UNDERSTANDING BELIEF REASONING AND ITS RELATION TO REASONING ABOUT REALITY

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Doctor of Philosophy

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December 2022

Abstract

Social cognition comprises a variety of psychological processes that allow us to take advantage of being part of a social group. Two such processes are Belief Reasoning and Visual Perspective Taking Level 2 (VPT-2). The first aim was to explore the differences between Belief Reasoning and VPT-2. Three experiments revealed a distinction between VPT-2 and Belief Reasoning using a novel Seeing-Believing Task. Belief Reasoning was with associated slower responses than VPT-2, suggesting that beliefs are more representationally complex than visual perspectives. The second aim was to explore if there are variations in VPT-2 and Belief Reasoning in adults with Autism Spectrum Condition (ASC). The Seeing-Believing Task was administered to a group of autistic and non-autistic adults. A difference between VPT-2 and Belief Reasoning was reported in non-autistic adults, but not autistic adults. Additionally, autistic adults were slowed more by changing perspectives than non-autistic adults. This hints towards an executive functioning explanation for the variations in social cognition reported in ASC. Finally, this thesis aimed to explore whether Belief Reasoning is likely to be involved in a specific type of social interaction, lying and deceiving. While deceiving is defined as requiring the representation of another's' beliefs, lying might be less complex. Using a variation of the Seeing-Believing Task, we observed a mixed pattern of results, where individuals may choose to employ Belief Reasoning in some contexts and not others when lying. All experiments in this thesis can be conceptualised as comparisons between reasoning about another's beliefs (Belief Reasoning and deception) and reasoning about reality (VPT-2 and lying), with the former proving to be the more demanding process based on consistently slower response times.

Keywords:

Visual Perspective Taking, Theory of Mind, Mentalizing, Autism, Lying, Deception.

Acknowledgements

First of all, I would like to thank my supervisors Professor Klaus Kessler, Dr Daniel Shaw and Professor Adrian Burgess without whom this thesis would not exist. Your unwavering support, guidance and patience has been invaluable. Despite an ever-growing number of obstacles, you were always there to help me to come up with a plan B. Thank you Klaus for giving me the confidence to continue when I did not believe in myself. Dan, I would like to thank you for supporting my aspirations even when they were inconvenient. Adrian, thank you for being the voice of reason to ground me when the pressures seemed overwhelming. I would also like to thank Dr Sarah Carrington who has guided me through the autism literature and supported the writing of Chapter 3.

I have been lucky enough to be a member of the ALIVE lab whose kindness and support has inspired me to continue when it felt like everything was going wrong. A special thanks to Dr Ulrike Senftleben who has been there through all of my meltdowns, no matter how ridiculous they were. Thank you Dr Sam Gregory for always making time for me and reminding me to take a step back and see the bigger picture. Cliona Kelly, I would like to thank you for being a permanent fixture in my academic journey, without your endless cups of tea and moral support this would not be have been possible. Thank you Dr Nikki Ng'Ombe for being in my covid bubble and always being willing to watch food and eat food to de-stress. I would like to thank Charly Billaud for his constant support and patience, especially through the writing up process. Dr Foyzul Rahman, thank you for your advice and thinking of me when you see relevant job postings. Thank you Dr Hongfang Wang for supporting my pilot data collection, reviewing my code and patiently explaining my mistakes. Dwayne May, thank you for being a fantastic placement student and always being organised, especially when I am not.

I would also like to thank my colleagues in SW506 for always being my support group and always reminding me that I can do this. Not to mention going out for drinks when I needed to forget about the stresses. A special thank you to Lucie Thomas who could always find time for coffee or lunch when I needed a pep talk. An extra thank you to the Aston Psychology department, Aston Institute of Health and Neurodevelopment and Psychology technicians for providing the support I needed to complete this research.

A final thank you to family for all their support throughout this journey. Thank you for always listening to me ramble on about my research even when you do not understand what I am talking about. A special thank you to my mother who always kindly offered to proof read my work, even though it is a very long and dull task.

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List of Abbreviations

ANOVA(s)	Analysis of Variance(s)
AQ	Autism Spectrum Quotient
ASC(s)	Autism Spectrum Condition(s)
BAPQ	Broad Autism Phenotype Questionnaire
DSM-5	Diagnostic and Statistical Manual of Mental Disorders
FB(s)	False Belief(s)
fMRI	Functional Magnetic Resonance Imaging
lTPJ	Left Temporo-parietal Junction
M	Mean
mPFC	Medial Prefrontal Cortex
Non-ASC	Non-autistic
OSF	Open Science Framework
RPM	Raven’s Progressive Matrices
rTPJ	Right Temporo-parietal Junction
RTs	Reaction Times
SD	Standard Deviation
SPT	Spatial Perspective Taking
SPT-1	Spatial Perspective Taking Level 1
SPT-2	Spatial Perspective Taking Level 2
TB(s)	True Belief(s)
ToM	Theory of Mind
VPT	Visual Perspective Taking
VPT-1	Visual Perspective Taking Level 1
VPT-2	Visual Perspective Taking Level 2
WISC-III	Wechsler Scales of Intelligence Three

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1. General Introduction

Social cognition comprises a variety of psychological processes that allow us to take advantage of being part of a social group (C. D. Frith, 2008). Being in a social group provides opportunities for social interactions, which are facilitated by the ability to understand the mental state of the individual we are interacting with. This thesis will explore the social cognitive functions that allow us to infer other's mental states and how this mental state information can be used in specific social interactions. Two social cognitive functions used to infer another's mental state are *Theory of Mind* (ToM) and *Visual Perspective Taking* (VPT) the ability to infer another's beliefs or mental state is referred to as ToM (Wimmer & Perner, 1983), whereas VPT refers to the ability to infer what another can see and *how* it appears to them (Flavell, Everett, Croft, & Flavell, 1981). VPT concerns how something appears to another person, whereas ToM refers to what that person believes about it.

There are, of course, similarities between ToM and VPT; when considering another's mental state, one must inhibit one's own mental state in favour of mentally representing another's, whether that mental state be another's belief or visual perspective. Despite this similarity, some argue that VPT is more complex than ToM and others vice versa. ToM and VPT will be compared with the aim of exploring the differences between them.

One such difference is *Deception,* a complex social strategy in which the deceiver must take into account the receiver's mental state (e.g., belief or visual perspective) to create a misrepresentation in the mind of the receiver with the intention of gaining a reward or avoiding punishment (Sobel, 2020). Deception is closely related to *lying*, which Sobel (2020) defined as the act of giving information to the receiver that the liar believes to be untrue, and this is regardless of the liar's intent or expected consequences. In other words, when lying to someone, you will say something that you believe to untrue without necessarily considering their mental state (i.e., whether they believe it is true or not) or whether this lie will allow you to gain a reward or avoid punishment. This key difference between these definitions is that deception requires explicit consideration of the receiver's mental state, whereas lying does not. Although lying does not necessarily require a consideration of the receiver's mental state (e.g., belief or visual perspective), it might still be used as part of this process. This thesis will explore whether individuals consider another's mental state in order to lie to them by comparing lying and deception.

