# Exploring the Influence of Theory of Mind Variability on Gaze Leading and Return to Face Onset Times

Tim Lentjes (s2480506)

Faculty of Behavioural, Management and Social Science (BMS), University of Twente

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Supervisor: Dr. Cesco Willemse

Second Supervisor: Dr. Martin Schmettow

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## Abstract

**Background:** Previous research has established a clear link between establishing joint attention through gaze leading and return-to-face saccade onset times. This return gaze typically slows down toward agents who attend to a non-selected object relative towards agents who do frequently follow the gaze of the participant. However, the role of the agents' individual predispositions (i.e. whether they typically respond with joint attention) in this process is still unclear.

**Objective:** The current study was conducted to explore if individual differences in the Theory of Mind ability have a moderating effect on sensitivity to gaze leading and the consequent return to face saccade. Additionally, the Uncanny Valley Effect was incorporated to assess the effect of differences in human likeness on return-to-face onset times.

**Methods**: The study consisted of an experimental part with a mixed factorial design. Participants completed an object selection task, being presented with 6 different faces ranging from robot to uncanny to human-like. Subsequently, participants were presented with the Godspeed, AQ-10 and MASC (selected items) questionnaires.

**Results:** The study failed to replicate the previously established link between joint attention, gaze leading and return to saccade onset times.

**Conclusion:** The study's results suggest that more research into replicability is necessary to better understand the aforementioned relationships.


*Keywords: Joint attention, Gaze Leading, Uncanny Valley Theory, Theory of Mind, human-robot interaction*

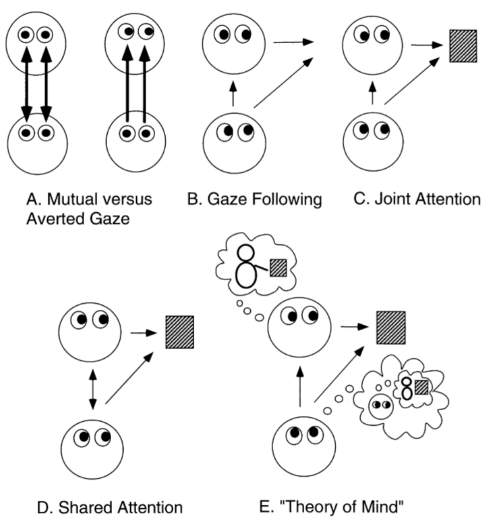
# Exploring the Influence of Theory of Mind Variability on Gaze Leading and Return to Face Onset Times

In our day-to-day lives, the eyes of others play an important role in social interactions. We can extract a wealth of information from the eye region in the human face. Using the eyes, we can infer emotional states, intentions and facial identity (Itier & Batty, 2009) Moreover, by looking at the eyes we spontaneously extract the attentional direction of other individuals. This ability is essential to comprehend the inner state of the people we encounter. The fact that we can display and perceive these subtle stimuli can be attributed to the requirements of living in large social groups (Emery, 2000). Our ability to process and understand this type of information relies on our understanding that the eyes are used to capture information about the world around us. Emery (2000) suggests this skill may only be present in primates. The information from the eyes we receive in this manner can even be used to determine information about social status in a dominance hierarchy, using a mechanism called social gaze.

An important aspect of gaze in social interaction is determining the spatial attentional allocation of another person. The direction of an individual's gaze gives insight into what external stimuli the other is looking at. Furthermore, this insight is thought to provide a deeper understanding of more complex underlying emotional, cognitive and social processes (Emery, 2000). Thus to receive the aforementioned information we need to follow the gaze of the other individual whose mental state we try to uncover. This will be referred to from now on as gaze following. When an individual follows the gaze of another and both individuals direct their gaze to the same external object this creates a situation called joint attention. When both individuals become aware of their joint attention state, this state is called shared attention and it is slightly more complex than the former, as it requires active awareness of the shared mental state (Emery, 2000).

**Figure 1**

*Schematic representation of various situations where gaze plays an important role in social context (Emery, 2000).*




The ability for joint attention develops in early infancy and is considered a fundamental requirement for the maturation of a child (Emery, 2000). Joint attention is believed to play a role in early language development by connecting spoken words to physical objects (Emery, 2000; Frischen et al., 2007). An important mechanism of initiating joint attention in infants is the movement of the eyes. If the ocular fixation is static, joint attention will not be established between the social object (agent) and the child (Farroni et al., 2003, 2004). This previous research emphasises the importance of pupil motion as an important factor for initiating joint attention in infancy. In that light, it is interesting to note that humans have an advantage in determining gaze direction due to their relatively small pupil and iris and larger white sclera than other primates (Kobayashi & Kohshima, 1997). Moreover, joint attention also plays a major role in the development of social cognition as it allows for discerning other individuals' intentions (Frischen et al., 2007). Once an infant has acquired the fundamental mechanics for joint attention it can learn to infer mental states from others' gaze.

As mentioned, an important function of gaze is to orient the gaze of others onto specific objects in our environment. The role of eye gaze direction and its effects on shifts in attention orientation have extensively been studied (Frischen et al., 2007). Research shows that when a face is centrally presented and objects are presented on the left or right sides of the aforementioned face, participants are quicker to shift their attention to the target when the gaze direction of the face is in a similar direction and longer when the gaze is directed towards the opposed target (Itier & Batty, 2009). These experiments, in which the participant responds to a stimulus' gaze shift, are referred to as gaze cueing paradigms, as they aim to initiate a shift in attentional direction.

On the other hand, paradigms in which the participant initiates a gaze shift to which the stimulus may respond, are known as gaze-leading. More specifically, the time it takes for an individual to reorient to the face after attention has been shifted to an object is referred to as return-to-face saccade onset time. In a series of experiments, Bayliss et al. (2013) showed that people are faster to shift their attention back towards agents who followed their gaze and thus established joint attention, compared with towards agents with whom joint attention was not established. Their findings further imply that we prefer agents that follow our gaze direction and find them more likeable. The researchers argue that this is an attempt to facilitate a state of shared attention caused by underlying mechanisms. This tendency may be important for social functioning, coordination and collaboration.

Given more recent technological advances, it is sensible to examine whether these mechanisms extend to interactions with humanlike robots, which can be perceived as unique social agents. Research by Willemse et al. (2018) aimed to bridge the gap of knowledge between the mechanisms of joint attention in human-human relationships and investigate the role of social gaze in human-robot interactions. The research modified the previous gaze-leading paradigms, to incorporate a human-like robot avatar in their screen-based experiment. The results of this experiment indicated that not only participants were quicker to redirect their attention to the robots' faces when joint attention was established, but robots in the joint attention condition were also perceived as more likeable. In a follow-up study, Willemse and Wykowska (2019) tested the ecological validity of their previous findings. Instead of conducting a screen-based experiment with virtual avatars, the researchers conducted their experiment using an embodied robot. This research replicated the findings of previous research that in the joint attention condition return-to-face saccade onset times were returned to face time slowed down when the expected pattern was broken and the agent did not follow the participant’s gaze. In a third study, Willemse et al. (2021) examined whether motor responses mimic the previously established relationship between return-to-face saccade onset times and joint or disjoint attention. The research concluded that the manual behaviour (i.e. mouse responses) resulted in similar results as the studies using eye-tracking. However, the study failed to explain individual differences in response times.

