Joint Attention in Human-Robot Interaction

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Abstract

This study investigates the effect of joint attention on trust immediately after an interaction with a robot and one week later. Participants interacted with two robots, one engaging in joint attention and the other disjoint attention. The trust levels that the participants felt towards the robots were measured immediately after the interaction and one week later. The results show no effect on trust due to joint attention during both these sessions. However, it was found that initial trust scores given to a robot were a very strong predictor for trust scores given during the second session. The likability that the participants felt towards the robots may have influenced the measured trust scores more than the presence or absence of joint attention. This insight and other possible limitations of the study design show the need for further research with an improved design. This research highlights the importance of initial trust and effective non-verbal cues in human-robot interaction and shows the dynamic understanding of trust.

Introduction

In today's world, where human-robot interaction is becoming increasingly common, understanding and applying social mechanisms is important to potentially enhance this interaction. One of these social mechanisms is joint attention. In this introduction, joint attention will be explained, followed by a discussion on the importance of trust in human-robot interaction, and a review of existing literature on the link between joint attention and trust in human-robot interaction. Finally, the focus of this study will be highlighted.

Significance of Joint Attention

Joint attention is a collaborative cognitive process in which individuals engage in nonverbal communication, such as following another's gaze or gesturing, to simultaneously attend to an object or event. This facilitates shared understanding and inference of intentions and mental states (Bruinsma et al., 2004; Emery, 2000; Staudte & Crocker, 2011b). Joint attention can be divided into two categories: Response to joint attention (RJA), where the follower responds to another's cue, and Initiation of joint attention (IJA), where the leader initiates joint attention by redirecting the follower's attention (Bruinsma et al., 2004; Edwards et al., 2015). Joint attention encompasses a wide range of behaviours, from quickly looking at the same object as a conversation partner to jointly performing tasks (Šipošová & Carpenter, 2019). This non-verbal behaviour, involving both a leader and a follower, is observed in communication among both human and non-human primates, showing its universality and significance in understanding social cognition (Emery, 2000). This becomes evident when investigating the role of joint attention in communication development.

Studies have shown that children develop joint attention from a very early age to learn both verbal and nonverbal communication and how to interact with their surroundings (Bruinsma et al., 2004; Edwards et al., 2015; Staudte & Crocker, 2011a; Tomasello & Farrar, 1986). This can be seen in language development where joint attention is believed to play a role. For example, a study by Mundy et al. (2007) shows that there is a correlation between the use of joint attention in the communication of children and their language development by observing children in a controlled familiar setting. Children respond to joint attention to understand the attentional focus of an adult to make a connection between the focus point and the language spoken by the adult. This goes further than merely gaze following in which the child would follow the gaze of the adult to attend to the same object. When engaged in joint attention, both the child and the adult, often unconsciously, infer and learn from the shared focus point, helping the child understand the adult better (Tomasello & Farrar, 1986; Staudte

& Crocker, 2011b). As the child ages, joint attention is not merely used for understanding adults and learning language but also for more complex cognitive processes. For example, learning the predictability of behaviours of individuals and the effect of these behaviours on the environment (Bruinsma et al., 2004). When children observe the same behaviour leading to the same outcome through joint attention repeatedly, they will be able to predict the outcome of this behaviour in the future. Older children will start to show initiation of joint attention when they are showing objects to others to infer their reaction toward the object and how the child is using the object (Kidwell & Zimmerman, 2007). This will teach them to deduce whether they are correctly using the object. Additionally, a study by Tomasello and Farrar (1986) shows that there is a correlation between joint attention episodes and vocabulary size of children emphasising that joint attention plays a part in the development of verbal communication.

Understanding Joint Attention

Joint attention plays a part in the development of both verbal and non-verbal communication and lays a foundation for interactions between individuals. It is interesting to investigate what exactly occurs when two individuals are participating in joint attention to see how this social mechanism can be studied. A study by Emery (2000) shows the importance of visual social signals. These are mostly present on the face with a focus on the eyes. The study states that the role of the gaze is central since it is the gaze that often leads a follower to the same object as the leader. They have shown this by observing what happens during a joint attention interaction and specifically, to what parts of the body humans pay attention to. This is also concluded by Seemann and Dow (2011). However, they also indicate that joint attention is not merely following the gaze of the leader and looking at the same object. They argue that both parties should be conscious that they are looking at the same object. This does not mean that both parties are conscious that they are partaking in joint attention but rather that they are both consciously paying attention to the same object or event. This is what makes joint attention a joint action and not a parallel action (Seemann & Dow, 2011). In a parallel action, there would be little interaction between the two actors since they are only focusing on the action that they are performing. Albeit, in a joint action, the two actors are paying attention to each other and the object simultaneously, allowing for social mechanisms to occur. From these sources, it can be concluded that joint attention is a mechanism in which two individuals are consciously paying attention to the same object in which a leader directs the followers' gaze using gaze leading. However, this would mean that blind children are not able to partake in joint attention since they can not detect the gaze of the leader. This has been proven to be false by Guthrie et al. (2018). This study indicates that there are a variety of non-verbal and verbal factors involved in IJA and RJA, for instance, auditory or tactile cues. To give an example, a caregiver might show a toy to a visually impaired child by letting the toy make sounds. Here the caregiver is showing IJA and if the child reaches for the toy, he or she is showing RJA. Now, both the caregiver and the child are focused on the toy. This example shows that joint attention is not merely following a gaze. This makes it difficult to indicate what exactly is happening when two individuals are showing joint attention and shows the complexity of this social mechanism. However, the easiest approach to mimic joint attention is using gaze leading, which is why this is most often used in experiments involving joint attention (De Belen et al., 2023; Parsons et al., 2019).

Influence of Trust on the Relationship Between Humans and Robots

According to a study by Matarić (2017), robots that are used in a social setting can benefit from using social cues present in human-human interaction. It is assumed that the social mechanisms that we use in our day-to-day interaction can also be used in human-robot interaction with the same beneficial effects. Joint attention is one of these social mechanisms that can be used in interaction between humans and robots (Huang et al., 2010). In the study currently presented, the aspect of focus within human-robot interaction is trust, this will later be linked to joint attention. The reason for this particular focus is the importance of trust when it comes to human-robot interaction. When humans and robots have to interact, an established trust in the relationship can help humans accept help and information from the robot (Cominelli et al., 2021; Hancock et al., 2011; Yagoda & Gillan, 2012). This is especially evident in high-risk situations where trust has a direct influence on the humans' acceptance of the robot and the provided information (Hancock et al., 2011; Yagoda & Gillan, 2012). In these situations, humans often have to make decisions based on the information that a robot is providing them. To make these decisions, the human has to believe that the information from the robot is trustworthy, which depends for the most part on whether the human trusts the robot. This trust towards a robot is based on multiple factors, including reliability, performance, appearance and behaviour (Cominelli et al., 2021; Yagoda & Gillan, 2012). In these high-risk situations, robots and humans often cooperate based on a deeper relationship than mere interactions between robots and humans. Modern technologies in robots have allowed this. An example is the use of sensors that help robots respond to input from the human (Ajoudani et al., 2017). This also leads to the possibility to use joint attention in human-robot communication since this mechanism is based on input from the leader. Other studies even emphasise the importance of inferring human responses by robots in human-robot collaboration suggesting that joint attention could also improve collaboration between humans and robots (Dragan et al., 2015).

