25 degrees of freedom, 58 cm in height. NAO has simplistic facial features only with mouth and eyes, and its face resembles to the age of a child's face. Some of the robot behaviors that were used in this game include text to speech functions, hand gestures, and NAO LEDs. The robot had a female voice and was speaking Dutch. In order to be able to differentiate the child's responses to the robot in the two conditions, the robot wore a different shirt (blue striped or white) in each condition (see Figure 1c.). TiViPE, which is a graphical programming environment was used to program the robot and for interaction during the sessions [5], [13]. A special interface was used for real-time interaction between robot and child and was connected to the previously programmed interaction scenario. The preprogrammed scenario consisted of a dynamical system of behaviors for complex interactions, emotions and behaviors. This interface for a real-time interaction through speech and simple movements was created as a part of this program especially for this experiment. The order of the robot behaviors and the shirt color were counter balanced.

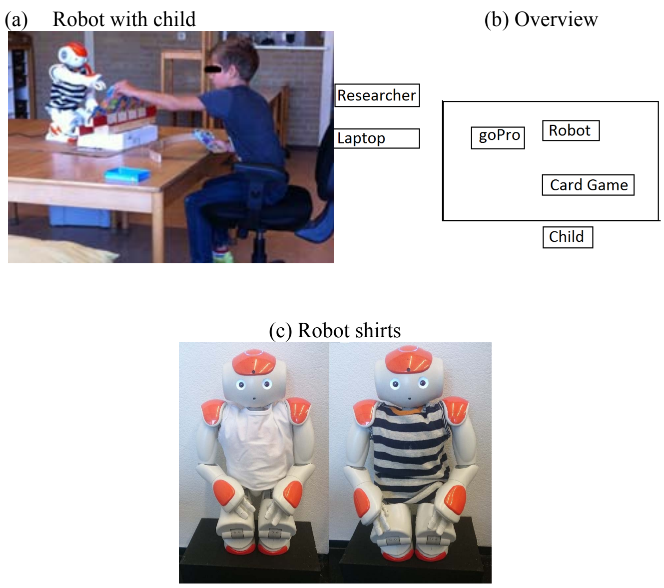

Fig 1. a) A child interacting with the robot. b) Experimental setup. c) The robot wearing the different shirts in the different conditions.

F. *Data collection*

All sessions were recorded using a video camera, the videos of the child-robot interaction were observed once the data-collection finished. All videos were random selections of one minute of the child interacting with the robot. For every condition three videos of one minute of the children were observed, therefore, the observers watched 6 videos of one minute per child, for 14 children. Three students and a researcher observed these videos; the students watched only half of the videos due to time restrictions, and consequently every video is observed at least two times. The observers were asked to count the times (frequency) that (1) the child looked at the robot, (2) the child looked at the experimenter, (3) the child said something to the robot that did not belong to the game (the observers did not count for the times the child asked for a card), (4) the child said something to the experimenter and (5) how much interest the child showed during this minute on a scale from 0 - 5 (see for an explanation of the interest measurement [14]). The interobserver agreement (IOA) was determined with the intraclass correlation coefficient (ICC). This statistic can be used to determine the degree that a group relates to each other. The coefficient varied between 0.57-0.94 with a mean of 0.79 (SD= 0.08), which indicates a substantial agreement between the observers.

G. *Questionnaires*

The questionnaires are based on the Immersive Experience Questionnaire [15] and indicate the immersion of the player. The questions were concerned with the degree of attention to the game and the degree of motivation to play the game and therefore relate to the player's overall experience of the game.

Within this experiment, only thirteen questions were translated to Dutch and simplified for the children. The questions that were explicitly about video games and duplicate questions were excluded. A pilot study performed by us indicated that children found it complicated to express themselves in degree of agreement (agree/slightly agree/slightly disagree/disagree). Therefore the children were asked to answer on a 4 point scale (yes!/slightly yes/slightly no/no!) or fill in that they did not know. The option for "Neutral" was excluded so the children had to choose. The questions were divided into four categories (questions about their enjoyableness (Q1-Q3), the robot (Q4-Q6), surroundings (Q7-Q9), the difficulty (Q10-Q13), see Table I for the questions).

TABLE I. The questions translated to English.

Q1	I found it fun to play this game
Q2	I wanted to win
Q3	I did my best
Q4	I want to play the game again with the robot
Q5	I really wanted to help the robot
Q6	I felt sorry for the robot/me that he/I lost
Q7	I wanted to quit during the game
Q8	I was quickly distracted during the game
Q9	During the game I noticed nothing around me
Q10	I think the robot played really clever
Q11	I found this game challenging
Q12	I found the game really easy
Q13	The game was quickly finished

After playing the game in both conditions, the children had to fill in a final questionnaire. They were asked which robot they preferred and with which robot they wanted to play the game again.