1.1 Theory of Mind and Belief Reasoning

ToM, also referred to as "mentalizing" and "mind-reading" (Quesque & Rossetti, 2020), has been investigated using a range of different tasks and age groups. Historically, ToM has predominantly been studied in developmental contexts with the aim of establishing when children develop ToM. Perhaps the most well-known ToM task, is a *belief reasoning* task informally referred to as the Sally-Anne task

(Baron-Cohen, Leslie, & Frith, 1985), which is based on Wimmer and Perner's (1983) *object transfer false belief task*. It should be noted there are other types of ToM task including trait judgments, strategic games (including deception), social animations, mind in the eyes and rational actions (see Schurz, Radua, Aichhorn, Richlan, & Perner, 2014), but belief reasoning tasks will be the focus here. In the Sally-Anne task, children watched a scene about two characters, Sally and Anne. Sally places an object into a red box and leaves the room. Whilst Sally is absent, Anne moves the object from the red box to a blue box. As Sally is not aware of the object's change in location, she now holds a *false belief (FB)*. The child is asked "Where will Sally look for the object?". To answer this question successfully, children must decouple Sally's FB from their own reality and simultaneously hold their own belief and Sally's opposing belief in mind (Baron-Cohen, Leslie & Frith, 1985). Typically developing children tend to begin passing FB tasks like this task between the ages of four and five years (Hogrefe, Wimmer, & Perner, 1986). More recently, FB reasoning is still largely studied using adaptations of the object transfer false belief task (see Yu & Wellman, 2022 for a review). For example, adaptions of the Sally-Anne task have been combined with functional magnetic resonance imaging (fMRI) to understand the neural correlates of belief reasoning in adults (Sommer et al., 2018). The Sally-Anne task is a *first-order* belief reasoning task. This means it describes what a character believes about real world events; whereas, more complex *second-order* belief reasoning tasks describe what a character thinks about another character's beliefs (Perner & Wimmer, 1985). For example, Perner and Wimmer (1985) tested second-order false belief reasoning using an ice-cream story. John and Mary are told that the ice cream van will be in the park all afternoon and Mary leaves to get money to buy ice cream. John speaks to the man in the ice cream van, and he tells John that he is going to sell ice cream at the church for the rest of the afternoon instead. Later in the afternoon, John looks for Mary and Mary's mother tells John that Mary has gone to buy ice cream. Participants were asked where John thinks Mary is. The correct answer being the park because John thinks that Mary thinks the ice cream van is still there. Perner and Wimmer (1985) reported that children tended to start passing this test between the ages of six and seven years. Using a simplified version of Perner and Wimmer's (1985) task, Sullivan, Zaitchik, and Tager-Flusberg (1994) reported that children began to reliably pass this task at six years. The later ages that children pass second-order FB tasks (6 years) compared to first-order FB tasks (4-5 years) supports the notion that these tasks are more complex.

Differences in ToM performance have been reported in a range of clinical populations including Autism Spectrum Condition (ASC; Happé, 1994a), attention deficit hyperactivity disorder (Maoz, Gvirts, Sheffer, & Bloch, 2019), schizophrenia (Sprong, Schothorst, Vos, Hox, & Van Engeland, 2007), social anxiety disorder (Washburn, Wilson, Roes, Rnic, & Harkness, 2016) and major depressive disorder (Washburn et al., 2016). This highlights the importance of developing accurate ToM tasks to explore the psychological profile of the mentioned clinical populations. For example, Autism Spectrum Condition (ASC; also referred to as autism spectrum disorder) is a complex, multifaceted and heterogeneous condition. According to the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-5; American Psychiatric Association, 2013), ASC diagnoses are based on two core symptoms: variations in social interaction and communication, and restricted, repetitive behaviours. Variations in social interaction and communication include responding inappropriately in conversation, or difficulty building relationships, whereas restricted, repetitive behaviours include strict adherence to routines and highly specific interests of abnormal intensity. ASC is of specific interest in ToM research as its some core clinical are social in nature and therefore might relate to variations in ToM. As such, many autistic children pass both first- and second-order belief reasoning tasks, but at later ages than non-autistic children (Kaland et al., 2002; Tager-Flusberg, Baron-Cohen, & Dohen, 2000; Tager-Flusberg & Sullivan, 1994), which might reflect variations in ToM ability. It should be noted that many autistic individuals do pass these tasks eventually, which indicates that, while delayed, they do possess at least some ToM abilities.

The Sally-Anne task and ice cream story task were originally developed for use in children, but FB paradigms have also been used in adults too. It has been acknowledged that pass or fail tasks can only provide limited information about ToM, so researchers have used reaction times (RTs) to understand the more subtle features of ToM in adolescents and adults. For example, Back and Apperly (2010) compared the RTs of true and FB trials. Going back to the example of the Sally-Anne task, if Anne did not move the ball to another location and it remained in the initial red box, Sally would hold a *true belief (TB)*, rather than a FB. TBs are theoretically simpler than FB because participants do not need to decouple Sally's competing belief from reality. In support of this notion, Back and Apperly (2010) reported slower RTs in FB trials relative to TB trials in adults. It has been suggested that a different approach should be taken to studying ToM in adults because FB paradigms do not mirror the demands of everyday social interactions. To this end, 'advanced ToM' tasks have been developed, such as the Strange Stories Task (Happé, 1994a), which is considered 'advanced' because it probes a broad range of social situations including double bluff, sarcasm and persuasion. Participants were instructed to read stories that describe social interactions and are asked questions that can only be answered correctly by inferring the character's mental states. Some studies using the Strange Stories Task have reported differences between autistic and non-autistic adults (Happé, 1994a; Kaland et al., 2002; Zalla et al., 2009), whereas others have not (Ponnet, Roeyers, Buysse, De Clercq, & Van Der Heyden, 2004; Roeyers, Buysse, Ponnet, & Pichal, 2001). The Strange Stories task requires the participant to read passages of written text and so the verbal and executive demands of these tasks are very different to first- and second-order ToM tasks making it difficult to compare these tasks. Developing ToM tasks that are more similar to previous belief reasoning tasks, whilst appropriately difficult for adults, will help us to understand adult ToM ability without substantially changing the non-social executive demands of the task.