Joint Attention and Trust

The relationship between trust and joint attention is bidirectional in the sense that joint attention can enhance trust in a relationship and that trust in a relationship leads to more joint interactions (De Jong & Dijkerman, 2019; Seemann, 2009; Wolf et al., 2015). When two persons are attending to the same object or event, it enhances their relationship and therefore their trust towards each other. This can be explained by considering the side of the leader who intuitively perceives that the other person is following their gaze and thus recognizes that the other person is paying attention to them. The relationship also increases on the side of the follower as they are paying attention to the leader. Hereafter, they can infer the mental state of the leader to conclude why they are looking at a certain object. Also, studies have shown that trust is fundamental for joint attention (De Jong & Dijkerman, 2019). This conclusion is drawn based on the observation that two persons who are in a trustworthy relationship show faster responses to jointly attended stimuli.

Joint attention can enhance trust in a relationship. As could be seen before, it is also clear that trust is a vital part of a good relationship between robots and humans. Therefore, one might conclude that joint attention can enhance trust in a human-robot relationship. Not much research has been done on this relationship, but some studies do (indirectly) prove that joint attention could contribute to the development of trust between humans and robots (Grigore et al., 2013; Staudte & Crocker, 2011). Since these studies show that joint attention in human-robot interaction is very similar to joint attention in human interaction, it is assumed that most of the benefits from joint attention in human interaction can be applied to a human-robot setting.

Long Term Effects

Most of the studies that have been cited in the introduction study the short-term effects of joint attention on the relationship between humans and robots. Some studies have measured the long-term effects of joint attention (Kaplan & Hafner, 2006; Kopp & Lindenberger, 2010), but very few studies have done this in the context of trust and robots. Since research has shown that both trust and joint attention are vital for human-robot interaction it is interesting to study the link between trust and joint attention in human-robot interaction. As robots and humans work together more often and for longer periods, it is intriguing to investigate whether the effects of joint attention on trust in a human-robot interaction can be long-term or only short-term. Since there seems to be a gap in the literature regarding this topic, this relationship on long-term effects will be investigated in this research. In this study, the concept of “long term” will be specified into one-week. To investigate the long-term relationship between joint attention and trust in robots, an IJA paradigm is used by Willemse et al. (2021) followed by trust measurement after the experiment and one week later. This leads to the following hypotheses:

1. A robot that engages in joint attention will have a higher trust score directly after the interaction has taken place than a robot that does not engage in joint attention.
2. A robot that engages in joint attention will have a higher trust score one week after the interaction has taken place than a robot that does not engage in joint attention.

Method

Participants

The experiment was executed with 40 participants, of which 35% were male and 65% were female. The mean age was 24 with a standard deviation of 11 years. Participants were recruited by the researchers to partake in the experiment using convenience sampling. Therefore, most participants were students from the University of Twente or family members of the researchers. The inclusion criteria were a sufficient level of English to understand the survey questions and no visual impairments that made it impossible to see the pictures in the experiment. There were no exclusion criteria. Ethics approval was obtained before starting the experiment from the BMS board (application number 240251.

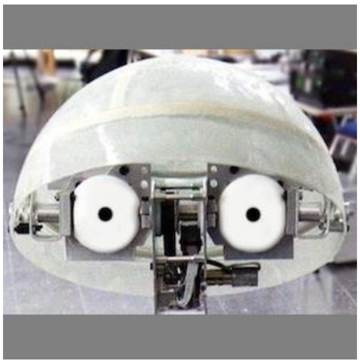
Materials

For this experiment, a variety of materials was used. The participants interacted with a joint attention and disjoint attention robot in an experiment that was created by Willemse et al. (2018). They conducted a study on whether joint attention influences the time that it takes a participant to return their gaze from an object back to the robot. In this program, two pictures of objects were shown with a robot face in the middle. There were two different robots, one for the disjoint and one for the joint robot. These robots both looked the same, but they were given a different name to offer a distinction between them. As stated in the introduction, joint attention is a cognitive process that can be initiated with gaze leading, followed by gaze following. This is imitated in the experiment by letting the participant be the initiator of the joint attention and the robot be the follower. In the experiment executed in this study, there were two robot faces instead of one, named Bob and Jim (see Figure 1 a and b). The choice of two robot faces was made to offer a very clear distinction between the joint and disjoint robot. There was one robot who would look at the chosen object 80% of the time (joint attention robot), and one robot who would look at the chosen object only 20% of the time (disjoint robot). These percentages are chosen to match the previous experiment by Willemse et al. (2018) which showed that the effects of joint attention will occur when the disjoint robot still looks at the object 20% of the time. The assignment of the joint attention and disjoint attention roles to the robots varies per participant. Thus, counterbalancing ensures that the type of robot does not influence the outcome (see Appendix C). In total, the participants will have to choose between two objects 160 times.

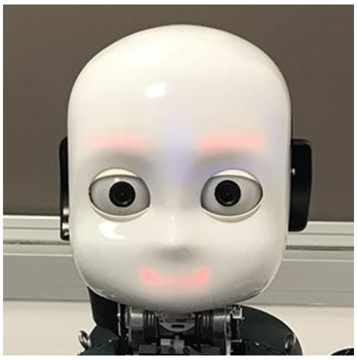
To answer the research question regarding trust, a trust perception scale was used by Schaefer (2016). This scale consists of 40 items measuring different aspects of trust. Taking the average of the score on these items concludes in a number that indicates how much trust a person feels towards a robot. There is also a shorter 14-item version that was used in this experiment since the 40-item scale was too time-consuming to fill in twice. Therefore, the validity was lower than when the 40-item scale would have been used. The study has demonstrated that there are correlations between the 14-item scale and other established measures of trust suggesting that this scale measures trust adequately. The study does not mention a Cronbach alpha to test reliability. This item scale is incorporated in the survey given during the first session. This survey also included a net promoter score. The question asked here was: "How likely are you to recommend Bob/Jim (names of robots) to a friend or colleague to use in a daily setting?". This question was used in both the first and second surveys. The assumption is that a higher net-promoter score means a higher trust level. Therefore, the net-promoter score offers another way to measure the difference in trust when joint attention is absent or present. The second survey asked the participants which robot they perceived as more trustworthy after they had done the experiment a week earlier. A likability scale is also included in the first survey to answer the research question of the other researcher and thus will not be looked at for this experiment.

Figure 1

a: Robot Bob



b: Robot Jim



Procedure

After the participants were seated in a quiet room behind a computer with a mouse, they were asked to read the information sheet and sign the consent form. Hereafter, they were explained the experiment. They were told that they would see two objects with a robot face in the middle, see Figure 2. The task was to choose one of the objects. It was emphasised that the reason for choosing a certain object was not important. When the participant had made their choice, they had to click on the object followed by clicking on the robot face to go to the next set of objects. Participants engaged in six sets of choices; each required them to select between two objects. The participants were offered three breaks to give them time to refocus, see Figure 3. The participants were told that there were two kinds of robots. These robots had different faces and names to facilitate distinction between them, see Figure 1 a and b. The participants were randomly assigned to the joint and disjoint robot conditions (see Appendix C) and were not informed which robot was the joint attention robot and which was the disjoint robot. The concept "joint attention" was not mentioned during the debriefing of the experiment to make sure that the focus was on the choice between the objects and not on the presence or absence of joint attention.

After the experiment, the participants were asked to fill in two surveys that were the same but targeted a different robot (see Appendix A). The survey consisted of a 14-item scale, a net promoter score and a likeability scale. The order in which the surveys were given varied for each participant to minimise confounding variables (see Appendix C). The first session was conducted in a controlled environment in the form of a quiet project room at the University of Twente to minimise external stimuli during the experiment and lasted on average 20-25 minutes. The second survey was sent to the participants a week later (see Appendix B). They were asked to fill in the survey within one day. This survey consists of a choice between the two robots with the question "Which of the two robots did you rate as more trustworthy?". The participants can also answer with "There was no difference". This survey included the net promoter score. The second session was conducted without a researcher present in an uncontrolled environment. The second session was estimated to last around 2-4 minutes.

