Critical Review: Is robot-assisted therapy a viable treatment option for improving social interaction in children with Autism Spectrum Disorders (ASD)?

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The aim of this critical review is to examine the effectiveness of using robot-assisted therapy to improve social interaction skills in children with Autism Spectrum Disorders (ASD). All literature search was completed and yielded the following study designs: two single group (post) tests, one single group (pre-post) test, one between-groups study, one case study and one longitudinal study. Overall, these studies provide growing evidence in support of the hypothesis that participation in robot-based therapy can facilitate increased social interaction for children with ASD. However, research in this area of interest is limited. Further research is required to systematically evaluate the effectiveness of this intervention.

Introduction

Autism Spectrum Disorders (ASD) are a group of neurobiological disorders, characterized by varying degrees of impairment in social interaction and communication as well as restricted and repetitive behaviours or interests (Stanton, Kahn, Severson, Ruckert, & Gill, 2008). Social skills deficits are a hallmark feature of children with ASD, and can sometimes be overlooked by parents during the early childhood years (MacKay, Knott, & Dunlop, 2007). Children with ASD have significant difficulty understanding human interactions and the rules of social conventions. As such, they fail to develop peer relationships that are appropriate to their developmental level, and often lack the ability to initiate and sustain a conversation with others. These difficulties tend to worsen as children enter adolescence as their social environment becomes more complex and demanding (MacKay et al., 2007). Therefore, interventions aimed at improving social interaction are of utmost importance for this population.

Historically, many treatments have been proposed to improve social skills in children with ASD; however, not all of these treatments have been proven effective (Ricks & Colton, 2010). Robot-assisted therapy is a relatively new field that has become increasingly prominent in recent years (Rick & Colton, 2010). It is driven by the idea that that a robot, which is "less complex in its interacting modalities compared with a human", can be used as a social mediator in therapy to facilitate social interaction skills of children with ASD (Duquette, Michaud, & Mercier, 2008). Robots can provide a safe and predictable environment, which can help reduce anxiety that is often accompanied by changes in these children's immediate surroundings (Ferrari, Robins, & Dautenhahn, 2009**)**. Therefore, these robots have the potential to provide a distraction-free environment in which children with ASD can explore interaction and communication safely thereby developing social skills.

There is evidence to suggest that children with ASD enjoy interacting with robots due to their simple and predictable behaviours (Ferrari et al., 2009; Robins, Dautenhahn, Te Boekhorst, & Billard, 2005; Dautenhahn & Werry, 2002). However, little is known about whether these social skills could be transferred and generalized across different settings. Therefore, the question still remains, *is robot-assisted therapy a viable treatment option for improving social interaction in children with ASD?* Many experts in this area argued that more experimental research is warranted for examining its efficacy in treating children with ASD (Giannopulu & Pradel, 2010; Duquette et al., 2008; Robins et al., 2005).

Objectives

The primary objective of this paper is to critically evaluate the existing literature pertaining to the effectiveness of robot-assisted therapy in improving social interaction in children with ASD. The second objective is to propose evidence-based recommendations for future research and application in clinical practice.

Methods

Search Strategy
Computerized databases including ProQuest, Google Scholar, PubMed and Web of Knowledge were searched using the following strategy: ((robot) OR (robotic therapy)) AND ((social interaction skills) OR (social skills) OR (social development)) AND ((autism)

OR (autism spectrum disorders) OR (ASD)). The search was limited to articles written in English between the years of 2000 and 2010.

Selection Criteria

Studies selected for this critical review paper were required to examine the effects of robot-based therapy in promoting social interaction among children with ASD who were less than 14 years of age. There were no restrictions related to the demographics of research participants or outcome measures.

Data Collection

Results of the literature search yielded six articles that met the aforementioned selection criteria for inclusion in this review. These included the following study designs: single group post-test only (2), single group pre-post test (1), between-groups study (1), case study (1) and longitudinal study (1).