1.2 Visual Perspective Taking

VPT is commonly divided into two levels. Level one (*VPT-1*) is the ability to judge whether an object can be seen from another point of view (Flavell et al., 1981) and is also referred to as 'line-of-sight tracing' because VPT-1 tasks can theoretically be solved by tracing an imaginary line between the character and the target (Michelon & Zacks, 2006). This explanation is supported by correlations between the distance between the character and target, and RTs (Michelon & Zacks, 2006). For example, Baron-Cohen (1989) measured VPT-1 in children. Children were seated in a room with six small toys placed in distinct locations around the room. The children were asked to name all the toys to ensure the names were in their vocabulary. The experimenter then looked a one specific toy and asked the child to name the toy they were looking at. VPT-1 tasks like this are typically passed at around two to two and a half years of age (Flavell, Shipstead, & Croft, 1978; McGuigan & Doherty, 2002; Moll & Tomasello, 2006).

Level 2 (VPT-2) is more complex and refers to the understanding that an object can be viewed by two individuals simultaneously and create different visual experiences if the viewing circumstances of the individuals differ (Flavell et al., 1981). That is, VPT-2 concerns *how* an object appears, rather than whether it is seen or not (VPT-1). For example, Hamilton, Brindley and Frith (2009) investigated VPT-2 performance in children using a panda toy and a doll. The panda was placed on a table in front of the child and then the panda was occluded. A doll, Susan, was placed at ±90° from the child's perspective and the child was asked "When I lift the pot, what will Susan see?". The child was presented with images of the panda from four distinct views and asked to point to their answer. To complete this task successfully, the child must deliberately inhibit their own view of the panda, then mentally transform their body schema into Susan's to adopt of visual perspective of the panda, which is referred to an embodied transformation (Kessler & Thomson, 2010; Zacks & Michelon, 2005). An embodied transformation into the other perspective is predominantly employed when there is at least 90° angular disparity between the self and the target, as angular disparities below 90° can theoretically be resolved by visual discrimination (Kessler & Rutherford, 2010). In addition, increasing angular disparities are associated with greater RTs above 40° angular disparity (Kessler & Thomson, 2010). Theoretically, VPT-2 tasks can be solved by mental transforming one's body schema into the target's perspective or mentally rotating the target object to match your own perspective, but the work of Kessler and Rutherford (2010) indicates that individuals tend to use embodied self-transformations to complete VPT-2 tasks. VPT-2 tasks, like in this example, are typically passed between the ages of four and five years (Flavell et al., 1981; Gzesh & Surber, 1985; Hamilton, Brindley, & Frith, 2009; Masangkay et al., 1974).

VPT is closely related to Spatial Perspective Taking (SPT), which refers to an understanding of the locations of objects in relation to a target (Kessler & Thomson, 2010). Like VPT, SPT can be divided into two levels, level one (*SPT-1*) and level two (*SPT-2*). Similarly to VPT-1, SPT-1 concerns in front or behind judgments and can be solved using line-of-sight tracing (Surtees, Apperly, & Samson, 2013a). SPT-2 on the other hand, concerns left and right judgements and, like VPT-2, is solved by rotating one's own body schema (Surtees et al., 2013a). Although SPT is not the subject of the current investigations, understanding the relationship between VPT and SPT is important as results from SPT studies will be extrapolated to VPT when findings from VPT studies are not available. It is also worth noting that VPT and SPT are not always differentiated, some investigations refer to visuo-spatial perspective (e.g., Kessler & Rutherford, 2010).

The experimental paradigms discussed thus far have been developed specifically to investigate VPT in children; however, there are several experimental paradigms used to investigate VPT in adults. To study VPT-1, Michelon and Zacks (2006) used photographs of an avatar seated at a table with some everyday objects on it. Varying numbers of occluders (objects used to block the view of an object) were used so, although all objects were visible to the participant, only some were visible to the avatar. Children were asked to judge whether the avatar could see a target object, or not, and Michelon and Zacks (2006) found that participants made very few errors. Złotogórska-Suwińska and Putko (2019) studied VPT-2 in adults. Participants were presented with an image of a household object and were asked if, either the avatar or themselves would see this view of the object. Participants were then shown a scene with the avatar and target object and participants responded yes or no to the preciously asked question. Złotogórska-Suwińska and Putko (2019) also reported relatively few errors.

VPT has also been studied in autistic individuals. It has been reported that autistic children demonstrated intact VPT-1 performance (e.g., Baron-Cohen, 1989) and therefore any variations in ToM ability in ASC are likely to affect performance on more complex tasks. There is evidence that autistic children were less accurate on VPT-2 tasks than non-autistic children (Hamilton et al., 2009; Ni, Xue, Cai, Wen, & He, 2021; Yirmiya, Sigman, & Zacks, 1994), whereas others do not report any difference (Tan & Harris, 1991). Hamilton, Brindley and Frith (2009) also compared autistic and non-autistic children's performance on an object rotation task and reported no differences. This indicates that autistic children may have a specific difficulty with self-rotations, rather than mental rotations per se. There have been studies comparing SPT-2 between autistic and non-autistic adults (David et al., 2010; Zwickel, White, Coniston, Senju, & Frith, 2011), which found no difference; none have examined VPT-2 performance in autistic adults, an omission this thesis aims to rectify.

1.3 The relationship between Visual Perspective Taking and Belief Reasoning

A relationship between belief reasoning and VPT-2 has been long postulated and Hamilton, Brindley and Frith (2009) have reported a correlation between FB reasoning and VPT-2 in children. Both FB reasoning and VPT-2 tasks require the participant to inhibit their own viewpoint in favour of mentally adopting the target's viewpoint. The difference between these processes is the information that is being mentally represented; in VPT-2, the target's visual perspective is being represented, whereas in FB reasoning, the target's belief state is represented. In support of this, Hamilton, Brindley and Frith (2009) reported that autistic children struggled with a battery of ToM tasks, including the Sally-Anne task, and a VPT-2 task. This suggests there may be something in common to VPT-2 and FB reasoning that autistic children find difficult, for example decoupling an alternative belief/perspective from their own reality (U. Frith, Morton, & Leslie, 1991). If stable differences can be detected in the relationship between belief reasoning and VPT-2, this may inform cognitive profiles of ASC, or provide a new avenue for objectively differentiating between autistic and non-autistic adults.

Children begin passing both VPT-2 and FB reasoning tasks between the ages of four and five years (e.g., Flavell et al., 1981; Hogrefe et al., 1986, respectively), but it is not clear which process develops first. It has been argued that VPT-2 is the starting point in the development of broader ToM abilities (Flavell et al., 1978). Evidence from primates indicates they are able to use simple physical alignment to understand the perspective of human experimenters (e.g., Bräuer, Call, & Tomasello, 2005; Tomasello, Call, & Hare, 1998). Although this is not VPT-2, it could reflect a basic understanding that one must make physical or mental transformation to understand another's view of the world (Kessler & Thomson, 2010). An increase in processing capacity via evolution may have allowed a change in perspective by emulated movement, rather than a physical one (Kessler & Thomson, 2010). This view is supported by evidence that VPT-2 involves rotation of one's own body schema, as opposed to a purely abstract transformation (Kessler & Thomson, 2010). Once individuals have the ability to represent multiple perspectives simultaneously, then they may be able to use this ability to represent more abstract beliefs simultaneously too.