## Theory of Mind

An important concept related to joint attention and shared attention is the Theory of Mind. The concept of Theory of Mind refers to the ability to understand other individuals' mental states, including desires, beliefs and intentions (Emery, 2000; Frischen et al., 2007; Itier & Batty, 2009). The fact that the concept is referred to as a “theory” is because we are not able to directly ‘look’ into the mind of another individual, but rather rely on making presumptions about their mental state based on information presented to us (Itier & Batty, 2009). Following from the important role that gaze plays in understanding other individuals' mental states, the ability to follow gaze and establish joint and shared attention are considered important developmental precursors to the development of the Theory of Mind. Individuals differ in their ability to make these inferences about mental states. The relationship between the Theory of Mind and Joint Attention is studied by Shaw et al. (2017), and their findings indicate that these two concepts arise independently. Their findings imply that when joint attention is established it does not indicate that thoughts about the own or the other's mental states are automatically triggered. This raises the question of how individual differences in the Theory of Mind affect the susceptibility for Joint Attention in human-robot interactions.

Moreover, a neurodevelopmental disorder characterised by a decreased Theory of Mind ability is autism, nowadays referred to as Autism Spectrum Disorder/Condition. The disorder is described by Baron‑Cohen et al. (1985, p.2) as *“a profound disorder in understanding and coping with the social environment, regardless of IQ level”.* In the *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.; DSM–5; American Psychiatric Association, 2013), multiple pervasive developmental disorders are combined into a spectrum approach. The aforementioned “spectrum” disorder approach is taken as individuals vary in the type and severity of symptoms experienced. ASD is characterised by persistent deficits with comprehension and prediction of their respective social environment. Additionally, people displaying autistic traits have an impaired ability to mentalise the unobservable cognitions of others (Baron‑Cohen et al.,1985). Morgan et al. (2021) suggest that this social impairment also affects task performance in tasks related to gaze behaviour. Consequently, it can be concluded that portraying autistic traits is related to an impaired Theory of Mind ability.

To measure the degree to which adults display autistic traits the Autism Quotient (AQ-10) was developed (Allison et al., 2012). During this test participants are asked to rate items with one of the following options: Definitely Agree, Slightly Agree, Slightly Disagree, and Definitely Disagree. An example of an item is the following statement: *"When I'm reading a story I find it difficult to work out the characters' intentions"*. Their constructed scale with 10 items has reported high internal consistency and was tested on an individual sample. Interestingly, a study by Bayliss et al. (2005) suggested a negative correlation between participants' scores on the AQ (50 items) and the sensitivity to gaze cueing paradigms. However, the researchers argue gender differences may partly explain this effect.

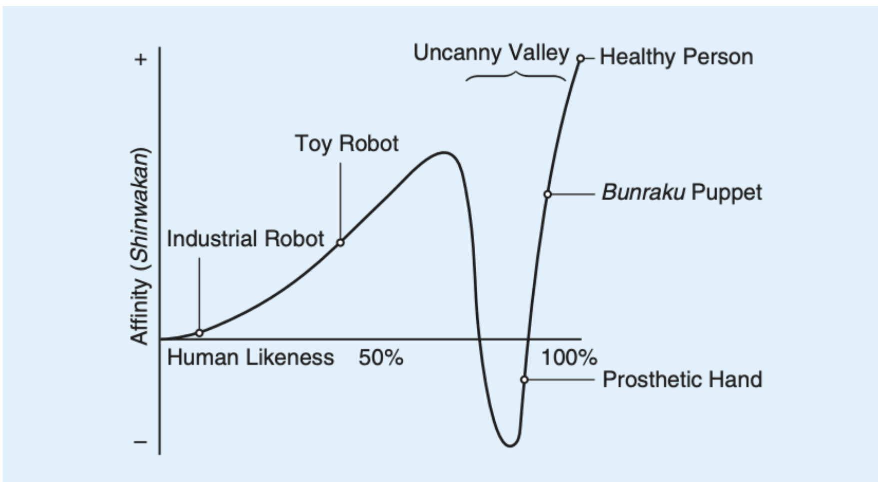
A more recently developed video-based test for measuring individual differences in Theory of Mind ability is the Movie for Assessment of Social Cognition (MASC) (Dziobek et al., 2006). According to Dziobek et al. (2006), the MASC tests inference of mental states in a more complex environment and allows for more insight than the traditional theory of mind concept.

**The Uncanny Valley**

When working with humanlike agents an important framework to consider is the Uncanny Valley Theory. The Uncanny Valley Theory states that the more the object resembles a human the more positive observers' response to the object becomes (Mori et al., 2012). However, from a certain point of resemblance, a point arises where the object evokes an 'uncanny' feeling. This dropoff in affinity is attributed to a state where an agent resembles a human likeness but does not quite feel like a human yet. After this "valley," a steep incline in the rate of affinity is observed once agents become closer related to human likeness. The area where more resemblance causes a worse evaluation by observers is coined "The Uncanny Valley" by Masahiro Mori (Mori et al., 2012).

**Figure 2**

*A visual representation of the hypothesised uncanny valley (Mori et al., 2012)*




The Uncanny Valley effect has been reported with robot faces and 3D animated faces (MacDorman & Chattopadhyay, 2016). One of the explanations for the uncanny valley effect is that the effect arises due to difficulty in categorizing ambiguous agents also referred to as category confusion. A study by Schwind and Jäger (2016) suggests that the more realistic a face is the more time participants need to identify them. Additionally, the research stresses the importance of the eye region in categorisation, as it draws a lot of attention. Moreover, Wang and Rochat (2017) indicate that faces that produce categorical uncertainty, in between real and unreal, report higher reaction times in sorting tasks. In addition, the researchers suggest that this difficulty in categorization adds to the eerie feeling. Further, a study by Weis and Wiese (2017) proposes that cognitive difficulties prime around the uncanny human likeness. Research by

Mathur et al. (2020) suggests that humans perceive a human/robot boundary in categorisation. An additional finding from their research suggests that the lowest point of the uncanny valley actually occurs when the face is perceived to be predominantly mechanical compared to the assumption that the lowest point was when the face is nearly indistinguishable from human. Their findings contradict the category confusion effect as a reason for a drop in likeability. The researchers propose an alternative hypothesis called "feature inconsistency", this theory states that inconsistency in realism in facial features causes the uncanny valley. For our current research, we are interested in whether category confusion or feature inconsistency influences return-to-face response time in gaze-leading paradigms. Therefore, we introduce three face types (robot, uncanny & human-like) to a gaze-leading paradigm. The first type consists of robot faces that do not evoke the uncanny valley, secondly faces close to the uncanny valley low point were included, and lastly, human faces were included (Mathur et al., 2020).

**The Current Study**

Our study consisted of an experimental part with a repeated measures design. Participants completed an object selection task, being presented with 6 different faces ranging from robot to uncanny to human-like. Subsequently, participants were presented with the Godspeed, AQ-10 and MASC (selected items) questionnaires. In the object selection task, participants were presented with a gaze-leading paradigm. The instructions were to select the object of preference (right or left side of the centrally presented face) by clicking on it. After selecting the object of preference a gaze behaviour of the stimulus would occur. Participants were exposed to a joint disposition and a disjoint disposition condition for each of the three face types. The face types used in the experiment were robot, uncanny and human. For each face type category, two different faces were selected. For the human-like condition, a male and female face were presented. In the joint condition participants' selection was followed by the avatar's gaze 80% of the time. In the disjoint condition, the avatar's gaze would follow the participant's choice 20% of the time. The gaze behaviour of the avatar can thus result in a followed action or an unfollowed action.