III. Results

This section shows the results of the observed behaviors of the children and the results of the questionnaires. The data analysis consists of five parts. The first part involved visual inspection of the data together with the calculation of the mean of all observers. The second part was a paired-samples t-test with the data of the observers to see whether there was a significant difference between the two behaviors of the robot. In the third part, the two questionnaires about the robots after each condition were compared, for all questions a paired-samples t-test was performed. An ANOVA was used to check whether age and school year was of influence. Last, a chi-square goodness-of-fit test was performed for the final questionnaire.

A. Behaviors children

Figure 2 summarizes the observed behaviors of the children in the two conditions: the robot that was remotely controlled and the robot that behaved autonomously. It was expected that the observers would rate the children looking less at the experimenter when the children played with the autonomous robot. However, no significant differences were found between the two conditions. It is noteworthy that the observers rated the children speaking significantly more with the human than with the robot in both conditions (mean= -1.31, SD= 1.33, p= 0.00 for the remotely controlled robot, mean= -1.46, SD= 1.85, p= 0.00 for the autonomous robot). The children turned to the experimenter to express their excitement the robot.

B. Questionnaires

The children filled in a questionnaire after playing the game with the robot in both conditions. It was expected that the children would like the autonomous robot more than the remotely controlled robot or find the robot smarter. As the results (see Fig. 3, paired t-test) show, there are no significant differences between the conditions.

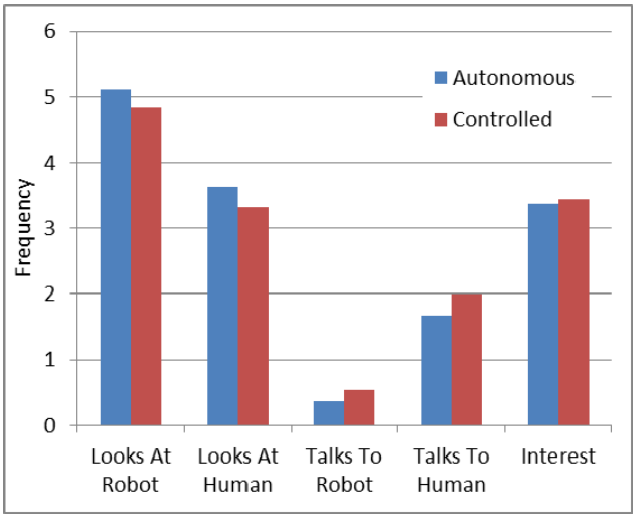

Fig. 2: Results of the children's gaze and speech behavior rated by observers. The observers could rate the interest of the children between 0 and 5.

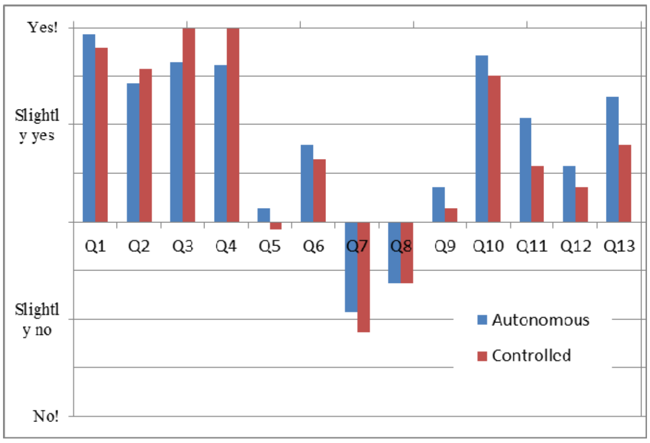

Fig. 3: Results of the children's answers on the questionnaire.

The children's answers about the surroundings were positive for positive questions (I noticed nothing around me, mean= 0.25, SD= 1.80) and negative for negative questions (I wanted to quit, mean= -1.04, SD= 1.71, I was quickly distracted during the game, mean = -0.64, SD= 1.77).

The influence of the children's age or grade on their answers was checked, because of the high standard deviation for some of the questions. It was expected that children of a younger age or lower grade, found the questions that had a longer length more complicated to understand and were less consistent with answering these questions. As the results in Table II show, the grade of the child significantly influences the answers of two of the questions. The children in a higher grade, showed less variation within the questions.

TABLE II. The results for the influence of the children's school level and their age on their answers for the questionnaire.