Results

Of the six studies examined for this critical literature review, two used a humanoid robot which is essentially a robot with human-like appearance; one employed an animal-like robot which is designed to resemble a pet; one used a mascot-type robot which retains a humanoid form but has an abstract appearance; and two employed a non-humanoid mobile robot which does not correspond to any living form. Despite the differences in appearance, all of them are equipped with various sensors which enable them to move in response to external stimuli, such as distance, acceleration, sound, vibration, and pressure.

Humanoid Robot

Duquette, Michaud and Mercier (2008) conducted a between-groups design across four participants with low-functioning autism ranging in age from 4 to 5 years. The participants in the study were selected on the basis of several criteria to ensure group homogeneity in response to their baseline level. The criteria included a requirement that children selected were diagnosed with autism confirmed by the *Autism Diagnostic Observation Schedule-Generic (ADOS-G),* children reactions were evaluated using a pre-established set of criteria, and their imitation skills were measured by the *Psychoeducational Profile Review (PEP-R)*. Furthermore, these measures were supported by comments gathered from their school teachers. The participants were assigned to one of two groups: one group paired with a robot mediator, while the other group paired with a human mediator. Each group consisted of one non-verbal child and one pre-verbal child. Trial sessions were conducted in a small room three times a week over a period of seven weeks. The room had a window, a chair and a familiar toy placed in the center. Further, a video camera was set up to record the session. One experimenter and one helper were present in the room with the child. Prior to the experiment, trials were done with three children not part of the selected sample of children with autism, to measure the practicality of the experimental method, the validity of the evaluation forms, the correct operation of the robot, and the reactions displayed by the children.

For baseline purposes, data were collected in the first and last session during which the mediator performed the following actions: say hello, express happiness, point and give back the hat, point to the mediator, show the door to exit and say goodbye. Observations were made in the following four categories of social behaviour: shared attention, shared conventions, absence of sharing and other phenomenon. The results indicated that children paired with the robot mediator showed significantly greater levels in shared attention, particularly visual contact and physical proximity, during activities involving facial expressions, actions with objects and actions without objects. However, it is important to note that the non-verbal children demonstrated an overall reduction in shared attention than the preverbal children in all activities. Interestingly, the researchers found that children exposed to the robot mediator showed more imitation of facial expression, specifically expression of happiness. However, these children demonstrated less imitation of gestures and actions, and showed a statistically significant decrease in imitation of words. Moreover, proximity and shared interactions were found more frequently in children paired with the robot mediator than in children paired with the human mediator. Furthermore, children who interacted with the robot mediator displayed no repetitive and stereotyped behaviour toward the robot.

The major strength in the present study is that the authors employed widely used tests (ADOS-G and PEP-R) to achieve a baseline level for the composition of the sample group. Furthermore, the authors were clear regarding the desired outcomes they wanted to measure.

In contrast, there are a number of limitations involved within the study that may decrease the strength of the results and should therefore be acknowledged. There were a total of four participants in the study. Such relatively small sample size can affect the external validity, that is, the ability to generalize findings to the larger population of children with autism can be difficult. The small sample size also precludes the use of statistical power to detect changes. However, it is important to note that obtaining large sample sizes in autism research is very challenging due to the small population and high variability in the disorder. The participants were selected, rather than randomly assigned, to one of the two treatment groups. Non-random assignment of participants to groups can heighten the risk of bias, and therefore one cannot generalize the results of this study to the larger target population. The participants were not blinded to the treatment they received and this may have resulted in subjective bias. The authors did not provide any information as to why the experimenter of this study was chosen and if the experimenter was blinded to the purpose of the study. This may have led to inherent biases in subjective judgment therefore weakening the validity of the results. Inter-rater reliability was another area of significant concern. The authors did not address whether inter-rater reliability was not measured or whether it was not reported in the study. A final and significant limitation is the lack of long term follow-up for determining whether treatment gains were maintained post-intervention.