The study aimed to investigate the influence of individual Theory of Mind variability on the relationship between joint attention and return-to-face onset times. Additionally, the role of the Uncanny Valley Effect was examined by including face stimuli ranging from robot to uncanny to human. Based on the literature review it is hypothesized that:

**H1:** *Participants' return-to-face reaction times slow down when the expectation of joint attention is violated.*

**H2:** *Participants with a higher score on the MASC are more susceptible to changes in return-to-face response time facilitated by the expectation violation in the joint condition.*

***H3:*** *Participants with a higher score on the MASC are more susceptible to the change in return-to-face response time facilitated by the joint or disjoint condition.*

**H4:** *Participants' category confusion is largest when presented with the human-like face type, resulting in a slower return-to-face response time.*

# Methods

## Participants

Participants for the study were recruited via convenience sampling, making use of the social network of the researchers involved. Additionally, participants were recruited through the Sona system from the University of Twente. Sona is a participant recruitment and management system implemented by the university to connect bachelor students from the Psychology program to research. Participation was voluntary. Furthermore, the student participants were awarded Sona credits. The research was conducted in English. The inclusion criteria were that participants had to be over the age of 18 years, comprehended the English language, and report normal or corrected-to-normal vision. In total, 36 participants were recruited for the study. The participants consisted of 20 Male participants (55%) and 16 Female participants (45%). The mean age was 24.78 (SD=10.00) with the age ranging from 18 to 60. Of the participants 3 were left-handed and 33 were right-handed  The study was granted ethical approval from the Ethics Committee BMS (request number 231475).

**Materials**

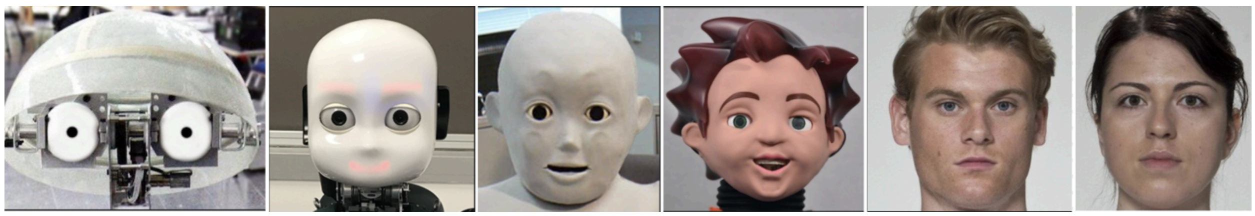
The current study comprised an object selection task followed by three questionnaires, all outlined below. Participants completed the study on a personal computer or a laptop. Responses were collected using the mouse and keyboard, and no additional hardware was used.

The experimental task was presented via PsychoPy v2023.2.3, an open-source software program for creating Python-based experiments for Psychological Research (Peirce, 2007). The preferred measure of visual reaction time was by using eye-tracking equipment. However, due to time constraints and logistical issues, the mouse has been chosen as a satisfactory substitute. Previous experiments by Willemse et al. (2021) indicate that using the mouse is a sufficiently reliable proxy for eye-movements.

In Figure 3 an overview of the presented faces is given. The human faces are selected from the London face repository (DeBruine & Jones, 2017). One male face and one female face were selected at random, however, the requirements were a clear distinction between sclera and iris/pupil. This criterion allows for editing in gaze behaviour in the experiment. Moreover, the faces had to look straight into the camera. The repository also comes with attractiveness ratings from a group of participants. It was assured the attractiveness ratings were similar (overall, both faces are rated 3 out of 7 by both genders.

**Figure 3**

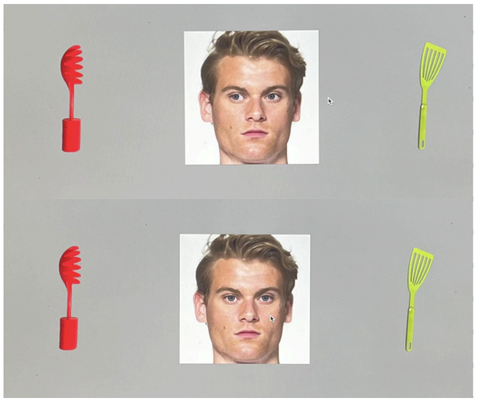
*Faces Presented During the Experiment*



For the robot faces, the iCub (See Figure 1, second figure from the left) was selected first. The iCub is an open-source robot designed to have similarities to a 3-year-old.  (Parmiggiani et al., 2012). The iCub was chosen since it has been used in similar studies regarding gaze behaviour in human-robot interactions(Willemse et al., 2018, 2021; Willemse & Wykowska, 2019). The additional robot faces were selected from a research paper by Mathur et al. (2020). The paper provides a large sample of robot and human faces ranging from mechanic to human Two faces from the mechanic end of the spectrum were chosen for the mechanical robots and two faces that were close to the uncanny valley low point were chosen for the uncanny faces. The robot faces had to satisfy the following criteria: be of good enough image quality, the face had to be facing straight ahead, and the distinction between sclera and pupil/iris had to be noticeable so it would be possible to edit in gaze behaviour.

**Figure 4**

*An example of a bilateral object selection task with a centrally presented face (human condition)*



The subsequent questionnaires were presented in Qualtrics, an online survey tool. The participants were first presented with the Godspeed questionnaire created by Bartneck et al. (2008) to accelerate the development of human-like robots (The Godspeed data will not be used in the current study). Secondly, participants were presented with the AQ-10 by Allison et al. (2012). The instrument is based on the Autism Spectrum Quotient (AQ) the shorter test uses 10 questions to asses if a more thorough diagnostic assessment is needed. The AQ-10 is therefore often used in research related to the Theory of Mind.

Finally, we presented 5 items from the Movie for the Assessment of Social Cognition (MASC) test. Due to time constraints for the whole experiment, the first 5 items on the MASC have been selected. Developed by Dziobek et al. (2006) the tool uses video fragments with accompanying questions to measure participants' mentalisation levels. The test has proven to have good discriminative qualities based on social cognition. The mask test was chosen over the Reading the Mind in the Eyes Test (RMET), another test frequently used in Theory of Mind-related studies (Baron-Cohen et al., 2001). Research by Oakley et al. (2016) suggested that the RMET score is related closely to alexithymia, and thus emotion recognition rather than strictly Theory of Mind ability.

**Procedure**

Before participating in the research, participants were presented with an informed consent form (See Appendix A). The informed consent form was offered in Qualtrics, after signing the informed consent form participants were asked to fill in their participant number, whether they were right or left-handed, their gender and their age. After filling out the demographic data participants were shown the following message: *"You will now do the experiment. Please do not close the survey as you will return to it afterwards"*.

Next, the researcher opened the experiment in PsychoPy and ensured a clear presentation of the task instructions. Participants were presented with 6 practice trials with an agent that was unique from the experimental trials to get acquainted with the task. During the experiment, participants were presented with one of the 6 faces. The presented face was accompanied by two objects from six object pairs. The left-right location of each object-pair was counterbalanced between trials. The instructions were to select the object of preference (right or left side of the centrally presented face) by clicking on it. After selecting the object of preference a gaze behaviour would occur (See Figure 2). Next, the participant would click on the centre of the face, after which a new combination of face and object pair would be shown. In the joint condition, the choice of the participant would be followed 80% of the time. In the unfollowed condition, the choice of the participant would be followed 20% of the time. This process would be repeated for 480 times. Participants were offered scheduled self-paced breaks after each block of 40 trials. Willemse et al. (2021) used a between-subjects design with 80 trials. The decision was made to use a repeated measures design so fewer participants were needed. Therefore each participant would have to complete 160 trials. Additionally, since the third condition face was added 160 trials were required for each condition, so 3 x 160 = 480 trials.