It has also been argued that ToM develops prior to VPT-2. Moll & Kadipasaoglu (2013) argue that social perspective taking develops at the earlier age of around two years, unlike VPT-1 which develops at around two to two and a half years (Flavell et al., 1978; McGuigan & Doherty, 2002; Moll & Tomasello, 2006) and VPT-2 around four years (Flavell et al., 1981; Masangkay et al., 1974). They define social perspective as an understanding of another's preferences, goals etc., which are typically discerned from temporally extended interaction, including dialog. This is primarily evidenced by success on disambiguation tasks, for example, Tomasello and Haberl (2003) reported one year olds could tell which object an adult wanted based on the adult's prior engagement with the object when the child was equally familiar with three possible alternatives. Moll & Kadipasaoglu (2013) suggest that children first learn to understand beliefs in scenarios that are defined by differences in experiential background (what they did, witnessed and heard), rather than defined by differences in visual perception. They go on to argue that it is easier for children to note and update experiential records compared to records of visual perception (Perner & Roessler, 2012; Samson, Apperly, Chiavarino, & Humphreys, 2004). Moreover, registering and remembering these experiential records does not increase the demands of the task, they act as helpful cues. Alternatively, there are no cues from prior encounters available in VPT-2, so VPT-2 may be more challenging than belief reasoning.

The link between belief reasoning and VPT-2 is also reflected in neuroimaging findings. A meta-analysis of fMRI data by Schurz and colleagues (2014) concluded that that both belief reasoning and VPT (VPT-1 and VPT-2) tasks are associated with activation in the left and right temporo-parietal junctions (lTPJ and rTPJ respectively), medial prefrontal cortex (mPFC) and precuneus. Seymour and colleagues (2018) proposed a functional VPT-2 network using magnetoencephalography which included a mentalizing sub-network. This ToM sub-network included the mPFC and was suggested to be involved in the representation of self and other perspectives (Seymour et al., 2018). It has been proposed that the precuneus is involved in mental imagery (e.g., Cavanna & Trimble, 2006). Seymour and colleagues (2018) reported that the rTPJ was the hub of the VPT-2 network and it was involved in shifting from externally driven stimulus processing to internal representations and endogenous processing. Additionally, the necessity of the lTPJ has also been demonstrated in belief reasoning research. For example, patients with lTPJ damage reportedly have a selective belief reasoning deficits (Apperly, Samson, Chiavarino, & Humphreys, 2004; Samson et al., 2004). The number of overlapping neural substrates highlights the similarity of belief reasoning and VPT-2.

Belief reasoning and VPT-2 share conceptual similarities, associations with ASC and similar developmental trajectories but, it is not clear which process is more cognitively demanding (measured in terms of speed and/or accuracy). To answer this question, belief reasoning and VPT-2 will be compared using a novel *"Seeing-Believing Task*", similar to the Sally-Anne task (Baron-Cohen et al., 1985) and Hamilton, Brindley and Firth's (2009) panda task adapted to make it appropriately difficult for adults. Unlike previous belief reasoning tasks, TBs will be the focus, rather than FBs. This is because TBs reflect reality, like VPT-2, and will be provide a clearer comparison. Both VPT-2 and belief reasoning reflect methods of inferring another's mental state, whether that be their visual perspective or belief, but it is not clear *how* humans use this mental state information in social interactions. Two specific examples of social interactions will be explored, lying and deception.

1.4 Lying and Deception

Lying and deception are common in everyday life (DePaulo et al., 2003) and may be used with prosocial or antisocial intentions (Ding, Sai, Fu, Liu, & Lee, 2014). Historically the terms lying and deception have been used relatively interchangeably in the literature to refer to a psychological process by which an individual deliberately attempts to convince another person to accept as true something that the deceiver knows to be false (Abe, 2009; Lee, 2013). More recently, however, Sobel (2020) proposed a distinction between deception and lying, which depends on whether the individual intends to create a FB in the receiver. Instances where the individual intends to create a FB in the receiver are referred to as *deception*, whereas instances where the individual does not consider the receivers beliefs are referred to as *lying* (Sobel, 2020). However, even without explicitly considering a change in the other's belief system, it is conceivable that ToM processes are part of the lying process, in other words, for a convincing lie one might have to track the other's knowledge/belief of reality. As per this definition, deception is conceived of as requiring belief reasoning (e.g.,Sodian & Frith, 1992), however it is unclear whether lying involves belief reasoning to the same extent or not.

Evans and Lee (2013) also recognised a distinction between lying and deception in young children, however they referred to these phenomena as *primary lying* and *secondary lying* respectively. Evans and Lee (2013) reported that younger children aged between two and three years told primary lies, which involve making statements that are untrue without necessarily taking into account the receiver's mental state (i.e., *lying* as per Sobel's (2020) dichotomy). On the other hand, slightly older children aged four to five years tended to use secondary lies, which involves understanding that the receiver is not aware of the true state of affairs and is, therefore, susceptible to FB (i.e., *deception* as per Sobel's (2020) dichotomy). The age where children began to deceive is in-line with the age children begin the pass explicit FB tasks (e.g., Hogrefe et al., 1986) supporting the notion that one must understand what FB is to create a FB in another. On the other hand, lying behaviour is reported in younger children who do not possess the same level of FB understanding. This suggests that belief reasoning is not necessary to lie – and/or that lying could be important as a simple preliminary form of belief reasoning. Older children and adults, on the other hand, do have a more developed ToM system and they could use belief reasoning when lying, for instance, to lie more convincingly. In other words, the line between lying and deceiving could be more blurred in adults. To understand whether lying involves belief reasoning, lying and deception will be compared using a novel "*Lying-Deception Task*" which assumes that if lying *does* involve belief reasoning, it is unlikely that there will be difference in speed and/or accuracy between lying and deception. Alternatively, if lying does not involve belief reasoning, it is likely that RTs and/or errors will be greater in deception trials compared to lying trials.