The decision to schedule the second survey one week after the initial session was made after considering several practical factors. Firstly, recruiting participants for a two-part study presents challenges, as it requires a greater commitment from participants. By spacing the sessions one week apart rather than further apart, the chance of participants answering the second survey increases. A one-week interval provides a balance between allowing for meaningful follow-up while minimising the burden on participants. Secondly, another study on the same topic (Kopp & Lindenberger, 2010b) also employed a one-week interval between sessions. As this study did not report any issues arising from this duration, it is deemed adequate for assessing the long-term effects of joint attention.

Figure 2

The Screen That the Participants See When They Have to Make a Choice Between the Two Objects

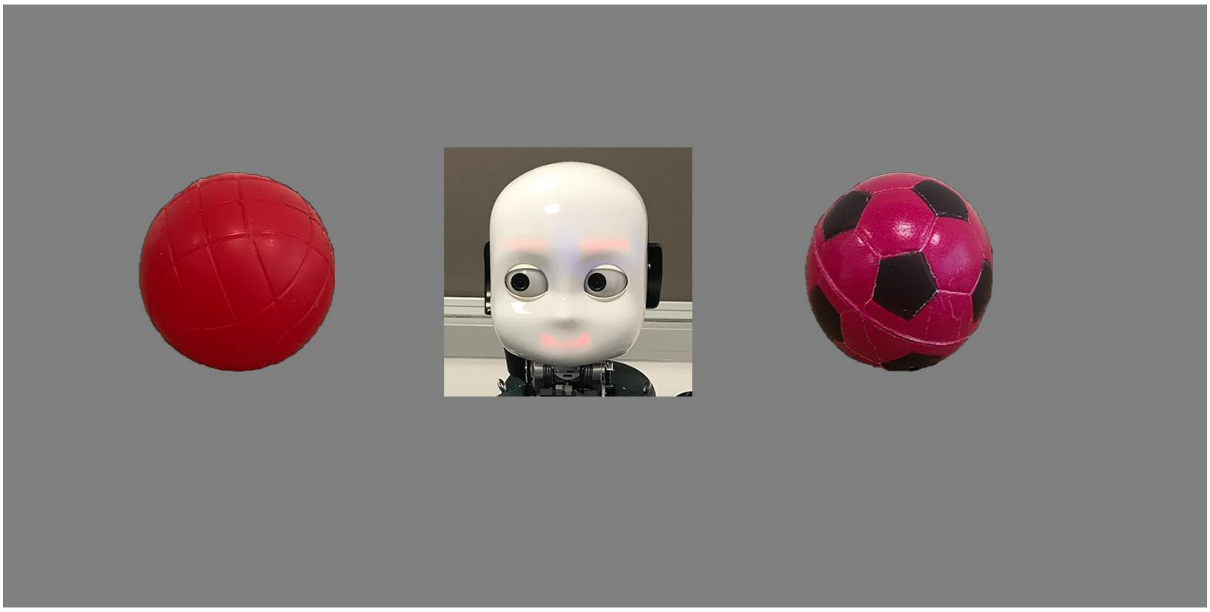


Figure 3

The Screen That the Participants See When They Can Take a Break.

Data Analysis

To answer the research question, we consider the correlation between joint attention and trust during the first and second sessions. Here, joint attention is the independent variable and trust is the dependent variable. To investigate this correlation, a within-subject design was used as participants were exposed to both a joint attention and a disjoint attention robot. Also, the assumption is made that a higher net-promoter score means higher trust. Therefore, the correlation between joint attention and the net-promoter score will be evaluated in both the first and second sessions.

To analyse the data, three of the items had to be reverse-coded. All the items were rated on a scale where 1 stand for “never” (no trust) and 11 for “always” (full trust) apart from the items “Unresponsive”, “malfunction” and “have errors”. For these items, the opposite applies in which “never” means full trust and “always” means no trust. Therefore, in the final data set, the scores on these items were interpreted reversed (e.g. a score of 4 became a score of 8). Hereafter, all the data was added to an Excel sheet (see appendix D) to be analysed in the statistical software R. The trust scores obtained during the first session were an average of the scores given on the 14-item scale. Therefore, the data from the first session was ordinal. Trust was measured differently during the second session as the participants were given a choice between two options resulting in dichotomous data.

To investigate the first hypothesis, a Wilcoxon test was used. This is a non-parametric test. This test was used because the assumption of normality is not met, and the trust scores are paired observations in a within-subject design. To test the second hypothesis, Logistic binomial regression was used because we wanted to test whether there is a significant association between two categorical variables.

To test the validity of the item scale that was used, a Cronbach alpha was calculated. This was done by making a data set with all the items and their scores. Hereafter, the Cronbach alpha was calculated in R studio.

Results

Hypothesis 1: A Robot That Engages in Joint Attention Will Have a Higher Trust Score Directly After the Interaction Has Taken Place Than a Robot That Does Not Engage in Joint Attention.

The participants all completed both surveys within the given time without any problems. The reliability of the 14-item scale was calculated with a Cronbach alpha. The Cronbach alpha for the scale was 0.93, which shows good internal consistency. If an item is dropped, the Cronbach alpha does not change significantly, concluding that all the items are contributing to the reliability. Only the items “malfunction” and “communicate with people” show lower correlations with the total score (r.cor < 0.5).

One participant did not fill in two of the 14 items. Therefore, their data was removed before the analysis. The results of the trust perception scale showed that the mean trust in the robot with the disjoint disposition during the first session was 6.10 (SD=1.93). In comparison, the mean trust reported for the joint attention robot during the first session was 6.81 (SD=1.05). Figure 4 shows two boxplots indicating the trust levels when the robot shows joint attention (joint attention value is 1) and when the robot shows disjoint attention (joint attention value is 0).

A Wilcoxon test was used to test this hypothesis. A comparative t-test could not be used because the assumption of normality is not met as the data was not normally distributed but skewed to the left, see Figure 5. According to the Wilcoxon test, there is no significant difference between trust scores with and without the presence of joint attention, W = 649, p = 0.148.

The correlation between joint attention and the net promoter score was also tested using a Wilcoxon test because the assumption of normality was not met. The test shows that there are no significant differences in the net-promoter scores based on joint attention, W = 644, p = 0.132.