When participants were finished with the experiment the researcher would redirect the participant to the Qualtrics survey. Firstly the participants were met with the selected items of the Godspeed questionnaire (See Appendix B). The participant would fill out a separate Godspeed for each of the six faces. The Godspeed data will not be used in the current study. Secondly, participants would fill out the AQ-10 (See Appendix C). Lastly, the participants would be shown 5 items from the MASC test. Each item from the MASC test consisted of a video fragment and an accompanying question (See Figure 4). After completion of the research participants were thanked for their time and effort. If participants were interested in the scope of the research they were debriefed at this point in the experiment. The entire session took approximately 45 minutes.

**Figure 5**

*The Protagonists from the MASC: Michael, Sandra & Betty*

**Data Preparation & Analysis Plan**

Before data analysis was performed the data was cleaned. Data from the trial run were removed. The data from the AQ-10 was coded. Participants were awarded 1 point for Definitely or Slightly Agree on each of items 1, 7, 8, and 10. Additionally, 1 point for Definitely or Slightly Disagree on each of items 2, 3, 4, 5, 6, and 9 (Allison et al., 2012). For the MASC data participants were awarded one point per correct answer. Total scores on the AQ-10 and MASC were calculated for each participant. Data from one participant was omitted as the experiment crashed resulting in a partial data set. Later the data from PsychoPy and Qualtrics were merged into one data set. Return-to-face on-site times lower than 100 milliseconds and longer than 2 seconds were omitted.

The data analysis was performed with a New Statistics Approach, which allows for quantitative interpretation of estimated effects. Moreover, the decision was made to utilise Bayesian statistics for the data analysis. The Bayesian analysis provides a posterior distribution which represents the complete distribution of certainty regarding parameter values (Schmettow, 2021). This posterior distribution is calculated through a method called Markov-Chain Monte Carlo (MCMC). By examining the resulting frequency distribution, we can approximate the levels of certainty associated with parameter estimates and make informed interpretations about the effects of the disposition, gaze-following, and face types on reaction times in our study. This approach provides a more comprehensive understanding of uncertainty and variability in the data, allowing for nuanced interpretations of the model results in the context of our research question and hypotheses. The effects of the disposition, gaze behaviour and face type were investigated using a Gaussian multilevel model. This type of regression model allows controlling for participant-level variation to help improve parameter estimation.

## Results

This study aimed to replicate the findings of Willemse et al. (2021), specifically investigating the effect of joint attention in a gaze-leading paradigm using a robot agent. Previous research suggested that return-to-face reaction times were slower when the robot infrequently looked at an unselected object, as opposed to following the participant's gaze. In our study, we sought to replicate these findings while also exploring potential interaction effects with additional measures such as the different face types, MASC, and AQ-10.

**Descriptive statistics**

The AQ-10 scores range from 0 to 8, with a median score of 3 and a mean score of 3.25 (M = 3.25, SD = 1.75). The AQ-10 consists of 10 items with a maximum score of 10 and a minimum score of 0. A cut-score of 6 was determined for the AQ-10 (Allison et al., 2012). From a score of 6 or higher, an individual is considered for a referral for clinical assessment. ASD was approached as a spectrum, but the sample did not obtain an adequate range of scores to treat it as a meaningful variable. Similarly, scores on the MASC range from 1 to 4, with a median score of 2.5 and a mean score of 2.58 (M = 2.58, SD = 0.94). In Appendix F two scatterplots are presented that were used to assess the difference in return-to-face response time based on the trial number and face type. An overview of the return-to-face response times based on the disposition (joint/disjoint) and the gaze behaviour of the avatar (followed/unfollowed) is given in Table 1. The average response times for the disposition and gaze behaviour show a low variance between the different dispositions.

**Table 1**
*Mean return-to-face onset times in milliseconds for the disposition and action*

| Disposition | Following | Mean Return-to-Face Onset Time | SD | Min | Max |
|---|---|---|---|---|---|
| Joint | Followed | 790. | 271 | 292 | 1996 |
| Joint | Unfollowed | 785 | 272 | 270 | 1988 |
| Disjoint | Followed | 791 | 284 | 271 | 1994 |
| Disjoint | Unfollowed | 790 | 270 | 227 | 1971 |

Additionally, average return-to-face response times were calculated for each of the face types. The results are presented in Table 3. This table indicates a marginally small variance for each of the different face types used in the gaze-leading experiment.

**Table 2**
*Mean Return-to-Face Onset Times in Milliseconds for the Facetype*

| Facetype | Mean Return-to-Face Onset Time | SD | Min | Max |
|---|---|---|---|---|
| Human | 787 | 268 | 270 | 1994 |
| Uncanny | 787 | 275 | 227 | 1960 |
| Robot | 794 | 273 | 271 | 1996 |

**Inferential Statistics**

The fixed effects of the disposition, gaze behaviour and face type on the return-to-face response times were estimated using a 2x2x3 multilevel model. The disposition variable consists of joint or disjoint. Gaze behaviour refers to the avatar's action, following the participant's object selection or unfollowed, eye movement towards the non-selected object. The third level is the face type, consisting of three different categories. The face type conditions are robot, uncanny and human. These findings are summarized in Table 3, which presents the fixed effects estimates and 95% credibility limits for the model.

**Table 3**

*Multilevel Model for the Effects of Disposition, Following and Facetype on Return-to-Face Onset Times in Milliseconds*

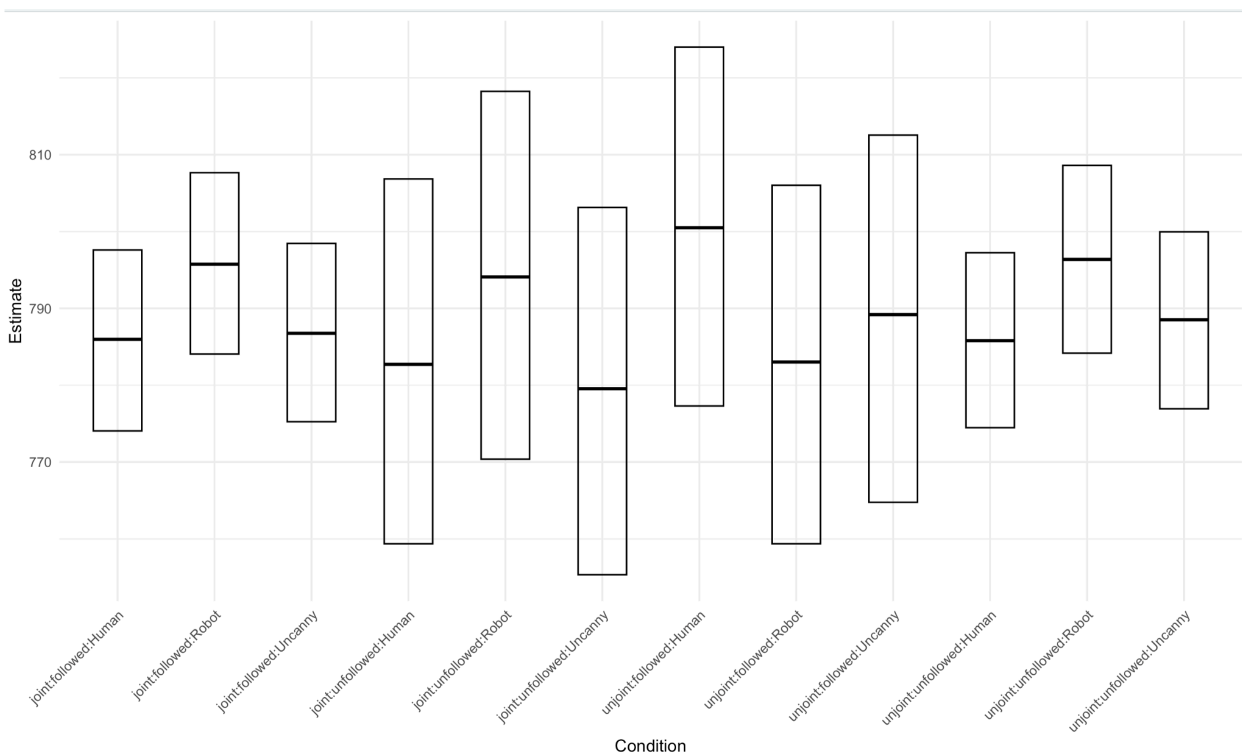
| **Parameter** | **Center Estimate** | **Lower Limit** | **Upper Limit** |
|---|---|---|---|
| Intercept | 887.28 | 821.61 | 946.05 |
| Disposition (Disjoint) | 6.66 | -13.48 | 25.59 |
| Following (Unfollowed) | -3.26 | -22.43 | 16.34 |
| Face Type (Robot) | 4.16 | -7.74 | 15.77 |
| Face Type (Uncanny) | -2.87 | -15.01 | 9.12 |
| Trial Number | -0.45 | -0.57 | -0.33 |
| Disposition (Disjoint) : Following (Unfollowed) | -3.21 | -31.46 | 23.67 |
| Disposition (Disjoint) : Face Type (Robot) | -14.95 | -42.46 | 13.65 |
| Disposition (Disjoint): Face Type (Uncanny) | 0.54 | -26.19 | 27.67 |
| Following (Unfollowed): Face Type (Robot) | 2.11 | -24.39 | 30.33 |