1.5 Aims of the current thesis

Broadly, this thesis aims to examine how adults infer and use the mental states of others in social interactions. If "seeing" is regarded as mental state then both belief reasoning and VPT-2 are methods of inferring another's mental state, whether that be their beliefs or visual perspectives. A small number of studies have correlated belief reasoning and VPT-2 performance on separate tasks, but this thesis aims to assess if there are differences between belief reasoning and VPT-2 using the Seeing-Believing Task. Some studies have reported variations in social cognition in autistic individuals, with specific interest in ToM and belief reasoning. This thesis aims to ascertain if the Seeing-Believing Task can detect any differences between autistic and non-autistic adults. Unlike other ToM tasks, the Seeing-Believing Task allows us to study the relationship between belief reasoning and VPT-2, which may be better able to detect the subtle variations in social cognition reported in ToM. Additionally, VPT-2 has not been studied in a sample of autistic adults previously, so autistic and non-autistic adult's VPT-2 performance will be compared. As well as studying how we infer another's mental state, it is unclear exactly how viewpoint information is used in social interactions. To purposely deceive someone, belief reasoning is used to generate a FB in another's mind (e.g., Ding, Wellman, Wang, Fu, & Lee, 2015). It is not clear; however, whether mental states are taken into account when simply lying to someone else. Finally, this thesis aims to use a novel Lying-Deception Task to understand whether lying requires belief reasoning.

Prior to the start of this thesis, pilot data using an earlier iteration of the Seeing-Believing Task was collected. This pilot experiment used a three question version of the Seeing-Believing paradigm where participants' understanding of the character's belief and visual perspective were probed, as well as the participant's visual perspective. Pilot data was acquired from 26 participants. The results of this pilot study were used to inform power calculations for the experiments included in this thesis.

1.6 Thesis structure

To achieve these aims, there are three empirical chapters and a discussion chapter. The first empirical chapter, Chapter 2, comprises of a series of behavioural experiments to validate the use the Seeing-Believing Task to compare belief reasoning and VPT-2. Chapter 3 uses the Seeing-Believing Task to gain a better understanding of social cognition in ASC and Chapter 4 compares lying and deception to understand if belief reasoning is required to lie to someone. Finally, Chapter 5 comprises a general discussion, which includes limitations, future directions, and a conclusion. Each of the three empirical chapters – Chapter 2, Chapter 3, and Chapter 4 – are outlined briefly below.

Chapter 2. The first empirical investigation is comprised of three behavioural experiments designed to validate the Seeing-Believing Task. The Seeing-Believing Task was designed to compare belief reasoning and VPT-2 performance in adults. Typically, belief reasoning tasks focus on FB performance, but here the focus will be on TB reasoning. As someone's visual perspective reflects reality, it might be more pertinent to compare VPT-2 to TB reasoning as this also reflects reality, rather than FB reasoning as this reflects a misrepresentation of reality. Furthermore, the influence of self and other judgements, as well as comparability to other common belief reasoning and VPT tasks was explored.

Chapter 3. In this chapter, the Seeing-Believing Task was applied to a sample of autistic adults. Belief reasoning and VPT-2 performance of those autistic and non-autistic adults was compared, as well as the relationship between TB reasoning and VPT-2. The contribution of memory processes to any performance differences were explored.

Chapter 4. The final empirical investigation uses a combined Lying-Deception Task adapted from the previous Seeing-Believing Task. It is generally agreed that deception requires belief reasoning, whereas it is unclear whether lying involves belief reasoning, so lying and deception will be compared to ascertain if belief reasoning is involved when lying to someone.

Thesis format. The chapters in this thesis are written in a 'publication format', where each chapter is constructed as a self-contained manuscript. All empirical investigations described in this thesis were pre-registered with the Open Science Framework. Pre-registrations, study materials, participant data and analyses are accessible online.

Chapter 2: https://osf.io/57wa9/

Chapter 3: https://osf.io/xwjub/?view_only=57e7a5fa2bc44ea986af0124dbbe9973

Chapter 4: https://osf.io/64kwc/?view_only=bee41d9209374ace8cee44c22c3c9434

2. Dissociating Visual Perspective Taking and Belief Reasoning

2.1 Introduction

Mentalizing refers to the human capacity to represent the mental states of others. Representing another's intentions and beliefs is typically subsumed under the psychological construct Theory of Mind (ToM; Baron-Cohen et al., 1985), while inferring their visuospatial experience of the world is referred to commonly as Visuospatial Perspective Taking (VPT; Newcombe, 1989). Of particular importance to the present study is Level-2 VPT (VPT-2; Flavell et al., 1981), which refers to our ability to understand *how* the world appears differently from another's viewpoint. Historically, these two aspects of mentalizing have been studied independently (e.g., Schurz, Aichhorn, Martin, & Perner, 2013). There is strong conceptual overlap between them, however, representing others' mental states, such as their beliefs and/or perspectives, requires us to disregard our own egocentric representations. Indeed, an increasing body of research indicates a strong correlational relationship between VPT-2 and ToM (e.g., Hamilton et al., 2009; Schurz et al., 2013). Further, both processes seem to develop around four to five years of age (Flavell et al., 1981; Wellman, Cross, & Watson, 2001), and various neuroimaging meta-analyses suggest commonalities in their underpinning brain networks (for reviews see Gunia, Moraresku, & Vlček, 2021; Schurz et al., 2013; Van Overwalle, 2009). Here, we investigated whether ToM and VPT-2 involve common or distinct cognitive processes.

2.1.1 Belief reasoning

False-belief (FB) reasoning paradigms are often employed to measure ToM, the most popular of which is the "Sally-Anne" task (Baron-Cohen et al., 1985; originally Wimmer & Perner, 1983). These tasks require participants, often children, to distinguish between their own privileged representation of reality (they know the true hidden contents of a box) and a protagonist's false representation (Sally is unaware that Anne swapped the contents of the box in Sally's absence). To represent Sally's FB, participants must be able to ignore their own privileged representation. Solving this FB task is therefore taken as a direct reflection of an individual having a developed ToM – i.e., an understanding that others represent reality differently to oneself, sometimes even incorrectly.

While such tasks are valid, albeit conservative measures of ToM ability, they place all emphasis on the representation of FBs – they offer no insight into the representation of true beliefs (TBs) or their potential contribution to ToM (but see Fabricius, Boyer, Weimer, & Carroll, 2010; Huemer et al., 2023). TBs are represented faster and more accurately compared with FBs (Apperly, Back, Samson, & France, 2008; Apperly, Warren, Andrews, Grant, & Todd, 2011). This is due largely to their congruence with reality, but also often due to their congruence with the participant's representation of reality and their visual perspective of the world – a common confound in typical "false location belief reasoning tasks" (e.g., Rahman et al., 2021). As such, these tasks offer little discriminatory value when assessing TBs and VPT-2 processing on the basis of behavioural outcomes. While another's visuospatial perspective can be dissociated from their belief on these tasks (e.g., if protagonists close their eyes, their perspective but not their belief is changed), many studies do not incorporate such manipulations.