Figure 4

Trust Scores During the First Session with Disjoint Attention (0) and Joint Attention (1)

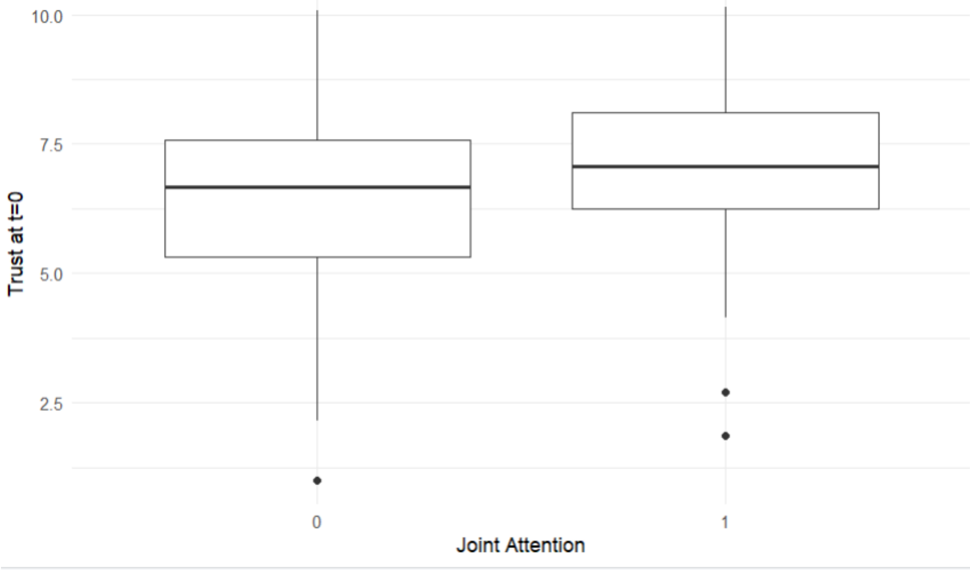
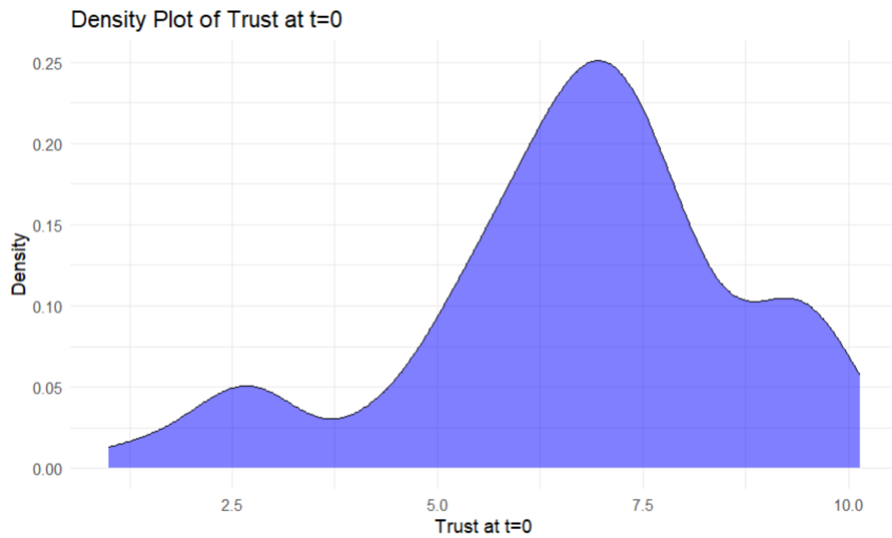


Figure 5

Distribution of Trust Scores Given During the First Session

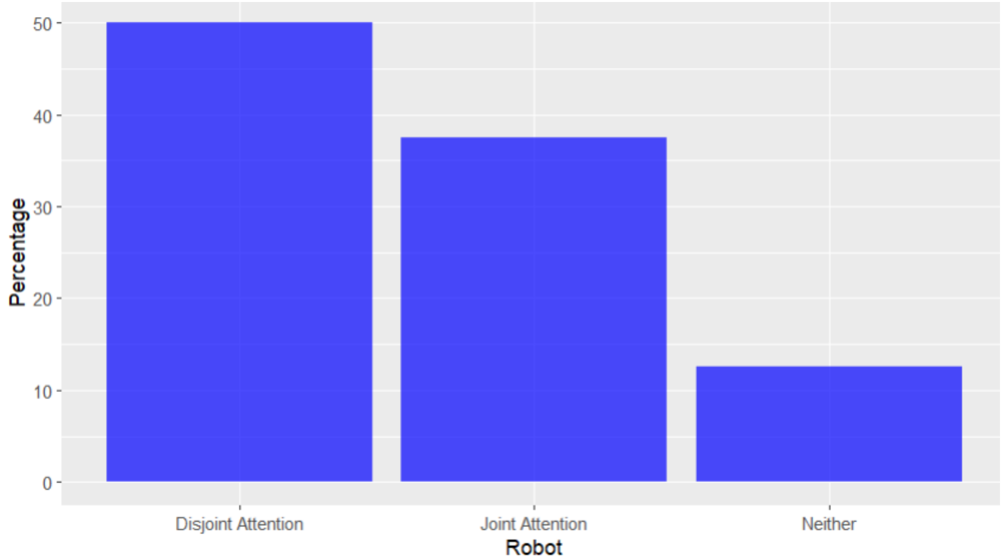


Hypothesis 2: A Robot That Engages in Joint Attention Will Have a Higher Trust Score One Week After the Interaction Has Taken Place Than a Robot That Does Not Engage in Joint Attention

During the second trust measure, the participants were asked to choose which of the two robots they rated as more trustworthy one week prior, during the first session. The data show that 37.5% chose the robot that was the joint attention robot as the most trustworthy robot, 50% chose the disjoint robot as the most trustworthy and the remaining 12,5% chose neither, see Figure 6.

Figure 6

The Proportion of Participants Preferring Each Robot During the Second Session



To test the second hypothesis, a logistic regression was used. In this regression, joint attention was the independent variable and trust at t=1 was the dependent categorical variable with two values allowing for a Logistic binomial regression. The regression revealed no significant association between joint attention and trust at t=1 (χ^2 (1, N = 80) = 1.72, p = 0.261). The regression coefficient for joint attention was not statistically significant (B = -0.51, SE = 0.45, z = -1.12, p = .261). The intercept was not significantly different from zero (B = 0.00, SE = 0.32, z = 0.00, p = 1.00).

The influence of joint attention on the net-promoter score in the second session was measured using a Wilcoxon test A parametric test could not be used as the data does not show a normal distribution. Therefore, a Wilcoxon test was used. This test shows no significant differences in the net-promoter score based on joint attention W = 728.5, p = 0.489.

Albeit there was not a significant difference in trust scores due to the presence of joint attention, there was a strong correlation between the trust scores in the first and second sessions (χ^2 (1, N = 80) = 25.77, p < .001). This was tested using a Logistic binomial regression. In this model, the most trusted robot (a score of 0 indicated the robot was not the most trusted and a score of 1 indicated the robot was most trusted) was the independent variable and the trust score at t=1 was the dependent variable. The trust score at t=1 was a binary and therefore a Logistic binomial regression could be used. The regression coefficient for most trusted at t=0 was statistically significant ($B = 2.51$, $SE = 0.55$, $z = 4.60$, $p < .001$). Therefore, we can assume that robots that were most trusted at t=0 will also be most trusted at t=1. The intercept was significantly different from zero ($B = -1.58$, $SE = 0.42$, $z = -3.81$, $p < .001$).

Discussion

The study investigated the relationship between joint attention and trust in human-robot interaction. Participants interacted with robots showing either joint attention or disjoint attention. Trust was measured immediately after the interaction with the robot and one week later. The results showed no significant increase in trust due to joint attention during both these sessions. This was tested by looking at trust scores gained from a 14-item scale and from a net-promoter score that is assumed to be correlated with trust scores. However, there was a significant correlation between trust levels immediately after the interaction and one week later. These findings suggest that while joint attention may not directly enhance trust in the short term, initial trust levels promise persistent long-term trust perceptions in human-robot interaction. These results contradict the first two hypotheses that predicted that joint attention significantly increases both short- and long-term trust.