| | | | |
|---|---|---|---|
| Following(Unfollowed) : Face Type(Uncanny) | -1.07 | -27.98 | 26.66 |
| Disposition (Disjoint) : Following (Unfollowed) : Face Type(Robot) | 13.19 | -25.87 | 52.03 |
| Disposition (Disjoint) : Following (Unfollowed) : Face Type(Uncanny) | 3.56 | -35.74 | 42.05 |

*Note.* Effect estimates are given with 95% credibility limits. Intercept refers to the joint attention disposition with the following behaviour and the human face type during the zeroth trial.

**Figure 6**

*Error Bar Plot Visualizing the Response Time Estimates for Effects of Disposition, Following and Facetype Stimuli with 95% Credibility Limits*




The effects examined are the disposition, gaze behaviour and face type, with the intercept referring to the joint attention disposition with the following behaviour and the human face type during the Zeroth trial. The estimated coefficient suggests a slight positive effect for the disjoint disposition, yet the wide credibility interval encompasses zero, which indicates uncertainty. Similarly, the estimate for unfollowed is a slight negative but close to zero with a wide credibility interval encompassing zero as well. This suggests a potential but uncertain influence of the infrequent gaze towards the unselected object on reaction times. Furthermore, the coefficients for the face types robot and uncanny are close to zero and the credibility intervals encompass zero with both positive and negative values, indicating that the face type does not significantly affect the return-to-face saccade times.

Additionally, the model also includes interaction effects for the variables. Where the disjoint: unfollowed coefficient shows a slight negative effect with uncertainty, while the coefficients for the disjoint disposition and robot and uncanny face types are close to zero with wide credibility intervals.  Moreover, the interaction effect with the disposition, following and face types included also shows estimates close to zero with wide intervals, indicating uncertainty in the estimates.

Interestingly the negative coefficient estimate for the trial number indicates that for each trial the response time decreases slightly. The credibility intervals for this effect suggest certainty that with each trial the response time decreases by 0.45 milliseconds. The experiment comprised 480 repetitions, which suggests that the difference between the zeroth and the final trial is 216 milliseconds.

## Discussion

The current study was conducted to further explore the effects of gaze leading on return-to-face onset times. More specifically, the goal of this study was to examine the effect that individual differences in Theory of Mind ability possibly exhibit on this effect. Moreover, the

Uncanny Valley Effect was taken into account while designing the experiment to asses if different levels of human likeness in face stimuli used during gaze-leading paradigms affect the previously established effect of violation of joint attention expectation on return-to-face onset times.

The current study, despite being adopted from Willemse et al. (2021) and incorporating the iCub robot face as a stimulus, surprisingly failed to replicate the relationship observed in previous gaze-leading paradigm studies, where return-to-face onset times slowed down in the joint attention condition when an agent directs their attention to an unselected object, as indicated by Willemse et al. (2018). However, recent findings suggest that prolonged exposure to non-human stimuli may decrease the likelihood of anthropomorphizing robots, with Abubshait and Wykowska (2020) demonstrating that shorter interactions with the iCub robot are preferable in gaze cueing paradigms. In the study by Willemse et al. (2021), there were 80 trials in total, and participants were offered a self-paced brake after 40 trials. In the current study, participants were tasked with 480 trials. The decision was made to use a repeated measures design and incorporate an extra three-level condition resulting in a significant increase in trials. This substantial amount of repetition could have resulted in participants focusing on completing the tasks as fast as possible, which would have affected the manipulation negatively. This is in line with Abubshait and Wykowska (2020) who suggest that the manipulation decreases dramatically when exposure to the face stimuli increases.

Notably, the intentional stance towards an agent is considered to be an important factor for social attunement (Abubshait & Wykowska, 2020). The intentional stance can be best explained as the assumption that an agent’s behaviour is determined by their internal cognitive processes, such as thoughts and emotions (Dennett, 1989). When participants are exposed to repetitive actions performed by robotic agents, social engagement with these robotic agents decreases. Thereby, decreasing the effect of attributing intentionality to the mechanical agent. This can be explained by a reduced interest in understanding the robot's behaviour and the tendency to anthropomorphize.

Additionally, researchers have highlighted the potential benefits of employing Bayesian statistics in quantifying effects in gaze cueing paradigms, particularly due to smaller sample sizes and the need to analyze reaction time parameters, allowing for the examination of effects in probabilities rather than mere significance (Abubshait & Wykowska, 2020). The study by Willemse et al. (2021) used a traditional ANOVA test to assess their effects. Benefits of the usage of Bayesian analysis include flexibility in model specification, the ability to create estimates and credible intervals for predicted variables, robust estimates and the ability to quantify support for the null hypothesis (Kruschke, 2021).

A secondary objective was to assess the effects of individual theory of mind variability on the effects of expectation violation in the joint attention condition. However, when analysing the AQ-10 data we concluded that we did not find the variance of scores in our sample that we were hoping for. Therefore we were unable to draw inferences about the effects of theory of mind variability. However, based on the literature review we cannot rule out that the Theory of Mind accounts for some individual variance in return to face onset times in gaze cueing paradigms (Bayliss et al., 2005; Emery, 2000; Frischen et al., 2007). Future research could perhaps be more succesful on recruiting a sample with a broader range of Theory of Mind abilities in order to further examine the theory of mind-related effects on gaze-leading paradigms.

Lastly, the addition of three distinct face types was made to assess the potential role that the uncanny valley theory plays in gaze-leading paradigms. It was hypothesised that the feature inconsistency would be greatest in the human-like avatar in the gaze-leading paradigm, resulting in a decreased return-to-face onset time. Further, it was hypothesised that the participants' category confusion would be largest when presented with the human-like face type, resulting in a slower return-to-face response time. However, the fitted multilevel model did not show a significant effect of the different face types on return-to-face onset times. The intentional stance mentioned earlier may have also affected the manipulation of the different face conditions. Although the differences in cognitive difficulties with categorisation have been proposed by previous research, the effect of different face stimuli was still unclear (Mathur et al., 2020; Schwind & Jäger, 2016; Wang & Rochat, 2017; Weis & Wiese, 2017). The results of the current study appear to indicate that the differences in processing times for face categories do not carry over to gaze-leading paradigms, however, more research needs to be conducted on the success of the manipulation.