2.1.2 Level-2 Visual Perspective Taking (VPT-2)

Tasks employed to investigate VPT-2 typically require participants to judge whether a target object is located to the left or right of another's perspective (e.g., Michelon & Zacks, 2006), whether the other person sees the front, side or back of a target object (e.g., Hamilton et al., 2009), or if the other perceives a "6" or a "9" from their viewpoint (e.g., Surtees, Apperly, & Samson, 2013b). The angular disparity between the participant's egocentric perspective and the other's (target) perspective plays a key role in this process, with response times (RTs) and errors increasing with larger disparities (see Kessler & Rutherford, 2010; Kessler & Thomson, 2010). This appears to reflect the process of "embodiment"; Kessler and Rutherford (2010) demonstrated that typically developed adults perform VPT-2 tasks by mentally rotating themselves into the other's orientation and embodying their viewpoint.

2.1.3 Levels of complexity

Although embodying another's perspective enables insights into how the world is experienced from that particular viewpoint, it might not necessarily require a complex representation of the other's mind. For example, Kessler and Thomson (2010) demonstrated that the same embodiment process of mental self-rotation was also employed when participants imagined themselves in a different viewpoint that was not defined by another person but indicated by an empty chair (see also Muto, Matsushita, & Morikawa, 2018); thus, the presence of another's mind was not strictly required for VPT-2. However, the same authors also reported that another person's presence facilitated VPT-2, suggesting that VPT-2 might bridge the gap between spatial cognition and mentalizing (Hamilton, Kessler, & Creem-Regehr, 2014). Some researchers have therefore argued that VPT-2 could be a developmental or even an evolutionary stepping-stone towards more complex forms of mentalizing, such as ToM (Gunia et al., 2021; Kessler, Cao, O'Shea, & Wang, 2014; Michelon & Zacks, 2006).

Such a distinction between perspective taking and belief reasoning vis-à-vis the complexity of representing another's mind is not a new concept. For instance, Howlin, Baron-Cohen, and Hadwin (1999) proposed five developmental levels of increasing complexity in representing another's mind, whereby perspective tracking (level 1) is distinguished from perspective taking (level 2), and representations of other's true (level 4) and false beliefs (level 5) occur at more advanced stages (but see Fabricius et al., 2010). In a similar vein, Apperly and Butterfill's (also 2009; Butterfill & Apperly, 2013) distinguish between minimal and full-blown ToM. Minimal ToM is proposed to rely on relational representations comprising objects and their locations relative to agents and what they can or cannot see. In contrast, full-blown ToM involves propositional representations, allowing inferences about the other's mental states and future actions. It has also been proposed that VPT-2 mechanisms develop from basic visuospatial cognitive processes, and then underpin the subsequent development of higher-level ToM abilities (Kessler & Rutherford, 2010; Kessler & Thomson, 2010). Such hierarchies of representational complexity would predict a distinction between VPT-2 and TB reasoning, but this has not yet been investigated directly. Establishing this in the first instance would enable further explorations into *how* the two aspects of mentalising differ in their processing and representational content.

2.1.4 The current study

In the current pre-registered study (https://osf.io/57wa9/), we devised a novel experimental paradigm that allowed us to compare TB reasoning and VPT-2 directly and in a way that allowed us to disentangle a participant's representation of another's perspective and belief from their own egocentric perspective and representation of reality: the *Seeing-Believing Task*. Each trial begins with a character sitting a table with their back to the participant, such that the participant and the character had identical visual perspectives of the table. Placed on the table is either a hare or locomotive at one of four orientations (front, rear, left side, right side; see Figure 2 for all eight options). In a subsequent image, the hare or locomotive has been hidden by an overturned bucket and the character may (Experiment 1 and 2) or may not leave the room (Experiment 3); thus, it is suggested that the character was unaware of whatever happened in their absence. At this point, the bucket is removed, and one of two events occurred: on 50% of trials, the object is swapped with another (e.g., the hare swapped with the locomotive) before the bucket is replaced; in the other 50%, the object remains and the bucket replaced over it. The character then returns to sit either in the same chair as before, in front of the participant (0^o angular disparity), or another chair to the left or right of their original position (±90° angular disparity). This 90^o angular disparity between the participant's egocentric (self) view and the character's new (other) orientation requires participants to mentally adopt the character's perspective rather than directly infer their perspective or belief state from their own egocentric representation. Finally, the participant is asked one of two questions in order to make a belief or a VPT-2 judgement: they are either asked "What will she expect to see?", requiring an inference of the character's belief, or "What will she actually see?", probing the character's perspective. In Experiment 2, participants are also asked two self-related questions. "What will *you* actually see?" and "What did *you* initially see?" (see Probe Questions in Figure 1). The first self-related question concerned the participant's current egocentric perspective and representation of reality, whereas the second self-related question is designed to mirror the potential memory demands of the belief question, "What will she expect to see?", whilst not requiring the participant to make a mental state judgement about the character (see Hypotheses 4 and 5).

In this task, participants are presented with scenarios in which a character's TB was congruent with their visual perspective, allowing us to investigate if differences arise between TB and VPT-2 judgements when they are identical in content (both representing the same state of reality) and require identical responses. We also included a manipulation of angular disparity between the viewpoint of the self and the other (0° = overlapping vs. 90° = disparate), with which we could distinguish between the participant's own egocentric perspective and representation of reality from their representations of another's perspective and their beliefs. To our knowledge, this manipulation is different from any ToM paradigm to date because it varies systematically the disparity between perspectives (0° vs 90°), resulting in meaningful differences in visuo-spatial representations between self- and the other-perspectives. This allowed us to compare TB and VPT-2 directly and without egocentric confound. Two alternative hypotheses were contrasted: First, in light of strong correlations between independent performance indices of ToM and VPT-2 (e.g., Hamilton et al., 2009) and a degree of overlap in their associated neural substrates (e.g., Gunia et al., 2021; Schurz et al., 2013), it might be expected that representing another's TB is identical to processing their visual perspective. If so, TB and VPT-2 judgements should take the same time and be equally accurate. Alternatively, should VPT-2 involve less complex social representations than TB reasoning, which is supported by evidence of VPT-2 mechanisms being employed in non-social contexts (for review see Hamilton et al., 2014; Kessler & Thomson, 2010) and sub-served by partially segregated neural substrates (Gunia et al., 2021; Schurz et al., 2014), VPT-2 judgements should be faster and more accurate than TB judgments.

In a series of three pre-registered experiments, we utilised the novel Seeing-Believing Task to contrast VPT-2 and (true) belief judgements as our primary research question. In addition, we sought to replicate previous findings regarding the greater processing effort for false (FB) vs true beliefs (TB), and the greater processing effort required for higher compared to lower angular disparities. Table 1 presents our main pre-registered hypotheses relating to each experiment.