Comparing Outcomes to Literature

Comparing the findings with existing literature reveals interesting insights. Studies by De Jong and Dijkerman (2019) and Wolf et al. (2015) show contradicting conclusions to the results from this study. While they suggest a significant impact of joint attention on trust levels, our study, focusing on human-robot interaction, did not find such a correlation. This difference could suggest that the effect of joint attention on trust may differ between human-human and human-robot interaction. A study by Admoni and Scassellati (2017) has a similar focus as this study as they are likewise focusing on a human-robot relationship. However, their conclusions are contradictory to the findings of this study. This could be explained by differences in environmental and contextual factors in which the studies were conducted. In their study, the participants had more interaction with the robot which is different from this study. Another study by Kahn et al. (2007) also found a link between joint attention and trust. However, their study focuses on children, indicating that age might influence the effect of joint attention on trust. Furthermore, a study by Ham et al. (2015) found that robots that use their gaze to initiate joint attention are perceived as more trustworthy. This contradicting finding can be explained by the focus on collaborative robots that were used in that study as opposed to the static robots in this study. In contrast, the results of this study are similar to a study by Złotowski et al. (2018) which shows that the impact of joint attention on trust might be less effective during an initial interaction. They suggest that a longer and more intense interaction with joint attention is needed to enhance trust. This can explain why trust scores did not increase seeing as the participants only had a short interaction with the robot. The difference in outcome between this study and most existing literature can be explained by several factors: the type of interaction, the design of the robot and the duration of the interaction with the robot. Therefore, while the literature proves that joint attention has a positive effect on trust, the findings from this study show that this effect might be context-dependent.

Limitations and Future Research Directions

As mentioned before, the results of this study are not in line with the expectations. This might be because the effect of joint attention on trust is context-dependent and other studies that have a very similar set-up as this experiment will obtain the same results. However, it is also possible that other factors were responsible for the results. In this paragraph, these factors will be discussed as possible limitations of this study. To start with, we look at the set-up of the experiment. When conducting the first session, many participants seemed to be looking for an underlying pattern in the visual cues of the robots. They often verbally expressed that they wanted to click on the “right” object, expecting the robot to look at certain objects in a pattern. Therefore, they might not solemnly be choosing between two objects and unconsciously registering the eye movements but rather pay close attention to the eye movements and try to discern patterns. This would have decreased the effect of joint attention as the participants did not see the eye movements as joint attention but as clues for the right choice. This would mean that the trust scale was not based on the presence of joint attention but on other factors.

Additionally, the study design does not give participants an opportunity to have a good interaction with the robots. The 14-item scale is designed to measure trust between humans and robots after they have had an interaction. In the experiment, the interaction is indirect since the participants are focused on choosing an object and not interacting with the robot. When the participants were given the trust perception scale, they often mentioned that they had no idea what to fill in since they had not had a real interaction with the robot.

Furthermore, it can be assumed that other factors play a more important role in the trust perception. Many participants expressed that they perceived one of the robots as "weird"," creepy" or other such terms. This could mean that the participants already formed an opinion about both robots before interacting with them and registering joint or disjoint attention. This occurrence was expected and controlled by using counterbalancing. However, it seems that the likability of a robot predicted the trust score more than joint attention. This claim is partly supported by literature on the relationship between trust and likability in human-robot interaction. A study by Zhu et al. (2023) shows that trust levels in robots increase when persons are interacting with the robot in a task and indicate an increased likability of the robot. However, another study by Kraus et al. (2018) suggests the opposite with their finding that more trust does not lead to more likability, denying a correlation between the two factors. The varying results on the relationship between trust and likability can be explained by the dynamic nature of trust, especially in the new and upcoming field of human-robot interaction of which not much is known yet (Rhim et al., 2023). Appendix E includes a graph showing the trust scores for each robot. This graph indicates that there is a slight difference in trust scores between the two robots. However, this does not mean that the likability was not a factor in the trust score since likability of a robot is different for each participant. To better understand the role of joint attention on trust with likability potentially being an interpretation in this relationship, more research needs to be done in this field.

The time between the two sessions might also present a limitation. The choice for one-week between the sessions was a conscious decision. However, a study design where trust is measured over a longer period with more measurement points would have given a more accurate picture of the trust perception over time. This could also offer an opportunity to have more controlled measurements and address the limitation that the second session was executed in an uncontrolled environment. As can be seen in earlier cited literature, a longer time could also offer more interaction between participant and robot, making the effect of joint attention stronger.

Moreover, a limitation could be the use of the 14-item scale instead of the larger 40-item scale. The benefit of using the short scale was more concentration from the participants for each item since the survey did not take too long to fill in. However, some important aspects of trust might not have been covered with the 14-item scale. Therefore, for a future experiment, the 40-item scale or another scale that is more adapted to this specific study design could be used to cover more aspects of trust between humans and robots. The addition of the net-promoter score as another means of measuring the trust might not have been enough to offer this.

Another point to consider is the choice of having two robots instead of one, which might have affected the study's outcomes. The two robots gave the opportunity to have a within-study design but might have led to the confounding variable of the likability of the robot that had a more direct impact on trust than the presence of joint attention. The original experiment of Willemse et al. (2018) used only one robot which limited the confounding variable of likability. It would be interesting to see whether the results would remain the same if this study were also conducted with a between-subjects design with only one robot.

Lastly, the sample used for this experiment was not big enough to offer a normal distribution in the trust scores. The sample was gathered using convenience sampling using mostly participants from the University of Twente and family members. In future studies that investigate similar effects, a more varying and bigger sample size would offer a less biased outcome and possibly a normal distribution in the trust scores.

Directions for future research are to keep these limitations in mind. It would be beneficial to use this study design with a real robot instead of a robot face on a screen. This would allow the participants to have a more real interaction with the robot. The original goal of this study was to investigate social mechanisms that can be used in real-life robots. Having a real-life robot would mimic this practical setting better than a robot face on a screen.

Meaningful Contributions and Practical Implications

As mentioned in the introduction, research on the long-term effects of joint attention in robot behaviour regarding trust is somewhat limited. This study offers future researchers a starting point to create a new and potentially better study design to investigate long-term trust in human-robot interaction. This study also offers a new angle showing that the relationship between joint attention and trust in a human-robot relationship might be non-existent under specific circumstances.

Several practical implications can be derived from this study. Firstly, this study shows that initial trust is a good predictor for long-term trust. Although this initial or long-term trust did not correlate with joint attention, it is important to note that, when initial trust is formed, this trust will also be perceived at a later point in time. This is useful when designing social robots that would help people in a daily setting. If a robot is perceived as trustworthy by its user at the start, not many adjustments have to be made to keep that trust perception towards the robot. To properly investigate this, research needs to be done specifically targeted at long-term trust.

A second practical implication derived from this study could be the way humans perceive robots on the first interaction. By observing the participants during the first session, it is clear that they were consciously registering what the robot was doing and trying to derive the meaning behind the cues of the robot could be. Many participants thought that the eye movements were clues as to which object they should choose. This could mean that humans try to attribute intentions to the behaviour of a robot, even at an initial interaction. This suggests that the design of non-verbal features of a robot plays an important role in the user's perception and interpretations. If these non-verbal cues are used properly during a first interaction with a robot, it could enhance likeliness and trustworthiness in the human-robot interaction.

Conclusion

This study examined the role of joint attention on trust in human-robot interaction, finding no significant relationship between the two variables. However, there was a significant correlation between initial trust and long-term trust. This lack of relationship between joint attention and trust contradicts the hypotheses and previous literature. The focus of the participants on pattern recognition and robot likability could explain these unexpected outcomes. It is also possible that limitations of the study design contributed. Therefore, more research with an improved study design is needed to investigate the relationship between joint attention and trust. Directions for this research are to use a longer period with more measurement times to measure long-term trust and use real-life robots. Despite its limitations, this research offers valuable insights into trustworthy social robots, highlighting the importance of initial trust and effective non-verbal cues for trust in a human-robot relationship.