**Strengths and Limitations**

As mentioned in the introduction, the preferred measure for saccade return onset time was using eye-tracking technology. However, due to technical issues and time constraints, the decision was made to use the mouse as a proxy. Previous research by Willemse et al. (2021) suggested that using mouse responses mimicked their previous findings regarding eye movement using eye-tracking equipment (Willemse et al., 2018). An important thing to note however is that the return-to-face saccade latency in milliseconds was larger in the first experiment which used an SMI RED500 eye-tracker. This might indicate that using eye-tracking equipment directly has advantages for manipulation during experiments regarding gaze behaviour compared to using the mouse as a proxy for eye movement.

A potential strength of the current study compared to the study by Willemse et al. (2021) is the fact that participants were asked to complete the experiment and concurrent surveys in person. This allowed the researchers to control the environment and ensure that participants were focused on the task at hand. The study by Willemse et al. (2021) used an online recruitment platform and monetary reward on completion of the online study. This results in a lack of information and control over the procedure of the experiment.

**Research implications**

Our findings of the current study indicate that there is no significant relationship where in the joint attention disposition condition, return to face onset times slow down when an agent violates the assumption of joint attention by directing their attention to an unselected object. These findings are contrary to previous research, which raises the question of what could be the cause of these conflicting findings (Willemse et al., 2018, 2021; Willemse & Wykowska, 2019). Although the difference might partly be explained by the excessive amount of trials in the gaze-leading task and the usage of more sophisticated statistical models, this still raises questions about the replicability of the previously established effect of expectation violation in gaze-leading paradigms. Therefore, future research should focus on assessing the replicability of the previous research and investigating the effect of gaze behaviour on return-to-face onset time.

Additionally, the experimental design from previous gaze-leading paradigms should be reconsidered. 2D screen-based stimuli and a large number of repetitive trials negatively affect manipulation (Bergmann et al., 2012). The unnatural nature of these types of gaze-leading paradigms raises concerns about ecological validity (Schilbach et al., 2013). Novel research can aim to overcome these barriers by radically rethinking experimental designs and focusing on developing experiments that are closer to day-to-day experiences to draw more practical conclusions.

**Conclusions**

The current study aimed to investigate if the previous finding that joint attention resulted in a slowed return on set times when the gaze behaviour was not followed, could be moderated by individual differences in Theory of Mind dispositions. However, to our surprise, the previously found effect was not replicated in the current study. This means that further research should be conducted to assess the replicability of previous findings.

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## Appendix A

*Informed Consent*

Dear participant,

Thank you for being willing to participate in the study!

The study is part of both a Master's thesis and a Bachelor's thesis at the University of Twente where we are investigating human-robot interaction. More detailed information about the research aim will be given at the end of the study.

The study consists of two parts; a screen-based experiment where you will be choosing objects, followed by a survey. In total, the study should take about one hour to complete. There will be scheduled breaks during the experiment.

Before you start the study, please read the following information carefully.

The data that is collected from both the experiment and the survey is confidential and processed anonymously, meaning that none of your data will be disclosed in a personally identifiable way. The data will only be used for academic purposes and will not be shared with any external individuals.

Your participation in this study is entirely voluntary, and you can withdraw at any time without stating a reason. If you choose to withdraw, any data collected from your participation will not be used in the study.

If you have any questions or would like some additional information, please let the researcher in the room know. Should you have any questions at any time after your participation in the study, please contact Ingvild Kvalsvik (i.t.kvalsvik@student.utwente.nl) or Tim Lentjes (t.r.j.lentjes@student.utwente.nl).
Thank you!

## Appendix B

*Godspeed*

*Please rate the impression you got of this face on the scales below*

*[ Image of face ]*

| | | | | | | |
|---|---|---|---|---|---|---|
| *Fake* | *1* | *2* | *3* | *4* | *5* | *Natural* |
| *Machinelike* | *1* | *2* | *3* | *4* | *5* | *Humanlike* |
| *Unconscious* | *1* | *2* | *3* | *4* | *5* | *Conscious* |
| *Artificial* | *1* | *2* | *3* | *4* | *5* | *Lifelike* |
| *Moving rigidly* | *1* | *2* | *3* | *4* | *5* | *Moving elegantly* |
| *Dislike* | *1* | *2* | *3* | *4* | *5* | *Like* |
| *Unfriendly* | *1* | *2* | *3* | *4* | *5* | *Friendly* |
| *Unkind* | *1* | *2* | *3* | *4* | *5* | *Kind* |
| *Unpleasant* | *1* | *2* | *3* | *4* | *5* | *Pleasant* |
| *Awful* | *1* | *2* | *3* | *4* | *5* | *Nice* |

## Appendix C

*AQ-10*

| | Please tick one option per question only: | Definitely Agree | Slightly Agree | Slightly Disagree | Definitely Disagree |
|---|---|---|---|---|---|
| 1 | I often notice small sounds when others do not | | | | |
| 2 | I usually concentrate more on the whole picture, rather than the small details | | | | |
| 3 | I find it easy to do more than one thing at once | | | | |
| 4 | If there is an interruption, I can switch back to what I was doing very quickly | | | | |
| 5 | I find it easy to 'read between the lines' when someone is talking to me | | | | |
| 6 | I know how to tell if someone listening to me is getting bored | | | | |
| 7 | When I'm reading a story I find it difficult to work out the characters' intentions | | | | |
| 8 | I like to collect information about categories of things (e.g. types of car, types of bird, types of train, types of plant etc) | | | | |
| 9 | I find it easy to work out what someone is thinking or feeling just by looking at their face | | | | |
| 10 | I find it difficult to work out people's intentions | | | | |

**Appendix D**

*MASC items*

Q13.1 What does Sandra feel?

- o Her hair does not look that nice
- o She is pleased about his compliment
- o She is exasperated about Michael coming on too strong
- o She is flattered but somewhat taken by surprise (Correct)

Q13.2 Why does Michael say this?

- o He wants to impress her with his good athletic abilities
- o He wants to meet Sandra alone (Correct)
- o He is a good squash player
- o He enjoys playing squash more than having dinner

Q13.3 Why does Sandra say this?

- o Because she wants Betty to divert Michael (Correct)
- o She wants to set up Betty with Michael
- o Because Betty is her best friend
- o She does not want to be alone with the guys

Q13.4 What does Betty feel?

- o Discontented about being taken by surprise with the dinner (Correct)
- o Saturdays are her only days off
- o She feels like doing something else on Saturday
- o She feels used and she does not want to deal with Michael either

Q13.5 Why does Sandra say this?