Overall, this study provides good evidence that robot-assisted therapy may be a viable treatment option for children with ASD. This level 3b research led to some suggestive to compelling results demonstrating the effectiveness of the intervention. However, these results should be interpreted with caution due to the possible reporting bias in the sample size and group assignment. As well, the lack of adequate research for the long term follow-up of participants should be considered when gauging the quality of evidence.

Robins, Dautenhahn, Te Boekhorst and Billard (2005) administered a longitudinal study investigating the effects of repeated exposures to a humanoid robot on social interaction skills of children with autism. Four participants with autism aged 5 to 10 years were included in the study. The participants were selected by their school teacher to participate in as many clinical trials as possible within a period of three months. The average number of sessions attended by each participant was nine.

Trials were conducted in a familiar room at the children's school. The room had a single door and several windows that overlooked the school playgrounds. Two video cameras were set up in fixed locations in the room to capture the children's facial expressions and their interactions with the robot. The duration of the trial was determined by the child's level of comfort with the environment and the examiner in the room, with an average of three minutes.

Data were collected from live and videotaped sessions and were analyzed quantitatively and qualitatively based on four main criteria including eye gaze, touch, imitation and proximity. Inter-rater reliability for these measures across all children was 96%. The results of the quantitative analysis showed an increase in eye gaze, imitation and proximity for three children over the course of the intervention. In particular, one of the children used the robot as a mediator to initiate an interaction with the examiner. The fourth child did not show a similar increase in the aforementioned behaviour. However, the researchers reported that the longitudinal approach allowed him sufficient time to become accustomed to the robot and to interact with the robot in his own way. The qualitative analysis of the video footage revealed further aspects of social interaction skills such as imitation and turn-taking as well as communicative competence. All the children had at least some spontaneous interactions with the examiner and the helper in the room. These interactions sometimes revolved around the robot when the robot was served as a mediator. At other times, however, these interactions were not robot related. The overall results of this study suggested the possible role of the robot as a mediator for facilitating social interaction in children with ASD.

A positive aspect about the present study is the use of longitudinal repeated-measures design, which allowed the authors to examine changes over an extended period of time. This is particularly useful for establishing a casual relationship and for making reliable inferences. Moreover, sampling errors were less because the study remained with the same participants over time. Another strength is that the videotaped observations were coded independently by two blinded raters, which can reduce the possibility that the participant's performance was influenced by rater bias. In addition, the study reported a high degree of inter-rater reliability thereby reducing the element of subjectivity. Furthermore, using a combination of qualitative and quantitative methods was desirable, as it may produce results of greater validity thereby providing a more complete picture of the effectiveness of the intervention.

There are some caveats regarding the study that are worth noting. There were four participants who took part in the research study. As mentioned before, the small sample size affects the ability to generalize results and reduces the statistical power to detect clinically meaningful effects. There was substantial heterogeneity among the participants with respect to chronological age and developmental level. Therefore, the comparable results of the study may be partially attributed to this factor. In addition to the above methodological weaknesses, there are other issues which could have influenced the interpretation of the results. Since the session length was determined by the participants themselves, some children may have spent more time interacting with the robot and/or the examiner in the trial compared to other children. The variability in the sample with respect to time spent in each trial may have had an effect on the outcome measures. Participants who had consistent contact with the robot may have experienced increased social interaction due to familiarity with the format of the therapy session. A final limitation is the absence of baseline measures or control groups, which makes it difficult to ascertain whether changes observed from pre-test to post-test were due to treatment or to maturation over time.

Overall, this study has a high level of evidence for the effectiveness of robot-assisted therapy in improving social interaction skills in children with ASD. This level 2b research led to some suggestive to compelling evidence for the effectiveness of the intervention. However, these results should be interpreted with caution due to the small sample size, potential for participant selection bias and lack of baseline measures.

