Robotic Task Complexity and Collaborative Behavior of Children with ASD

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***Abstract*— Social interactions are essential in the everyday lives of humans. People with an autism spectrum disorder (ASD) display shortages of social skills, thus making their day-to-day encounters more difficult. This paper reports on two small-scale studies, investigating whether the use of collaborative robot tasks in an educational setting stimulates the collaborative behavior of children with ASD, and whether robotic task complexity affects collaborative behavior. A total of 24 children participated in robotic tasks of varying complexities. The sessions were videotaped and analyzed. Children's supervisors completed questionnaires, evaluating the social behavior of participants. Results demonstrate that children collaborated during the robot activities. The influence of robotic task complexity on collaboration skills was not significant, possibly due to the small number of participants. The results show the promise of using robots in education for children with ASD, although further research is needed to investigate the implementation of robots in special education.**

Keywords—robot, autism spectrum disorder, education, collaboration

I. Introduction

Autism Spectrum Disorder (ASD) is mainly characterized by a deficit in social skills [1]. ASD is a (neuro)-developmental disorder commonly defined by its symptoms according to the Diagnostic and Statistical Manual of Mental Disorders (DSM) [2]. Children affected by ASD generally experience difficulties with social communication and interactions and exhibit recurring behaviors, also referred to as the "dyad of social impairments" [2], [3], [4], [5]. The deficit of social communication and interaction is particularly fundamental for ASD, as this attribute distinguishes ASD from many other developmental disorders [6]. Children experience difficulties in forming relationships with peers and participating successfully in reciprocal interactions [7], [4]. Many autistic children are predisposed to experience difficulties in joint attention and react fewer and shorter to social cues [8], [9], [10]. Besides this, children with ASD possess weaker motor skills [11], [12]. Studies in this regard have demonstrated a correlation between deficits in motor skill and social skill in autistic children [11], [12]. This has led to an awareness that motor skills should also be addressed in early interventions to support the improvement of social skills.

On the other hand, individuals with ASD frequently display remarkable skills in recognizing repeating patterns, known as systemizing [13]. As a result, children with ASD commonly possess a high interest and talent towards technology and robots, attributable to the general predictiveness of technology [14], [15]. This remarkable skill may be a useful support when implemented in ASD treatment and therapy.

As a result of the impairment of their social skills, it stands to reason that the ability of children with ASD to collaborate is typically at a lower level compared to children without ASD. Because of this, various studies have explored interventions to specifically induce collaborative behavior in children and thus strengthening them. Some studies incorporated technological tools such as digital games in which participants engaged virtually with other individuals [16], [17], [18]. Similar research utilized technology to foster social skills by creating a virtual tabletop interface on which children would play a puzzle game in pairs [19], [20], [21]. The games used as intervention tools in these studies included tasks that required children to work together to complete the game successfully.

Numerous studies investigated the use of robots in therapeutical settings for the treatment of children with ASD. However, the research of robotics in an educational context and non-clinical environment is limited [15]. Studies exploring the utilization of robots in general education suggest a high potential of robotics as a learning tool, especially in the case of further developing skills not specifically related to robotics [22]. So far, research of robots within therapy shows improved participation of children with ASD while being taught a certain skill and when responding to a robot rather than a human [23]. Reference [21] particularly suggest the use of such technologies in educational settings to strengthen collaborative abilities. The results demonstrate a positive effect of interactive robotic tasks and classes on the children's behavior [19], [21], [24]. There exists a large variety of robots with potential of use in education, however it is unknown which robot type best elicits the desired behavior and is most practical to use within a classroom setting. In accordance with previous research and the shortage of studies conducted within an educational context, the following research questions were composed, "How do robot-related tasks in an educational setting affect the social behavior of children with ASD, specifically collaboration?" and "What is the influence of robot task complexity on the collaborative behaviors of children with ASD?". Two separate studies were conducted to examine the possible impact of robot and task complexity on the collaboration skills of children with ASD within an educational context.

II. STUDY I

The goal of the first study was to find out whether a robot would elicit interactions and collaborative behavior between children with ASD, and whether robot task complexity affected the degree of collaboration.

A. Method

A total of 15 children from a special needs after-school institution participated in the tasks, ranging from ages 7 to 13 (M=11, SD=1.9, 13 boys, 2 girls). Prior to data collection, parents signed informed consent. All participating children were previously diagnosed with ASD by a professional diagnostician.