2.1.4.1 Experiment 1

The first experiment (https://osf.io/us9xp/) provided an initial evaluation of our basic paradigm and the first test of our main research question. TBs have been shown to be represented faster and with fewer errors compared with FBs due to their congruence with reality (Apperly et al., 2008; Apperly et al., 2011). However, typical "false location belief reasoning tasks" employed to investigate this often do not distinguish clearly between the other's TB, their visual perspective, and the individuals' own representation of reality and perspective (e.g., Rahman et al., 2021). Although our representations of another's TB and perspective might be identical in content (both representing reality in the current paradigm), they can be distinguished logically (e.g., closing my eyes will affect my visual perspective but not my belief about reality) and are proposed to differ regarding their conceptual complexity (e.g., Howlin et al., 1999). If the latter is true, the two processes will differ in processing time and accuracy.

First, we predicted that TB and VPT-2 judgements would differ in their underlying socio-cognitive processes (Hypothesis 1), leading to differences in response times (RT) and errors (average number of errors). Note that RTs were expected to provide cleaner data due to low overall number of errors. We expected TB to result in higher processing costs compared to VPT-2 (greater RTs and errors, with RTs the main focus of analysis) due to potentially more complex socio-cognitive processes involved in the former. Importantly, an angular disparity manipulation in our paradigm (0° *vs.* 90° disparity between the participant's and the character's perspective) allowed us to disentangle the participant's egocentric view and representation of reality from the character's perspective and belief. We therefore anticipated that the difference between TB and VPT-2 might be revealed more reliably at 90° angular disparity, and thus predicted an interaction between angular disparity and judgement type in addition or instead of a main effect of judgement type. We also expected to replicate previously reported effects: we predicted greater RTs and errors for VPT-2 judgements at 90° relative to 0° angular disparity (Hypothesis 2), and faster and more accurate processing for TB compared with FB trials (Hypothesis 3 in Table 1; for a review see Apperly et al., 2011).

2.1.4.2 Experiment 2

It has been suggested that to truly measure ToM processes, paradigms must require the participant to distinguish explicitly between themselves and a protagonist (Quesque & Rossetti, 2020). Such scholars might therefore argue that in Experiment 1, the participant is only required to process the character's perspective, so they might merge the character's (Other) with their own (Self) perspective. While we believe this to be unlikely given our manipulation of angular disparity, whereby the egocentric perspective is dissociated from the character's perspective at 90° disparity, we included explicit egocentric Self judgements in a second experiment (https://osf.io/xpycv/) to demonstrate that any effects in Experiment 1 cannot be explained by an absence of Self-related judgements.

Further, it can be argued that TB trials might not only differ from VPT-2 trials in the complexity of social representations. While a question about the other's perspective clearly refers to the current state of reality, a question about the other's expectations includes further variables. These might be social in nature, such as having to represent another's expectation/belief in addition to their visual experience of reality, or they might be unrelated to social processing. For instance, a question about the other's expectations might trigger a check back in memory to the initially presented scene, even if the state of reality has not changed on a particular trial (i.e., TB trials). Following this rationale, higher processing costs (greater RTs and errors) in TB compared to VPT-2 trials will not allow us to disentangle if this increased cognitive effort reflects social or memory-related cognitive processes. To examine any mnemonic aspects of processing in our paradigm, the second experiment included an explicit memory judgement along with "current" Self-judgements; in addition to asking participants about their current perspective (their representation of reality), we also asked them about their memory of reality (the stimulus presented at the start of the trial; Hypothesis 4). Note that experimental conditions were only distinguishable at the very end of each trial when the required judgement was presented as a question.

It is therefore safe to assume that participants encoded events in the same way across all trials up to the point where distinct judgements were required. This allowed us to understand how participants encode the events in any given trial, and if the cognitive costs of a memory check to the initial state of reality (even if unchanged) is a likely explanation for any differences observed between VPT-2 and TB judgements in Experiments 1 and 2 (Hypothesis 5). Adding this second "past" Self-related question also allowed us to balance the overall number of Other (Belief *vs.* Perspective) and Self-judgements trials (Self-current *vs.* Self-past perspective), avoiding any bias due to asymmetric numbers between judgement types.

2.1.4.3 Experiment 3

In a third experiment (https://osf.io/zbkyg/), we assessed how the results from Experiments 1 and 2 compared to those of previous studies that have used a different FB manipulation. Frequently, the belief of a protagonist is manipulated by having them witness (TB) or be absent for a change in an object's location (FB; e.g., "Sally-Anne" task). This differs from Experiments 1 and 2, in which the target object was either swapped for another object (FB) or not (TB; see Methods) but always in the protagonist's absence (similar to Back & Apperly, 2010). This procedural difference was chosen purposely to avoid a late change in visual experience – an object swap requires a cognitive update, thereby increasing cognitive demands/processing time that could potentially mask differences between TB and VPT-2 judgements. Hence, there was no swap in VPT-2 and TB trials in Experiments 1 and 2. In contrast, belief states (TB *vs.* FB) were induced in Experiment 3 by manipulating whether the character was present or not to witness the object swap. A swap occurred in all trials, equalizing cognitive updating demands across conditions, while keeping the overall number of trials manageable for an online study. Hypotheses for Experiment 3 paralleled those for Experiment 1 (Table 1).

Table 1. Summary of pre-registered hypotheses and associated statistical tests across Experiments 1-3.

No. (Experiment)	Predictions	Statistical test
Hypothesis 1 (Experiments 1-3)	TB ≠ VPT-2 especially at 90º angular disparity: If TB reasoning and VPT-2 are at least partially distinct processes there will be a difference in RTs and/or errors, especially at 90º, where self and other perspectives are distinct.	ANOVA for No-swap trials only: Judgement Type main effect and/or Angular Disparity x Judgement Type interaction. *t*-test TB_90º vs VPT-2_90º.
Hypothesis 2 (Experiments 1-3)	90º > 0º Judgements about another made at 90º angular disparity will be associated with greater RTs and/or errors than judgements made at 0º (replication of previous findings).	H2A: Angular Disparity main effect ANOVA. H2B: Angular Disparity x Judgement Type interaction.
Hypothesis 3 (Experiments 1-3)	FB > TB: FB judgements will be associated with greater RTs and/or errors than TB judgements (replication of previous findings)	Main effect Belief State (FB, TB) ANOVA.
Hypothesis 4 (Experiment 2)	Self_PastPerspective > Self_CurrentPerspective: If the task requires a check back in memory to the originally presented object, past self-perspective judgements should be slower/more error-prone than current self-perspective judgements.	*t*-test Self_Past vs. Self_Current
Hypothesis 5 (if H1 for Hypotheses 1 and 4 are correct) (Experiment 2)	(TB_90º – VPT-2_90º) > (Self_PastPerspective - Self_CurrentPerspective): If there is a “memory effect” in self-perspective judgments (Hypothesis 4), does it explain (is it the same size as) the difference between TB and VPT-2 at 90º (Hypothesis 1)?	*t*-test (TB_90º - VPT-2_90º) vs. (Self_Past - Self_Current) for no-swap trials.