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Appendix A

Survey about Jim and Bob respectively

Trust in human robot interaction (first session Jim)

Start of Block: Block 1

Q8 What is your participant number?

____

Q14 What is your date of birth?

____

Q16 What is your gender

- Female (1)
- Male (2)
- Prefer not to say (3)

End of Block: Block 1

Start of Block: Default Question Block

Q5 Thank you for participating in this study. In this survey, you will be asked to judge the robot that you just interacted with named **Jim** (see picture below).

To answer these questions, please imagine that you would have to interact and cooperate with this robot in a daily setting (eg. this robot is helping you to do home chores or is taking care of you in a hospital). Underneath the questions, more information is provided if you need an explanation of what the items meant. You do not have to look at the this, if you can understand all the item texts. If you have questions, please let the researcher know.

Q11 How often will this robot be ...

	ever (27)	lick to write Scale Point 2 (28)	lick to write Scale Point 3 (29)	lick to write Scale Point 4 (30)	lick to write Scale Point 5 (31)	alf of the time (32)	lick to write Scale Point 7 (33)	lick to write Scale Point 8 (34)	lick to write Scale Point 9 (35)	lick to write Scale Point 10 (36)	lways (37)
Dependable (1)	○	○	○	○	○	○	○	○	○	○	○
Reliable (2)	○	○	○	○	○	○	○	○	○	○	○
Unresponsive (3)	○	○	○	○	○	○	○	○	○	○	○
Predictable (4)	○	○	○	○	○	○	○	○	○	○	○

Q12 How often will this robot ...

	ever (1)	lick to write Scale Point 2 (4)	lick to write Scale Point 3 (5)	lick to write Scale Point 4 (6)	lick to write Scale Point 5 (7)	alf of the time (8)	lick to write Scale Point 7 (9)	lick to write Scale Point 8 (10)	lick to write Scale Point 9 (11)	lick to write Scale Point 10 (12)	lways (13)
Act consistently (1)											
Provide feedback (2)											
Meet the needs of the task (3)											
Provide appropriate information (4)											
Communicate with people (5)											
Perform exactly as instructed (6)											

Follow directions (7)	○	○	○	○	○	○	○	○	○	○	○
Function succesfully (8)	○	○	○	○	○	○	○	○	○	○	○
Have errors (9)	○	○	○	○	○	○	○	○	○	○	○
Malfunction (10)	○	○	○	○	○	○	○	○	○	○	○

Q6 **Function successfully**: Measures the overall effectiveness and efficiency of the robot in performing its intended tasks or functions.

Act consistently: Measures the degree to which the robot's behavior remains stable and predictable over time and across different situations.

Reliable: Similar to dependability, this item evaluates the robot's consistency and trustworthiness in fulfilling its role or duties.

Predictable: Assesses the consistency and foreseeability of the robot's actions or behavior.

Dependable: Assesses the reliability and consistency of the robot's performance over time.

Follow directions: Assesses the robot's compliance with specific instructions or commands provided by human users or team leaders.

Meet the needs of the task: Measures the robot's effectiveness in fulfilling the requirements or objectives of a given mission, assignment, or task.

Perform exactly as instructed: Assesses the robot's adherence to precise instructions or commands without deviation or error.

Have errors: Measures the occurrence or frequency of mistakes, inaccuracies, or faults in the robot's functioning or behavior.

Provide appropriate information: Evaluates the relevance, accuracy, and usefulness of the information provided by the robot to human users or team members.

Malfunction: Assesses the frequency or likelihood of technical failures or errors in the robot's operation. **Communicate with people**: Assesses the robot's proficiency and effectiveness in interacting and communicating with human users or team members.

Provide feedback: Measures the robot's capability to offer constructive feedback, information, or guidance to human users or team members.

Unresponsive: Measures the extent to which the robot fails to react or respond appropriately to stimuli or commands.

End of Block: Default Question Block

Start of Block: Block 3

Q12 **Jim**

Q17 Please rate your impression of the robot on these scales:

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	
Fake	○	○	○	○	○	Natural
Machinelike	○	○	○	○	○	Humanlike
Unconscious	○	○	○	○	○	Conscious
Artificial	○	○	○	○	○	Lifelike
Moving rigidly	○	○	○	○	○	Moving elegantly

Q18 Please rate your impression of the robot on these scales:

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	
Dislike	○	○	○	○	○	Like
Unfriendly	○	○	○	○	○	Right
Unkind	○	○	○	○	○	Kind
Unpleasan t	○	○	○	○	○	Pleasan t
Awful	○	○	○	○	○	Nice

Q13 How likely are you to recommend Jim to a friend or colleague to use in a daily setting?

○ 0 (0)

○ 1 (1)

○ 2 (2)

○ 3 (3)

○ 4 (4)

○ 5 (5)

○ 6 (6)

○ 7 (7)

○ 8 (8)

○ 9 (9)

○ 10 (10)

End of Block: Block 3

Start of Block: Block 2

Q9 This experiment consists of 2 parts. For the second part, we need your email to send the follow up survey. This is the only email you will receive from us, nothing else will be done with your email address. If you do not want to give us your email, you can fill in "-".

Fill in your email here:Click to write the question text

____

End of Block: Block 2

Trust in human robot interaction (first session Bob)

Start of Block: Block 1

Q10 What is your participant number?

____

Q19 What is your date of birth?

____

Q20 What is your gender

○ Female (1)

○ Male (2)

○ Prefer not to say (3)

End of Block: Block 1

Start of Block: Default Question Block

Q5 Thank you for participating in this study. In this survey, you will be asked to judge the robot that you just interacted with named **Bob** (see picture below).

To answer these questions, please imagine that you would have to interact and cooperate with this robot in a daily setting (eg. this robot is helping you to do home chores or is taking care of you in a hospital). Underneath the questions, more information is provided if you need an explanation of what the items meant. You do not have to look at the this, if you can understand all the item texts. If you have questions, please let the researcher know.

Q12 How often will this robot be ...

	ever (1)	lick to write Scale Point 2 (2)	lick to write Scale Point 3 (3)	lick to write Scale Point 4 (4)	lick to write Scale Point 5 (5)	alf of the time (6)	lick to write Scale Point 7 (7)	lick to write Scale Point 8 (8)	lick to write Scale Point 9 (9)	lick to write Scale Point 10 (10)	lways (11)
Dependable (1)	○	○	○	○	○	○	○	○	○	○	○
Reliable (2)	○	○	○	○	○	○	○	○	○	○	○
Unresponsive (3)	○	○	○	○	○	○	○	○	○	○	○
Predictable (4)	○	○	○	○	○	○	○	○	○	○	○

Q13 How often will this robot ...

	ever (1)	lick to write Scale Point 2 (2)	lick to write Scale Point 3 (3)	lick to write Scale Point 4 (4)	lick to write Scale Point 5 (5)	alf of the time (6)	lick to write Scale Point 7 (7)	lick to write Scale Point 8 (8)	lick to write Scale Point 9 (9)	lick to write Scale Point 10 (10)	lways (11)
Act consistently (1)											
Provide feedback (2)											
Meet the needs of the task (3)											
Provide appropriate information (4)											
Communicate with people (5)											
Perform exactly as instructed (6)											

Follow directions (7)	○	○	○	○	○	○	○	○	○	○	○
Function sucesfully (8)	○	○	○	○	○	○	○	○	○	○	○
Have errors (9)	○	○	○	○	○	○	○	○	○	○	○
Malfunction (10)	○	○	○	○	○	○	○	○	○	○	○

Q17 **Function successfully**: Measures the overall effectiveness and efficiency of the robot in performing its intended tasks or functions.