Differential levels of robot complexity were to be induced by means of two robot types. When choosing a robot for this study, it was important to consider realistic factors for implementation in schools, including cost, ease of use and robustness. With respect to this, the educational robots "Ozobot" (Starter Pack Model Bit 1.0 & Puzzle Pack Extension) and "Lego Mindstorms" (Model EV3) were chosen. The Ozobot, acts as the simpler category, whereas Lego Mindstorms is more complex to use. Ozobots can be operated by drawing a path using color code markers on paper or by building a track with "pre-coded" puzzle pieces. The robot then follows the course if it has been drawn correctly. Besides this, specific color combinations or "codes" can make the robot perform simple actions such as "spin", "turbo" or "U-turn" [25]. In comparison, the more complex Lego Mindstorms involves building the hardware in addition to programming. Children can build the robot to their liking and include different sensors prior to programming it on the computer [26].

Working in pairs, children were given the task to "create a track" for the Ozobot robot. With respect to collaboration, they were simply instructed to "work as a team". During pilot tests of the lessons, it became clear that the use of Lego Mindstorms required previous lessons, as the task was too difficult for children to master without previous knowledge. Children already experienced challenges when assembling the robot and several got frustrated easily, hampering coding. On that account, instructions given for the task using Lego Mindstorms specifically mentioned "build a robot" and "work as a team". However, the differing instructions may limit the internal validity. In order to limit this confound, the data collected with Lego Mindstorms was analyzed separately and not compared to Ozobot in the results section. The collected data from Lego Mindstorms trials is therefore excluded from this report. Both simple and complex robot tasks were carried out using the Ozobot, however by means of using the pre-coded puzzle pieces (simpler task) or drawing the track entirely new using the pen (complex task) . Collected data of these two trials are compared.

To ensure professional evaluation of children's behaviors, supervisors of the children completed a questionnaire which assessed the children's social behavior, interactions, and collaboration in comparison to their usually observed behaviors. Initially, the supervisors gave a short description and summary of the observed behavior throughout the task. Following this, three Likert-scale rating items were to be filled out, which each consisted of a five-point rating scale ranging from "disagree" (1) to "agree" (5). Supervisors indicated if during the tasks they (Item 1) noticed more social behavior between the children than usual, (Item 2) if the children interacted with each other more than usual and (Item 3) if the children worked more collaboratively than usual. The next paragraphs describe the operational definitions of 'interaction' and 'collaboration'.

B. Video analysis and data preparation

The method of video analysis was selected for the purpose of objectively quantifying qualitative data [21], [24|, [27]. The tasks and interactions of the participants were recorded using Panasonic HDC-SD60 camcorders. A coding scheme allowed for identification of behavior, classified as being collaborative during the complex and less complex robot tasks. Firstly, the general concept of collaboration was operationalized, for which observable behavioral indicators were defined and described. Based on previous studies [21], [28], along with the definition of the term "collaboration" [29], [30], [31], the variables "circles of communication (CoC)" [27] mutual support", "negotiation" and "reciprocal interactions" were designated as conceivable key collaborative behaviors. With reference to previous literature, specific indicators were defined for each of these generic terms. Each indicator is not mutually exclusive, as more than one of the behaviors can occur simultaneously. The indicators, "accepting", "disagreeing", "initiating" and "responding", were split into "verbal" or "non-verbal" indication. An initiating behavior therefore could occur verbally or non-verbally, merely by gaze or similar action.

Prior to coding, each video was shortened to 10 minutes by discarding the instruction and sampling 10 minutes of footage thereafter. The videos were transcribed before coding with MAXQDA [32]. Data was coded quantitatively, hence, videos were scored using the appropriate behavioral indicators as defined in the codebook whenever they occurred, and the behaviors were related to the tasks. To ensure validity of the coding-scheme and inter-rater reliability, 10% of the data was coded on every variable by a second coder. After comparison of the coded videos by both coders, an average percentage agreement level of 0.61 was achieved, which indicates a rather weak agreement level. The discrepancies between observers were discussed and resolved at a consensus meeting.

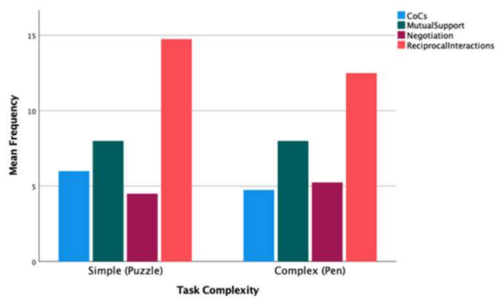
The objective of this study was to examine a possible influence of robotic task complexity on collaborative behavior of children with ASD, measured by the frequency of CoC's, Mutual Support, Negotiation and Reciprocal Interactions. Considering that the data is not normally distributed and the small sample size of this experiment (four trials per experimental variable), a non-parametric test was chosen to compare the two samples. For this reason, a Wilcoxon Signed Ranks test with an alpha level of .05 was performed separately for both the video analysis and questionnaire results to determine statistically significant differences within the collected data.