- o If Betty will not come, she will not speak to her anymore
- o To try to blackmail Betty into coming on Saturday
- o To persuade Betty in an ironic way to come (Correct)
- o Because Betty has better things to do on Saturday

## Appendix E

*The R-Script Used During Data Analysis*

```
---
title: "Data analysis Final Version"
author: "Tim Lentjes"
date: "2024-04-25"
---
library(dplyr)
library(readr)
library(tidyverse)
library(lme4)
library(ggplot2)
library(reshape2)
library(lmerTest)

##setwd("/Users/Tim/Downloads/DataProcessing/Data_nobrackets_2024")

# Function for data preparation
prepare_data <- function(file_path) {
  data <- read_csv(file_path) %>%
    select(participant, list, trials.thisN, Following, Face, mouse_face_trial.time) %>%
    slice(9:n()) %>%

    mutate(
      mouse_face_trial.time = gsub("\\[|\\]", "", mouse_face_trial.time) %>% as.numeric,
      half = ifelse(row_number() <= n() / 2, "first_half", "second_half"),
      RT = round(mouse_face_trial.time * 1000)
    ) %>%

    filter(RT >= 100 & RT <= 2000)
```

```
  return(data)
}

# Listing all the csv files
csv_files <- list.files(pattern = "\\.csv$")

# Apply the function to each csv file
list_of_data <- lapply(csv_files, prepare_data)

# Combining data into one data frame
combined_data <- bind_rows(list_of_data)

# Adding condition as a column (joint / disjoint)
combined_data <- combined_data %>%
  mutate(condition = case_when(
    (list == 1 & (Face == "human1" | Face == "robot1" | Face == "uncanny1")) ~ "joint",
    (list == 1 & (Face == "human2" | Face == "robot2" | Face == "uncanny2")) ~ "unjoint",
    (list == 2 & (Face == "human1" | Face == "robot1" | Face == "uncanny1")) ~ "unjoint",
    (list == 2 & (Face == "human2" | Face == "robot2" | Face == "uncanny2")) ~ "joint",
    TRUE ~ NA_character_
  ))

# Show average RT for each participant
average_response_time_participant <- combined_data %>%
  group_by(participant) %>%
  summarize(avg_mouse_face_time = mean(RT, na.rm = TRUE))

##compare conditions via boxplot
combined_data %>%
  ggplot(aes(x = condition, y = RT, color = Face)) +
  geom_boxplot()
```

```
summary


##compare conditions via boxplot
combined_data %>%
  ggplot(aes(x = condition, y = RT, color = Following)) +
  geom_boxplot()

## Histogram of RT
ResponseTime <- combined_data$RT
hist(ResponseTime)

##Summary
summary(combined_data)

#average RT joint or disjoint disposition
average_response_time_condition <- combined_data %>%
  group_by(condition) %>%
  summarize(avg_mouse_face_time = mean(RT, na.rm = TRUE))

#Barplot RT for joint or disjoint disposition
barplot(height=average_response_time_condition$avg_mouse_face_time,
names=average_response_time_condition$condition,
        col=rgb(0.8,0.1,0.1,0.6),
        xlab="Condition",
        ylab="Response Time (MS)",
        main="Mean Response Time by condition",
        ylim=c(750,800)
)

#Table with average RT
```

```
average_response_time_face <- combined_data %>%
  group_by(Face) %>%
  summarize(avg_mouse_face_time = mean(RT, na.rm = TRUE))

#Barplot average RT for each face
barplot(height=average_response_time_face$avg_mouse_face_time,
names=average_response_time_face$Face,
        col=rgb(0.8,0.1,0.1,0.6),
        xlab="Face",
        ylab="Response Time (MS)",
        main="Mean Response Time by Facetype",
        ylim=c(750,800)
)

##Mean, Standard Deviation (SD), Minimum, and Maximum Values of RT by Condition and
Following
 combined_data %>%
   group_by(condition, Following) %>%
   summarise(
     mean_RT = mean(RT),
     sd_RT = sd(RT),
     min_RT = min(RT),
     max_RT = max(RT)
   )

 ##Creating a variable for the facetype
 combined_data_facetype <- combined_data %>%
   mutate(Face_type = case_when(
     (Face == "human1" | Face == "human2") ~ "Human",
     (Face == "robot1" | Face == "robot2") ~ "Robot",
     (Face == "uncanny1" | Face == "uncanny2") ~ "Uncanny",
```

```
    TRUE ~ NA_character_
  ))

 ##Mean, Standard Deviation (SD), Minimum, and Maximum Values of RT by Facetype
 combined_data_facetype %>%
   group_by(Face_type) %>%
   summarise(
     mean_RT = mean(RT),
     sd_RT = sd(RT),
     min_RT = min(RT),
     max_RT = max(RT)
   )



## New variable combining disposition and gaze behaviour
combined_data$Condition_Following <- paste(combined_data$condition,
combined_data$Following)

library(ggplot2)
library(viridis)
library(hrbrthemes)


 ##Barplot Average Response Time for disosition (joint/disjoint) and gaze action
(followed/unfollowed)
ggplot(average_response_time_condition_following, aes(fill=Following,
y=avg_mouse_face_time, x=Following)) +
   geom_bar(position="dodge", stat="identity") +
   scale_fill_viridis(discrete = T, option = "E") +
```

```
  ggtitle("RT based on condition") +
  facet_wrap(~condition) +
  theme_ipsum() +
  theme(legend.position="none") +
 coord_cartesian(ylim = c(750, 800))
  xlab("")
  ylab("Average RT")

##Trying out Multiple Scatterplots with RT and Trial Number
(prelim_plot <- ggplot(combined_data, aes(x = trials.thisN, y = RT)) +
   geom_point() +
   geom_smooth(method = "lm"))

##Color based on Face
(colour_plot <- ggplot(combined_data, aes(x = trials.thisN, y = RT, colour = Face)) +
   geom_point(size = 2) +
   theme_classic() +
   theme(legend.position = "none"))

(split_plot <- ggplot(aes(trials.thisN, RT), data = combined_data) +
   geom_point() +
   facet_wrap(~ Face) +
   xlab("Trial Number") +
   ylab("Response Time"))

(split_plot <- ggplot(aes(trials.thisN, RT), data = combined_data) +
   geom_point() +
   facet_wrap(~ condition) +
   xlab("Trial Number") +
   ylab("Response Time"))
```

```
#importing qualtrics data
##setwd("/Users/Tim/Downloads/Bachelor's Thesis iMac/Robots and Gaze_Updated.csv")

#Importing Qualtrics dataset
qualtrics_data <- read_csv("Robots and Gaze_Updated.csv")  %>%
  dplyr::select(participant, Hand, Gender, Age, `Total Score AQ-10`,`Total Score MASC`)
str(qualtrics_data)

## Demographics
count_hand <- table(qualtrics_data$Hand)
print(count_hand)
# 3 left handed, 33 right handed

count_gender <- table(qualtrics_data$Gender)
print(count_gender)
# 20 Male, 16 Female



avg_age <- mean(qualtrics_data$Age, na.rm = TRUE)
print(avg_age)
# mean age = 24.78

sd_age <- sd(qualtrics_data$Age, na.rm = TRUE)
print(sd_age)
# SD age = 10.00

median_age <- median(qualtrics_data$Age, na.rm = TRUE)
print(median_age)

summary(qualtrics_data$`Total Score AQ-10`,)
summary(qualtrics_data$`Total Score MASC`,)
```

```
# Calculate standard deviation for Total Score AQ-10
sd_aq10 <- sd(qualtrics_data$`Total Score AQ-10`)

# Calculate standard deviation for Total Score MASC
sd_masc <- sd(qualtrics_data$`Total Score MASC`)

# Print the results
print(paste("Standard Deviation for Total Score AQ-10:", round(sd_aq10, 2)))
print(paste("Standard Deviation for Total Score MASC:", round(sd_masc, 2)))


psychopy_qualtrics <- merge(combined_data, qualtrics_data, by = "participant", all.x = TRUE)
%>%
  select(-Hand, -Age, - Gender)



##New Statistics
library(rstanarm)
##install_github("schmettow/bayr")
library(bayr)

##Creating Joint + following variable named condition_following
psychopy_qualtrics_updated = unite(psychopy_qualtrics,col='condition_following'
                                   , c('condition', 'Following') , sep = "_", remove = TRUE)


#Trying out different models for the dataset
M_1 <- stan_glm(
  formula = RT ~ condition,
```

```
  data = psychopy_qualtrics
)

fixef(M_1)

clu(M_1)

M_1.5 <- stan_glm(
  formula = RT ~ condition*Following,
  data = psychopy_qualtrics
)

fixef(M_1.5)

clu(M_1.5)

M_1.75 <- stan_glm(
  formula = RT ~ condition_following,
  data = psychopy_qualtrics_updated
)

fixef(M_1.75)

clu(M_1.75)

M_2.5 <-
  stan_glmer(RT ~ condition + Following + (1|participant),
             data = psychopy_qualtrics)

fixef(M_2.5)
```

```
clu(M_2.5)

M_2.75 <- stan_glmer(
  formula = RT ~ condition_following + (1|participant),
  data = psychopy_qualtrics_updated
)

fixef(M_2.75)

clu(M_2.75)

M_3 <-
  stan_glmer(RT ~ condition + trials.thisN + (condition + trials.thisN|participant),
           data = psychopy_qualtrics
  )

fixef(M_3)

clu(M_3)

M_4 <-
  stan_glmer(RT ~ condition + trials.thisN + (condition + trials.thisN|participant) + (condition +
trials.thisN|Face),
           data = psychopy_qualtrics
  )

fixef(M_4)

clu(M_4)

M_5 <-
```

```
  stan_glm(RT ~ condition * TotalScoreMASC + trials.thisN,
           data = psychopy_qualtrics)

fixef(M_5)

clu(M_5)



## Creating a variable for the facetype
psychopy_qualtrics_facetype <- psychopy_qualtrics %>%
  mutate(Face_type = case_when(
    (Face == "human1" | Face == "human2") ~ "Human",
    (Face == "robot1" | Face == "robot2") ~ "Robot",
    (Face == "uncanny1" | Face == "uncanny2") ~ "Uncanny",

    TRUE ~ NA_character_
  ))

##Creating a factype column
average_response_time_face_type <- psychopy_qualtrics_facetype %>%
  group_by(Face_type) %>%
  summarize(avg_mouse_face_time = mean(RT, na.rm = TRUE))

##Final Model with Facetype variable
Final_Model_Facetype <-
  stan_glmer(RT  ~ condition * Following * Face_type + trials.thisN + (condition +
trials.thisN|participant) ,
             data = psychopy_qualtrics_facetype
  )

fixef(Final_Model_Facetype)
```

```
clu(Final_Model_Facetype)

summary(Final_Model_Facetype)

##Creating error barplot for the fitted model
~ 0 + Dispostion : Following : Face Type

F_X <- stan_glm(RT ~ 0 + condition : Following : Face_type, data =
psychopy_qualtrics_facetype)
fixef(F_X)
coef(F_X) %>%

library(ggplot2)

# Extract coefficients with 95% credibility limits
coefficients <- coef(F_X)

# Rename coefficients for clarity
coefficients <- coefficients %>%
  rename(Trigger = fixef)

# Extract specific condition names from the Trigger column
coefficients$Condition <- gsub("condition|Following|Face_type", "", coefficients$Trigger)

# Create error bar plot using ggplot2 with rotated x-axis labels
ggplot(coefficients, aes(
  x = Condition,
  y = center, ymin = lower, ymax = upper
)) +
  geom_crossbar(width = 0.5, fatten = 2) +  # Add error bars
```

```
  labs(x = "Condition", y = "Estimate") +  # Axis labels
  theme_minimal() +  # Minimal theme
  theme(axis.text.x = element_text(angle = 45, hjust = 1))  # Rotate x-axis labels and adjust
alignment
```