Act consistently: Measures the degree to which the robot's behavior remains stable and predictable over time and across different situations.

Reliable: Similar to dependability, this item evaluates the robot's consistency and trustworthiness in fulfilling its role or duties.

Predictable: Assesses the consistency and foreseeability of the robot's actions or behavior.

Dependable: Assesses the reliability and consistency of the robot's performance over time.

Follow directions: Assesses the robot's compliance with specific instructions or commands provided by human users or team leaders.

Meet the needs of the task: Measures the robot's effectiveness in fulfilling the requirements or objectives of a given mission, assignment, or task.

Perform exactly as instructed: Assesses the robot's adherence to precise instructions or commands without deviation or error.

Have errors: Measures the occurrence or frequency of mistakes, inaccuracies, or faults in the robot's functioning or behavior.

Provide appropriate information: Evaluates the relevance, accuracy, and usefulness of the information provided by the robot to human users or team members.

Malfunction: Assesses the frequency or likelihood of technical failures or errors in the robot's operation. **Communicate with people**: Assesses the robot's proficiency and effectiveness in interacting and communicating with human users or team members.

Provide feedback: Measures the robot's capability to offer constructive feedback, information, or guidance to human users or team members.

Unresponsive: Measures the extent to which the robot fails to react or respond appropriately to stimuli or commands.

End of Block: Default Question Block

Start of Block: Block 2

Q28 **Bob**

Q23 Please rate your impression of the robot on these scales:

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	
Fake	○	○	○	○	○	Natural
Machinelik e	○	○	○	○	○	Humanlik e
Unconscio us	○	○	○	○	○	Consciou s
Artificial	○	○	○	○	○	Lifelike
Moving rigidly	○	○	○	○	○	Moving elegantly

Q24 Please rate your impression of the robot on these scales:

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	
Dislike	○	○	○	○	○	Like
Unfriendly	○	○	○	○	○	Friendly
Unkind	○	○	○	○	○	Kind
Unpleasant	○	○	○	○	○	Pleasant
Awful	○	○	○	○	○	Nice

Q15 How likely are you to recommend Bob to a friend or colleague to use in a daily setting?

- 0 (0)
- 1 (1)
- 2 (2)
- 3 (3)
- 4 (4)
- 5 (5)
- 6 (6)
- 7 (7)
- 8 (8)
- 9 (9)
- 10 (10)

End of Block: Block 2

Appendix B

Second survey

Trust in human robot interaction (Second session)

Start of Block: Block 1

Q7 What is your participant number?

____

End of Block: Block 1

Start of Block: Default Question Block

Q8 Which robot did you rate as more trustworthy one week ago?

○ Jim (1)

○ There is no difference in trustworthiness between the two robots (2)

○ Bob (3)

Q9 How likely are you to recommend Jim to a friend or colleague to use in a daily setting?

- ○ 0 (0)
- ○ 1 (1)
- ○ 2 (2)
- ○ 3 (3)
- ○ 4 (4)
- ○ 5 (5)
- ○ 6 (6)
- ○ 7 (7)
- ○ 8 (8)
- ○ 9 (9)
- ○ 10 (10)

Q10 How likely are you to recommend Bob to a friend or colleague to use in a daily setting?

○ 0 (0)

○ 1 (1)

○ 2 (2)

○ 3 (3)

○ 4 (4)

○ 5 (5)

○ 6 (6)

○ 7 (7)

○ 8 (8)

○ 9 (9)

○ 10 (10)

End of Block: Default Question Block

Appendix C

Conditions

Table 2

Distribution of Participants over the Different Conditions

Participant	Joint attention robot	No joint attention robot	List	Survey first given is about robot …
1, 5, 9, 13, 17, 21	Bob	Jim	1	Bob
2, 6, 10, 14, 18, 22	Jim	Bob	2	Bob
3, 7, 11, 15, 19, 23	Bob	Jim	1	Jim
4, 8, 12, 16, 20, 24	Jim	Bob	2	Jim

To limit confounding variables, the disjoint and joint attention robot is different per participant. Some participants get Bob as the joint attention robot and the other half will get Jim as the joint attention robot. This translated into “lists” that needed to be selected when running the experiment in PsychoPy. Also, per participant, there is a difference in which survey is given first. For some participants, the survey about Bob is given first and for the other half it is Jim.

Appendix D

Participant data

Table 3

Explanation for the Table Containing the Data

Robot	
0	Bob
1	Jim
Time	
0	first session
1	second session
Joint attention	
0	no
1	yes
Trust (t=1)	
0	Not chosen
1	Chosen

Table 4
Participant Data

Participant	Robot	Joint attention	Trust (t=0)	Most trusted (t=0)	Net promotor score (t=0)	Trust (t=1)	Net promotor score (t=1)

1	0	1	7,07	1	6	0	7
1	1	0	6,21	0	7	0	3
101	0	1	8,07	1	7	0	2
101	1	0	7,57	0	8	1	7
2	0	0	2,86	0	0	0	3
2	1	1	7,5	1	9	1	8
102	0	0	7,71	1	6	1	7
102	1	1	5,79	0	2	0	3
3	0	1	9,64	1	5	0	3
3	1	0	9,43	0	5	0	7
103	0	1	5,43	0	3	0	4
103	1	0	7	1	5	1	7
4	0	0	6,64	0	4	0	4
4	1	1	7,64	1	6	1	8
104	0	0	5,21	0	3	0	5
104	1	1	5,93	1	6	1	7
5	0	1	9,43	1	8	1	8
5	1	0	2,64	0	0	0	2
105	0	1	6,14	1	7	1	6
105	1	0	5,14	0	0	0	0
6	0	0	8,29	1	4	1	6
6	1	1	4,21	0	2	0	3
106	0	0	9,5	0	7	0	7
106	1	1	10,14	1	8	1	8
7	0	1	1,86	0	1	0	1
7	1	0	2,71	1	1	0	1
107	0	1	6,64	0	5	0	4
107	1	0	8,93	1	8	1	7
8	0	0	5,36	0	8	0	7
8	1	1	7,21	1	9	1	7
108	0	0	7,21	1	7	1	8

108	1	1	6,64	0	6	0	5
9	0	1	9,57	1	10	1	10
9	1	0	1	0	0	0	0
109	0	1	6,57	0	7	0	7
109	1	0	6,79	1	8	0	5
10	0	0	5,93	0	6	1	7
10	1	1	7,71	1	3	0	3
110	0	0	7,21	0	3	0	2
110	1	1	7,5	1	4	1	4
11	0	1	6,71	0	10	0	8
11	1	0	9,36	1	0	1	6
111	0	1	5,14	0	3	0	2
111	1	0	5,93	1	5	1	5
12	0	0	5,36	0	0	0	1
12	1	1	9,07	1	9	1	8
112	0	0	7,21	1	6	1	7
112	1	1	5,71	0	4	0	5
13	0	1	7,14	0	7	0	6
13	1	0	7,43	1	8	1	7
113	0	1	7,86	0	6	0	6
113	1	0	7,93	1	6	1	6
14	0	0	5,79	0	4	0	4
14	1	1	7,07	1	6	1	7
114	0	0	7,36	0	4	1	7
114	1	1	8,21	1	5	0	6
15	0	1	8,36	0	5	0	7
15	1	0	8,43	1	6	1	8
115	0	1	7,43	0	7	0	7
115	1	0	7,62	1	7	1	7
16	0	0	5,93	0	7	1	7
16	1	1	6,93	1	6	0	6