C. Results

Eight Ozobot sessions were filmed, resulting in a total of 2 hours and 10 minutes of video footage (excluding Lego Mindstorms sessions). Each session lasted between 10 and 30 minutes (M=16:17 minutes, SD=10:43 minutes). Collected data of the video analyses was used to calculate for high vs. low robotic task complexity. Findings of the Wilcoxon Signed Ranks Tests determined no statistically significant difference between robotic task complexity and collaborative behavior during the tasks ($p > 0.05$ for all tested variables). Results from each Wilcoxon Signed Ranks test per variable are presented in Table 1. Regardless, on average, the children demonstrated more reciprocal interactions in both task conditions compared to the remaining variables (Variable Reciprocal Interactions: Simple M=13.75, Complex M=13). Besides this, average mutual support occurred more frequently than acts of negotiation or CoC's in both task conditions (Variable Mutual Support: Simple M=7.5, Complex M=8).

FIGURE I

MEAN COLLABORATIVE BEHAVIORS VS. ROBOTIC TASK COMPLEXITY



To compare the results of the Likert-scale items of the questionnaires between robotic task complexities, a Wilcoxon Signed Ranks Test was conducted separately for each item of the survey. Results indicate no significant difference between robotic task complexity and perceived collaborative behavior ($p>0.05$ across all items).

III. STUDY II

Besides the first study, it was of interest to investigate robotic task complexity within the setting of a special primary education. This second study took a similar method to the first study, yet due to the small sample size and the corresponding low statistical power, it was not possible to perform valid statistical analyses. Therefore, it is not possible to draw firm conclusions regarding the generalizability of the observed relations of robotic task complexity with collaborative behavior. The results however may still be used for exploratory purposes.

A. Method

Data was collected at a school for special primary education. A total of 9 students diagnosed with ASD enrolled at the primary school participated in this study, ranging from ages 8 to 13 (M=10.64, SD=1.36, 5 boys and 4 girls). A teacher at the school instructed and supervised each trial. Three different groups with each three different participants engaged in the tasks. Before data collection, informed consent was obtained from parents of the participating children. Data collection was conducted at the school during a regular school day.

The choice of robot used in each of the tasks was made in accordance with the school. The educational robot "Bee-bot" is easy in use and an affordable option for schools. The Bee-bot features different buttons relating to varying commands, e.g., forwards, backwards, right, or left turn. During the forwards and backwards orders the robot travels exactly 15 cm in the respective direction, whereas right or left turns causes the robot to turn 90°. The robot is programmed by pressing a sequence of desired commands and ultimately executing these via the "go" button [33].

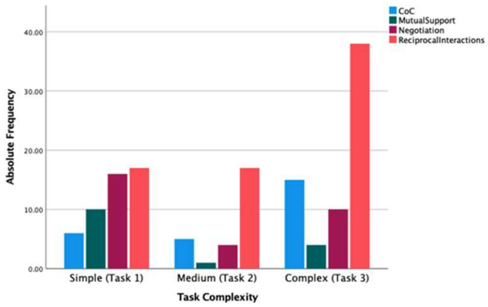
The robotic task followed progressively more complex instructions for each of the three trials. The task structures and directions were contrived by the teachers independent of this study. During each trial, a differing group of three children participated and worked together to complete the task as instructed by the teacher. Each task included the general instruction to create a track for the robot. During the least complex trial (Task 1), children were instructed to first create a path for the robot to follow using cards displaying arrows pointing in varying directions. Thereafter, the robot had to be programmed by the participants in such a way that it would follow the previously assembled path. In the more complex trial (Task 2) the track was to be assembled using individually colored papers. These were to be placed on the floor, creating a pathway for the Bee-bot to follow, after correct programming. Ultimately, the most complex trial (Task 3), asked for the children to assemble their track with the help of long wooden blocks. Children had to build a three-dimensional representation of their track with the blocks, respecting the movement distance of 15 cm of the robot for forward commands. To do this, they made use of rulers and measured the 15 cm distances in their track beforehand, to prevent the robot from moving out of bounds. The teacher clarified each of these tasks thoroughly before the groups began.

Data collection of Study 2 partly followed the method as employed in Study 1, unless stated differently. Within this study, video recordings were conducted using the same coding scheme as in the first study. All videos were shortened to a uniform length of eight minutes by removing the first few minutes of the teachers' instructions and sampling the remaining 8 minutes thereafter. The data was coded with MAXQDA [32]. Due to the small sample size and each task complexity level being conducted only once, the collected data is not suitable to carry out statistical testing.