# Appendix F

*Explorative plots*

**Figure 1**

*Scatterplot based on Face Type*

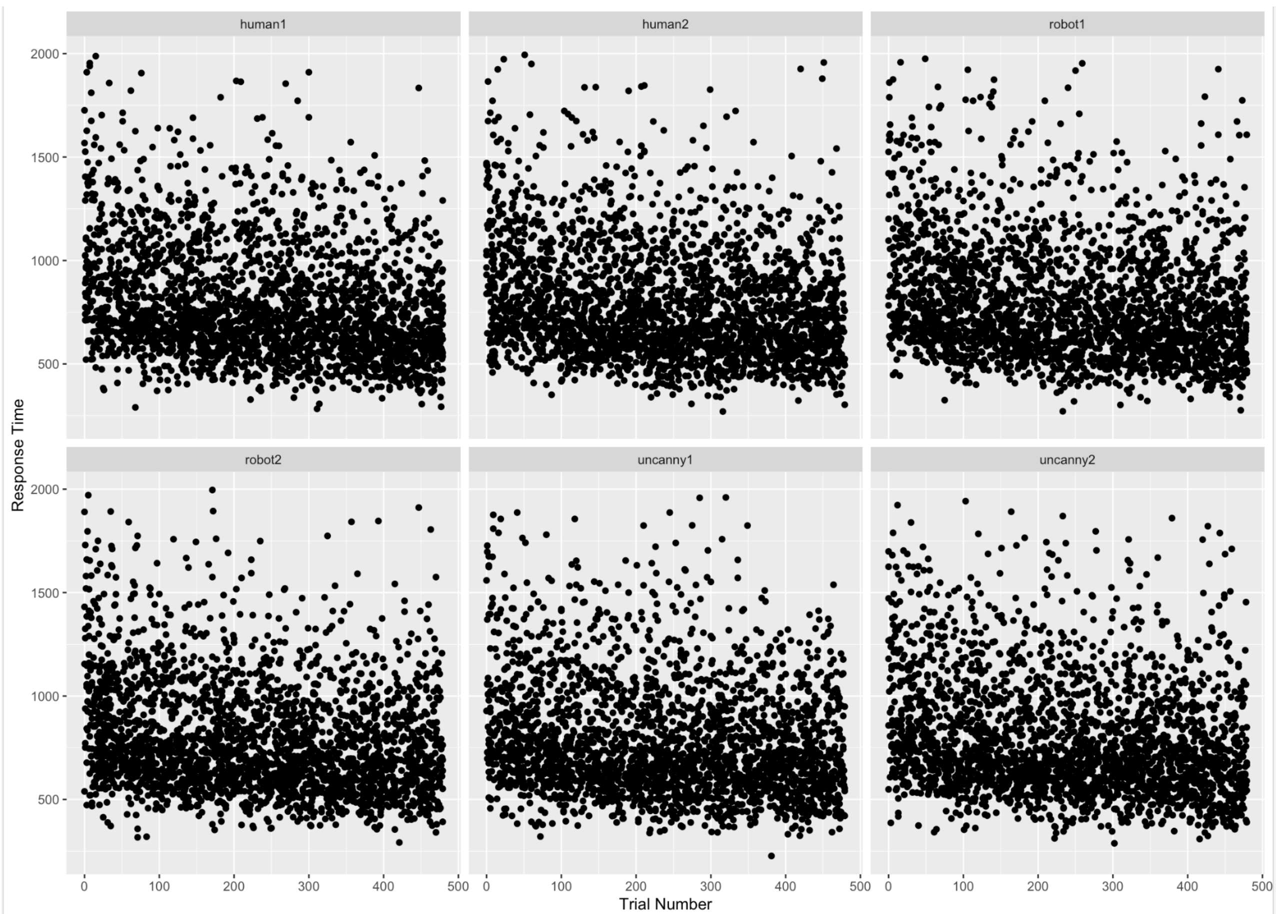

**Figure 2**

*Basic Linear Regression Response Time and Trial Number*