<u>Animal-Like Robot</u>

Stanton, Kahn, Severson, Ruckert and Gill (2008) implemented a single group pre- and post-test design to examine the effectiveness of using an animal-like robot to improve social skills of children with autism. The study recruited eleven participants with autism between the ages of 5 and 8 years.

There was a dearth of information on the experimental setting provided. Prior to beginning the experiment, each child received a brief warm-up period designed to familiarize the child with the environment. Once the child appeared comfortable in the setting, the examiner introduced either a robotic dog or a toy dog (depending on the counter-balanced conditions) and allowed the child thirty minutes of play time. First the child was given some time to explore the object in a self-directed play. Next the examiner asked a series of pre-established questions, while the child continued to play, and invited the child to engage in pre-established interactions with the object. This was done to ensure consistency across all sessions for this study. After thirty minutes, the examiner introduced the other artifact and allowed the same length of play time.

Quantitative data were collected using videotaped observations and were analyzed according to the following four criteria: interaction with artifact, spoken communication to artifact, behavioural interactions with artifact typical of children with autism as well as behavioural interactions with artifact typical of children without autism. Inter-rater agreement for these measures ranged between 73-97%. The results revealed that compared with the toy dog, the robotic dog stimulated longer play interactions and more spoken communication (words per minute), and it increased the participants' intention to engage in more reciprocal exchanges. Furthermore, the results showed that authentic dyadic interaction (between child and object) and authentic triadic interaction (between child, object, and examiner) occurred more frequently in the robot condition compared to the toy condition. As well, the researchers found a reduction in stereotyped behaviours across all the participants.

A major strength of the study is that the authors matched the participants on medical history and language skills to ensure group homogeneity. Another strength is that both the independent raters were trained in the coding of participants' behaviour thereby making the results more reliable.

Among the strengths of the study are also some weaknesses. First, the sample size included a total of eleven participants, which makes generalization of the findings problematic. Of the eleven participants, ten were males and only one was female, which may have altered the results. Although there were more male participants than female participants; however, it is important to understand that autism is three to four times more likely to affect boys than girls. As well, participant selection bias may have likely occurred as the participants were not chosen randomly. Moreover, maintenance and generalization of newly acquired skills to situations outside the clinical setting were not addressed. Furthermore, the authors did not report any follow-up data to demonstrate long term effects of the intervention. However, it is important to note that the study employed an animal-like robot, which makes generalization of the skills learned in these therapy sessions more difficult, as the robot cannot mimic human-human interactions.

Overall, this study provides good evidence that the robot-based intervention is effective in remediating social skills deficits in children with ASD. This level 3b research study led to some suggestive results. However, these results should be interpreted carefully due to the methodological flaws and lack of generalization and maintenance data that were addressed above.

<u>Mascot-Type Robot</u>

Giannopulu and Pradel (2010) utilized a single group post-test design to examine the interaction between children with autism and a mobile robot during spontaneous play. The sample consisted of four participants with autism ranging from 7 years 11 months to 9 years 5 months of age. Each participant received five minutes of free play with the robot**.**

Sessions took place in a small room with a wardrobe and a table to reduce possible distractions. The robot was placed in the middle of the room facing toward the entrance. A video camera was used to record activity during the trial session. One experimenter was present in the room.

Data were obtained from video recordings of the session for later analysis of each child's interactive behaviour with the robot. Raters were two individuals blinded to the study. Inter-rater reliability were cited but were not reported. The following four target behaviours were observed during the session: eye gaze, touch, manipulation and postural position relative to the robot. The results indicated an overall increase in the duration of time the children spent playing with the robot. The duration of eye gaze was found similar across all children; however, wide individual variations were observed in the duration of touch, manipulation and postural position.

An important strength of the study is the blinding of the two independent raters who were responsible for the coding of the videotaped sessions. This may lead to reduced bias therefore making the results stronger and more reliable.