	Grade (Groep)	Age
I wanted to quit during the game	F(1,25)= 11.363**	F(1,25)=3.054
During the game I did not notice anything around me	F(1,25)= 0.128	F(1,25)=0.000
I was quickly distracted during the game	F(1,25)= 8.703**	F(1,25)=3.405
Multivariate	F(3,23)= 4.837**	F(3,23)=1.493

*p<0.05, **p<0.01, ***p<0.001

TABLE III. The percentages of children that answered the final questionnaire with the remotely controlled robot and the autonomous robot

	Robot behavior			
	Remotely controlled	Autonomous	Chi-Square	Asym p. Sig.
I liked the game more with	53.33	46.67	40	1
I would like to play again with	60	40	0.286	0.593

In the final questionnaire the children were asked to choose between the two conditions which robot they liked more and with which robot they wanted to play again (see Table III). There are no significant differences in the children's answers.

IV. DISCUSSION

The main goal of this study was to investigate whether children can perceive the difference between a robot that performed behavior either partly-autonomous or through full remote control. Fourteen typically developed children played a card game with the Nao robot displaying remotely controlled and autonomous behavior in an experiment. We measured the children’s subjective explicit opinions with a questionnaire and observers rated the children’s gaze and speech behavior. There were no statistical difference in the children’s opinions of a partly-autonomous robot or a remotely controlled robot and the observers did not rate the children’s gaze and speech behavior significantly different during the recorded interactions. These results suggest that children do not experience the robot behaviors differently or react differently to the two robot behaviors. Furthermore, our results do not confirm our hypothesis that children find the autonomous robot behavior more intelligent than the robot that is remotely controlled (H1) and children interact less with the researcher when playing with the robot that is autonomous than with the robot that is controlled by the researcher (H2).

The observers were also asked to rate how much interest the children showed in the robot and the game. No significant differences were found between the two conditions. In both conditions the observers rated the children's interest slightly above neutral. A neutral interest means that the children were observed to be eager to continue the game, not to rebel and to passively accept the situation. The children were not more motivated to play the game in one of the two conditions (H3 is not confirmed either).

In all, the results introduce the opportunity for the operators to use the partly autonomous robot in interactions reducing their energy for controlling the robot, this would free some time for the operator, allowing them to focus more on the child. As the children do not see a difference between the robot behaviors, they may benefit from the extra attention of the human.

In the case of therapy, the study of Senft et al. [10] shows that the therapist's workload can be reduced with a partly autonomous robot. Their methods slightly differed from our methods, as they used a learning algorithm for the robot to learn from the guidance of the therapist. In our experiment the robot behaviors were already implemented and the experimenter only needed to press keys to indicate who's turn it was and had indicate where the robot had to point to during the child's turn. Children with ASD turn to the therapists to show their joy and excitement about interacting with the robot [8]. The extra time that therapist wins with the autonomous robot, can be used for reacting to such actions.

There are some limitations in this work: first, the novelty effect that might lead children to be focused on the robot almost exclusively and not on the experimenter. The children, therefore, may not have noticed that the robot was controlled by the experimenter. The results of the questions about their surroundings support this suggestion.

Second, there is a possibility that the children could not recall events that happened during the experiment. That would imply that the answers on the questions would be based on the last part of their interaction with the robot. Eight-year old children can relate better to events that occurred at some time in the past than seven-year old children [16]. The high variance of the questions about events that happened during the game underpins this possibility. The language development of children of the fifth and fourth grade is also different. Events that happened in the past are complicated because they ask the children to reflect on their behavior during the game. Children need more understanding of language to be able to do so. Our results showed that the children's grade made a difference but not their age, and only for two of the three questions (I was quickly distracted during the game; during the game I noticed nothing around me). Children from a higher grade showed less variance in the two questions than the children from a lower grade. This means that children from a higher grade understood these complex questions better than children from a lower grade. For future experiments it will be important to reduce such interfering factors.

Moreover, an important improvement would be to increase the robot’s autonomy, e.g. by enabling it to adapt its behavior when it is too easy or too complicated for the child. Enabling the robot to detect when a child gets bored or uninterested and then adapt its behavior would be an important, if difficult to achieve, advance.

V. Conclusion

Extensive research is done towards interventions with children and robots in a Wizard of Oz setting with the researcher being invisible for the child. However, less research is done with the researcher in the same room. The goal of this paper is to explore whether a child is differentially influenced by robot that is either acting autonomously or through remote control by a nearby person in the same room. The results of the study show that typically developed children did not respond differently to these two types of robot behavior. An interesting application would be that a therapist can use the partly autonomous robot instead of the remotely controlled robot thereby reducing the workload of the therapist. This, in turn, would allow the therapists focus more on the child. More research should be done to measure accurately if this will increase the effectiveness of the therapy and whether our findings also apply to children with ASD.

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