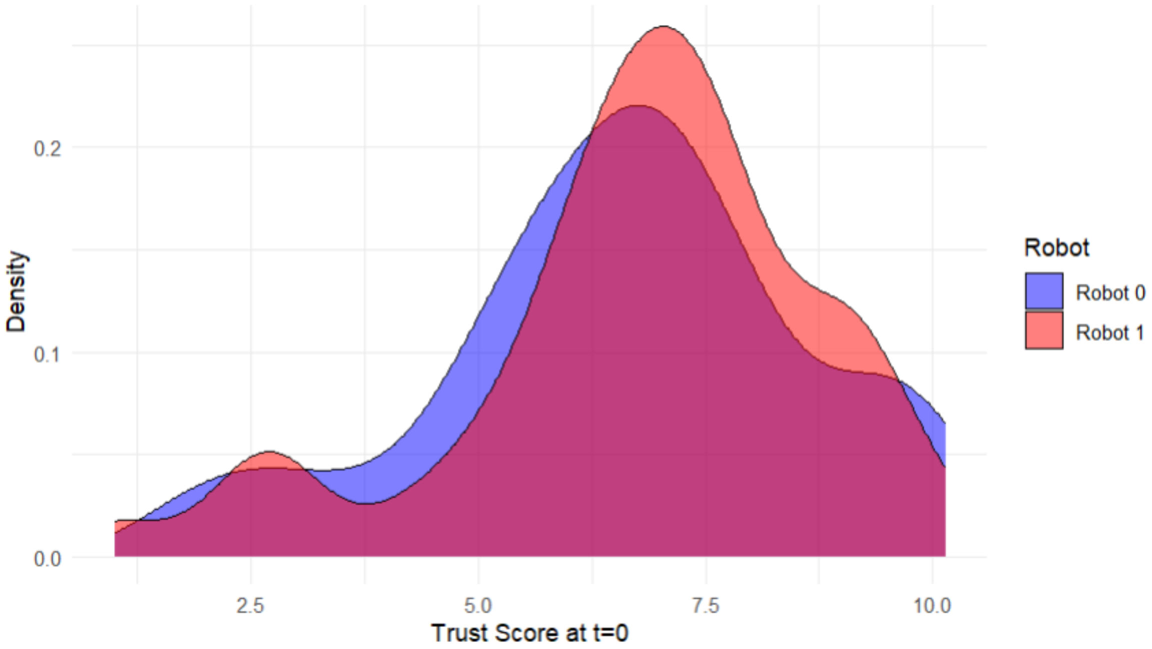
116	0	0	4,64	0	1	0	0
116	1	1	6,29	1	6	1	3
17	0	1	9,79	1	9	1	8
17	1	0	6,5	0	0	0	2
117	0	1	4,14	0	3	0	6
117	1	0	4,93	1	5	1	8
18	0	0	3,21	0	1	0	0
18	1	1	9	1	6	1	3
118	0	0	10,07	1	9	1	8
118	1	1	9,07	0	3	0	6
19	0	1	6,43	0	5	1	5
19	1	0	6,71	1	3	0	3
119	0	1	6,79	0	5	0	6
119	1	0	6,79	0	6	1	7
20	0	0	6,21	0	7	1	6
20	1	1	6,5	1	4	0	4
120	0	0	2,14	0	1	0	1
120	1	1	2,71	1	0	0	1

Appendix E

Trust score per Robot

Figure 7

Distribution of Trust Scores During the First Session (t=0) for Bob (Robot 0) and Jim (Robot 1)



Appendix F

R Code

```
#load packages needed
library(readxl)
library(tidyverse)
library(readxl)

#load data
Bob <- read_excel("experiment thesis.xlsx", sheet = "Bob")
Jim <- read_excel("experiment thesis.xlsx", sheet = "Jim")
All <- read_excel("experiment thesis.xlsx", sheet = "All")
Items <- read_excel("experiment thesis.xlsx", sheet = "Items")

#Calculate cronbach alpha
data_subset <- items[, c("Dependable", "Reliable", "Unresponsive (reverse coded)",
                         "Predictable", "Act consistently", "Malfunction (reverse coded)",
                         "Provide feedback", "Meet the needs of the task",
                         "Provide appropriate information", "Communicate with people",
                         "Perform exactly as instructed", "Follow directions",
                         "Function sucesfully", "Have errors (reverse coded)")]

data_subset <- na.omit(data_subset)

cronbach_result <- cronbach.alpha(data_subset)
print(cronbach_result)

#remove missing data
All <- na.omit(All)

# Subset the data to include only rows where Joint attention is 0
no_joint_attention <- subset(All, Joint_attention == 0)

# Calculate mean and standard deviation of Trust (t=0) when there is no joint attention
```

```
mean_trust <- mean(no_joint_attention$Trust_t.0)
sd_trust <- sd(no_joint_attention$Trust_t.0)

# Print mean and standard deviation
cat("Mean Trust at t=0 with no joint attention:", mean_trust, "\n")

# Subset the data to include only rows where Joint attention is 1
joint_attention <- subset(All, Joint_attention == 1)

# Calculate mean and standard deviation of Trust (t=0) when there is joint attention
mean_trust <- mean(joint_attention$Trust_t.0)
sd_trust <- sd(joint_attention$Trust_t.0)

# Print mean and standard deviation
cat("Mean Trust at t=0 with joint attention:", mean_trust, "\n")

# Load necessary library
library(ggplot2)

# Plot
ggplot(All, aes(x = joint_attention_data, y = trust_t1)) +
  geom_boxplot() +
  labs(x = "Joint Attention", y = "Trust at t=0") +
  theme_minimal()

# Create a density plot for Trust at t=0
ggplot(All, aes(x=`Trust (t=0)`)) +
  geom_density(fill="blue", alpha=0.5) +
  labs(title="Density Plot of Trust at t=0",
       x="Trust at t=0",
       y="Density") +
  theme_minimal()

# Perform the Wilcoxon rank-sum test
```

```
result <- wilcox.test(`Trust (t=0)` ~ `Joint attention`, data = All, paired = FALSE, correct = TRUE)

# Display the results
print(result)

# Perform the Wilcoxon rank-sum test
result <- wilcox.test(`Net promotor score (t=0)` ~ `Joint attention`, data = All, paired = FALSE, correct = TRUE)

# Display the results
print(result)

# Fit the logistic regression model
logistic_model <- glm(`Trust (t=1)` ~ `Joint attention`, data = All, family = binomial())

# Display the summary of the model
summary(logistic_model)

# Perform the Wilcoxon rank-sum test
result <- wilcox.test(`Net promotor score (t=1)` ~ `Joint attention`, data = All, paired = FALSE, correct = TRUE)

# Display the results
print(result)

# Create a density plot
ggplot(All, aes(x=`Trust (t=0)`, fill=factor(Robot...2))) +
  geom_density(alpha=0.5) +
  labs(title="Distribution of Trust Scores at t=0 for Robot 0 and Robot 1",
       x="Trust Score at t=0",
       y="Density",
       fill="Robot") +
  scale_fill_manual(values=c("blue", "red"),
```

```
                labels=c("Robot 0", "Robot 1")) +
  theme_minimal()

# Bar chart for trust preference one week later
trust_preference <- data.frame(
  Robot = c("Joint Attention", "Disjoint Attention", "Neither"),
  Percentage = c(37.5, 50, 12.5)
)

ggplot(trust_preference, aes(x = Robot, y = Percentage)) +
  geom_bar(stat = "identity", fill = "blue", alpha = 0.7) +
  labs(title = "Proportion of Participants Preferring Each Robot One Week Later",
       x = "Robot",
       y = "Percentage")
```