The present study suffered from the same methodological flaws as the previous ones, such as small sample size and absence of random selection of participants, which limit the generalizability of the results. As well, the authors did not measure the participants' involvement in external educational or treatment programs. This can potentially confound the results thereby limiting the value of this study. Inter-rater reliability was assessed but the authors did not report any reliability data in the study, which makes the findings potentially less reliable. Information regarding the length of the intervention or the interval between pre- and post-intervention was not provided. This may result in a limited ability to determine the immediate versus long term effects of the therapy.

Overall, this study provides limited evidence that the robot-assisted therapy may be a possible treatment option for improving social skills in children with ASD. This level 3b research study led to some suggestive results. However, these results should be interpreted cautiously due to potential reporting bias and confounding variables. Also, the small sample size may not be representative of the ASD population as a whole.

<u>Non-Humanoid Mobile Robot</u>

Dautenhanh and Werry (2002) employed a case study design with an interactive robot as the treatment condition and a non-interactive object as the control condition. The purpose of the experiment was to evaluate the effectiveness of socially-engaging robots for children with autism. Seven participants with autism aged 8 to 12 years were recruited for the study.

There was limited information provided on the experimental setting. All sessions were videotaped. One or two experimenters and one familiar teacher were always present in the room during the experiment. The sessions were divided into three parts. Part one required the child to interact with the toy truck. Part two allowed the child to play with both the toy truck and the robot; however, the robot was turned off and therefore passive. Part three introduced the robot in an "active" mode.

Data were recorded and analyzed in terms of a set of fourteen criteria. For example, eye gaze, eye contact, operate, handling, touch, approach, move away, attention, vocalization, speech, verbal stereotype, repetition, blank and others. A brief description of each criterion was provided. The study indicated a high inter-rater reliability of the data analysis; however, it did not report any kappa coefficients corresponding to the agreement between the two observers. The results revealed that four children demonstrated significantly more eye gaze behaviour directed to the robot than to the toy truck. Interestingly, although a different child made less eye contact with the robot, the videotaped footage showed that the robot was clearly a focus of attention. This was demonstrated by his multiple attempts to initiate social interactions with the experimenter by using the robot as a mediator.

This study has several limitations that should be considered when interpreting the results. There was a small sample size, which makes it difficult to generalize results. Moreover, the authors did not describe where the participants were recruited from nor did they outline a set of inclusion and exclusion criteria used to select participants and to ensure participants shared similar characteristics. Given that the method for participant selection was not identified, it is possible that there could have been selection bias in the research which, in turn, may influence the generalizability of the findings. Information regarding the experimenters was not provided, and therefore the results may have been subject to observation bias. The authors measured inter-rater agreement, but did not report the reliability coefficient thereby providing a low level of evidence. A final limitation is the lack of descriptive analysis of the graphed data. The use of visual inspection of the data alone may not be reliable due to the possibility of under- or over-interpretation of the results.

Overall, this study offers some evidence of increased social skills in children with autism who participated in robot-assisted therapy. This level 4 research study led to some suggestive results. However, these results should be interpreted carefully as a result of issues concerning the sample size, participant selection bias, and inter-rater reliability.

Werry, Dautenhahn, Ogden and Harwin (2001) conducted a single group post-test design investigating the role of a mobile robot as a social mediator. Six participants with autism between the ages 8 and 12 years took part in the study as pairs in three groups. The participants were selected by school teachers based on their shared interests in technology and outgoing personality.

Trials were held in a room at the children's school. The room consisted of a door and a window that overlooked the school parking lot. Two experimenters and one familiar school staff were present in the room. While the jobs of the experimenter were to document the trials with a video camera and to intervene only when the child behaved inappropriately toward the robot, the school staff was responsible for providing occasional prompts for the child. Each trial lasted until one of the experimenters or the staff requested an end, either due to the state of the robot or the emotional state of the child. The average duration of trials was nine minutes.