B. Results

A total of three sessions (one of every task complexity) was filmed, each lasting between 8 and 36 minutes, cumulating to 36 minutes and 58 seconds of video material (M=12:19 minutes, SD=05:01 minutes). In tasks, children demonstrated the ease of use of the Bee-bot. The data reveal that the number of reciprocal interactions is highest, compared to the other variables. When comparing the different increments of task complexity, the most complex task displays the largest increase of reciprocal interactions. Figure 1 shows the absolute frequencies of each variable according to task complexity. Further analysis of the footage gave insights to the task process. The observed group proxemics indicate two of the children collaborating, whereas the third participant stands or sits rather distantly to the other two, yet the tasks were ultimately completed successfully.

FIGURE 2
FREQUENCIES OF COLLABORATIVE BEHAVIORS VS. TASK COMPLEXITY



IV. DISCUSSION

The purpose of both studies was to examine a possible influence of robotic task complexity on collaborative behavior of children with ASD in an educational context. Both studies addressed the research questions, “How do robot-related tasks in an educational setting affect the social behavior of children with ASD, specifically collaboration?” and “What is the influence of robot task complexity on the collaborative behaviors of children with ASD?”. Video recordings and questionnaires were utilized to analyze children’s behavior. Because of the small sample size, the assumptions made in the results of this study lack power.

Results show that the tasks of this study elicit collaboration between children. Participants collaborated to complete the common goal of creating a track in both studies using Ozobots and Bee-bots. These findings tie well with previous studies demonstrating the positive influence of robotic tasks on behavior [19], [21], [28]. Concerning the second research question, results of Study 1 demonstrate no significant difference between collaborative behaviors during tasks with higher and tasks with lower complexities. An explanation for this could be that the complexity levels of both tasks in Study 1 may not be large enough to cause a change in behavior. However, robot complexity might still play a leading role, as there appeared to be an increase in collaborative behavior throughout the most complex task in Study 2. This interpretation is also motivated by the fact that the most complex task of Study 2 displayed a higher frequency of social interactions than in less complex trials. From this emerges the hypothesis that complexity of tasks can help in fostering collaborative skills of children with ASD. However, this trend could be limited by a too complex task, as the amount of CoC’s during Mindstorms tasks were lower. Furthermore, there appears to be an influence of group size on social and collaborative behaviors of children with ASD. The comparison between both studies and the quantity of group members showed a clearer collaboration in tasks which were mastered with only two children instead of three. This implies that partnered tasks might a be better option for children with ASD to demonstrate collaborative work.

Both studies displayed reciprocal interactions occurring most frequently during tasks than any of the other variables (Mutual Support, Negotiation & CoC’s). The CoC’s in turn are the least frequent variable throughout the robotics sessions. An explanation for this observation is that many of the attempts in reciprocal interactions failed, meaning that these couldn’t be labelled as successful CoC’s. The counting of CoC’s is already a good and established approach [27], however the qualitative aspects should be taken more into account and given more importance within analyses.

This study highlighted the importance of creating a task that affords collaborative behavior. This corresponds to the task chosen in previous studies [21], where a puzzle could only be completed on a virtual tabletop interface if both children touched puzzle pieces. Results of Study 1 demonstrated, whenever participants had the option of following their own goal, the collaborative interactions were low. For example, this was the case when children were given more than one sheet of paper to draw the track, or when several LEGO bricks were available to build a Mindstorms robot. From the results of both Study 1 and Study 2, it can be inferred that task structure itself predestines a certain degree of collaboration, since if children only have one robot at hand they are required to interact and negotiate to complete their task. With this, it is recommended that collaborative tasks are structured with limited options for individual work.

The overall robot acceptance and motivation during the tasks in this study are consistent with the theory of systemization, which explains the preference and talent towards robots in terms of their repeatability and predictability [13]. To verify these results, further studies need to be conducted with a larger sample size and under more controlled conditions. However, both Ozobot and Bee-bot have demonstrated their ease of use and easy implementation in schools.

A limitation of the current study is the weak percentile agreement, indicating large discrepancies between the two coders. A possible explanation is the large room for interpretation of behavior in the terms of the categories. An improvement measure for future studies is to further detail the codebook and its descriptions. Besides this crucial limitation, this study is restricted by the absence of a control group, examining the frequency of collaborative behaviors in non-robotic tasks. Another restricting component is that different children participated in each condition. This might be improved by assigning the same participants to complete each task condition, enabling a direct comparison between the tasks. Moreover, it is difficult to comprehend from these results alone, the extent to which the tasks studied might be useful for children with ASD outside the educational setting and in everyday encounters. Yet, the findings of this paper allow for the next step in developing tasks using robots to support the development of social and collaborative skills of children with ASD within everyday school settings.

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