Qualitative data were collected through video recordings of interactions between the child and the robot. The results of the study revealed that only one pair of children demonstrated increased social interaction, both with the robot and with each other. As well, they were socially responsive and showed eye contact, touch, vocalization and exploration of the robot. The other two pairs of children were observed to engage in mostly non-social play. They attempted to interact with the robot, but no interaction between the children themselves was observed.

While qualitative research provides more in-depth and comprehensive information on social behaviour that is difficult to measure, there are also challenges associated with employing this type of research. Qualitative data are limited in their ability to be generalized to the larger population as the findings of this type of research are not tested for statistical significance. Additionally, the quality of the data collection and the results were highly dependent on the skills of the experimenters for whom no information was provided. This makes the findings vulnerable to subjective bias. A further limitation is that the number of participants was relatively small. A sample size of six participants is too small to allow broad generalization to be drawn about the impact of using robots as interventions for children with autism. Furthermore, the participants were not a homogeneous group as some of them were of a higher functioning level and had more previous experience with the robot than others. Such heterogeneity may have altered the quantity and quality of interactions observed thereby weakening the validity of the study findings. As well, the participants were chosen by their teacher which may have led to participant selection bias. Moreover, the study could be criticized for assigning both children in each pair to one single robot. This may have influenced the type of play that occurred during the session therefore confounding the results of the study.

Overall, this study provides equivocal evidence that robot-based therapy may be a promising treatment option for children within ASD. This level 3b research study led to limited results. However, these results should be interpreted cautiously due to problems with small sample size, sample selection bias as well as the overall quality of the research design of the study.

Discussion

In spite of varying degrees of evidence, the results of the six studies suggest that robot-assisted therapy may be a viable treatment option to teach social skills in children with ASD. In particular, the use of a humanoid robot in studies conducted by Duquette et al. (2008) and Robins et al. (2005) appeared to elicit more diverse social interaction patterns in children with autism than the use of other robots. This finding suggests that humanoid robots may play a larger role in facilitating the development of social skills. However, caution should be taken when interpreting the current research due to inherent limitations that may have compromised the external validity. Common limitations across the studies include a small sample size, non-random participant selection, lack of maintenance and generalization data as well as inconsistencies in implementation procedures (e.g., session length, duration of treatment, location of intervention, number of experimenters involved). Given the limitations of the existing literature, there is a need for additional research to confirm that robot-assisted therapy is an effective and efficient social skills intervention for children with ASD.

Research Recommendations

In order to address the methodological issues mentioned earlier, there is a need for future research. It is recommended that future research employ high-quality randomized controlled trials to gain further insights into the effectiveness of robot-assisted therapy. As well, future research should obtain adequate sample sizes in order to provide sufficient statistical power to detect treatment effects. Moreover, future research should include baseline measures to examine changes from pre-treatment to post-treatment. It is important to ascertain whether the changes observed are due to treatment or due to maturation. Future research should also include long-term follow-up data to assess generalization and maintenance of social skills following withdrawal of therapy. Lastly, more research needs to be conducted in the Canadian context before the effectiveness and efficacy of robot-assisted therapy can be determined.

Clinical Recommendations

The existing literature provides information that is relevant to clinical practice. First, robots should be tailored to meet the specific skills and needs of children with ASD. Second, treatments should be conducted in a more natural environment to promote carryover of acquired skills. Finally, although results suggest that robot-assisted therapy has a positive impact on social skills, clinicians should be mindful not to rely on this therapy as their sole form of social intervention.

Conclusion

In summary, while all of the reviewed studies contain methodological errors, they provide some preliminary evidence to support the claim that robot-assisted therapy may be a promising treatment option for enhancing social skills in children with ASD. Further research in this area needs to be conducted before we can arrive at any concrete conclusions about therapy effectiveness in the treatment of social skills deficits. It is important that clinicians be cognizant of the limitations imposed by the existing literature and be mindful of future research as it becomes available.

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