Note. TB = true belief; FB = false belief; VPT-2 = Level-2 Visuospatial Perspective Taking; ToM = Theory of Mind; RT = response times; H_1 and H_0 refer to the alternative and null hypotheses, respectively. For any rejected H_1 Bayesian tests were used to assess support for H_0. Not all Hypothesis numbers in this table map onto those used in the preregistration. Additional Hypotheses 6 and 7 are reported in Supplemental Materials.

2.2 *Methods*

2.2.1 Design

The current study utilised the Seeing-Believing Task in three pre-registered experiments designed to assess whether TB reasoning can be dissociated from VPT-2. Hypotheses, study designs and planned analyses and study materials for all experiments are available on the OSF (https://osf.io/57wa9/). Each experiment employed a three-factor design (see Table 2); factors included Belief State, Angular Disparity, and Judgement Type.

Table 2. Summary of experimental designs and factor levels.

Experiment	Object-Swap (Belief State)	Angular disparity	Judgement type
1 (2x2x2)	No-swap (TB), Swap (FB)	0^{o}, $\pm 90^{o}$	Belief, Perspective
2 (2x2x4)	No-swap (TB), Swap (FB)	0^{o}, $\pm 90^{o}$	Belief, Perspective, Self-Current, Self-Past
3 (2x2x2)	Witnessed Swap (TB), Unwitnessed Swap (FB)	0^{o}, $\pm 90^{o}$	Belief, Perspective

2.2.2 Participants

Details of the final sample for each experiment are presented in Table 3. Sample size calculations were performed using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007); calculations were computed to achieve a small effect size (f = 0.15) with 95% power and resulted in sample sizes of 48 (planned recruitment of 50) for Experiments 1 and 3, and 64 (planned recruitment of 70) for Experiment 2. Experiments 1 and 3 had a 2x2x2 design (8 variables across 3 factors), whereas Experiment 2 used a 2x2x4 design (16 variables across 3 factors). A correlation of r = .81 for repeated measures was used, based on unpublished pilot data. Participants were aged between 18 and 40 years, had normal or corrected-to-normal vision, were fluent in written and spoken English, had access to a desktop computer, and could sit comfortably at a computer for ~1 hour. Individual participant data was included in our final sample if they completed a minimum of 3 out of 12 trials per condition correctly (see Table 3). This threshold, which is greater than chance level (1/8), was chosen to produce more reliable condition means. Note that the final sample sizes for Experiments 1 and 2 were reduced to 42 and 62, respectively, because additional participants had to be rejected due to issues with the exit questionnaires, which was only noticed after data collection was complete. We decided to continue with the somewhat reduced samples instead of collecting further participants after preregistration.

Table 3. Participant demographics

Experiment	Age (years)	N *(No. females)*	BAPQ	Participants excluded	
				Performance criterion	Exit questionnaires
1	23.71 *(3.95)*	42 *(21)*	114.55 *(22.98)*	12	8
2	24.15 *(5.69)*	62 *(28)*	113.58 *(20.80)*	38	8
3	26.57 *(6.27)*	51 *(29)*	114.52 *(22.46)*	14	0

Note. Values presents Mean *(SD).* BAPQ = Broad Autism Phenotype Questionnaire. Descriptive statistics were calculated after the removal of participants with low accuracy on the Seeing-Believing Task.

2.2.3 Procedure

Due to the current global pandemic, which suspended participant-facing research in the UK, all three experiments were designed to be conducted online. All paradigms were programmed in PsychoPy Builder (PsychoPy v2020.1.2), using realistic stimuli created with Unreal Engine Version 4.17.2 (Epic Games, Carry, NC). The table and chairs were selected from ‘Startpack’ defaults, and the character, hare and locomotive from Adobe’s Mixamo (Adobe, San Jose, CA). Participants were recruited via Prolific (https://www.prolific.co/), the experimental task was administered through Pavlovia (Peirce, 2007), and information sheets, consent forms and questionnaires were completed on Qualtrics (https://www.qualtrics.com/uk/). Participation in each experiment as compensated with £6.50, £10 and £6.50, respectively. Aston University’s Research Ethics Committee approved all experimental procedures, and all participants provided informed consent before taking part.

2.2.4 Materials

2.2.4.1. Experiment 1

As shown in Figure 1, each trial began with an image of a character sitting at a table with their back to the participant, such that the participant and the character had identical visual perspectives of the table. Placed on the table was either a hare or locomotive at one of four orientations (front, rear, left side, right side; see Figure 2 for all eight options). In a subsequent image, the hare or locomotive had been hidden by an overturned bucket and the character had left the room; thus, it was suggested that the character was unaware of whatever happened in their absence. At this point, the bucket was removed, and one of two events occurred: on 50% of trials, the object was swapped with another (e.g., the hare swapped with the locomotive) before the bucket was replaced; in the other 50%, the object remained and the bucket replaced over it. The character then returned to sit either in the same chair as before, in front of the participant (0º angular disparity), or another chair to the left or right of their original position (±90° angular disparity). This 90º angular disparity between the participant's egocentric (self) view and the character's new (other) orientation required participants to mentally adopt the character's perspective rather than directly infer their perspective or belief state from their own egocentric representation.

Finally, the participant was asked one of two questions in order to make a belief or a VPT-2 judgement: they were either asked "What will she expect to see?", requiring an inference of the character's belief, or "What will she actually see?", probing the character's perspective. The range of stimuli used resulted in an eight-choice response (2 objects x 4 orientations; see Figure 2). Since the large number of options may have affected participants' RTs, they were asked to press the space bar as quickly as possible once they had visualised their answer before subsequently making a choice between the eight options. RTs were measured in relation to pressing the space bar. Note that due to the complexity of the task (Judgement Type, Angular Disparity, Object Swap) it was advantageous for participants to imagine their answer while the stimulus configuration remained on screen, rather than pressing the space bar as quickly as possible and then determining their answer. Immediately after pressing the space bar, the 8-choice response display was shown and participants could take their time to select which of the eight options reflected their envisioned answer. The experiment consisted of 16 practice trials and 96 experimental trials split into 3 equal blocks of 32 trials, resulting in 12 trials per condition overall (2 x 2 x 2 design; Table 2). Each trial lasted approximately 12 seconds, depending on the duration of the participant's response. RT and error data were collected.

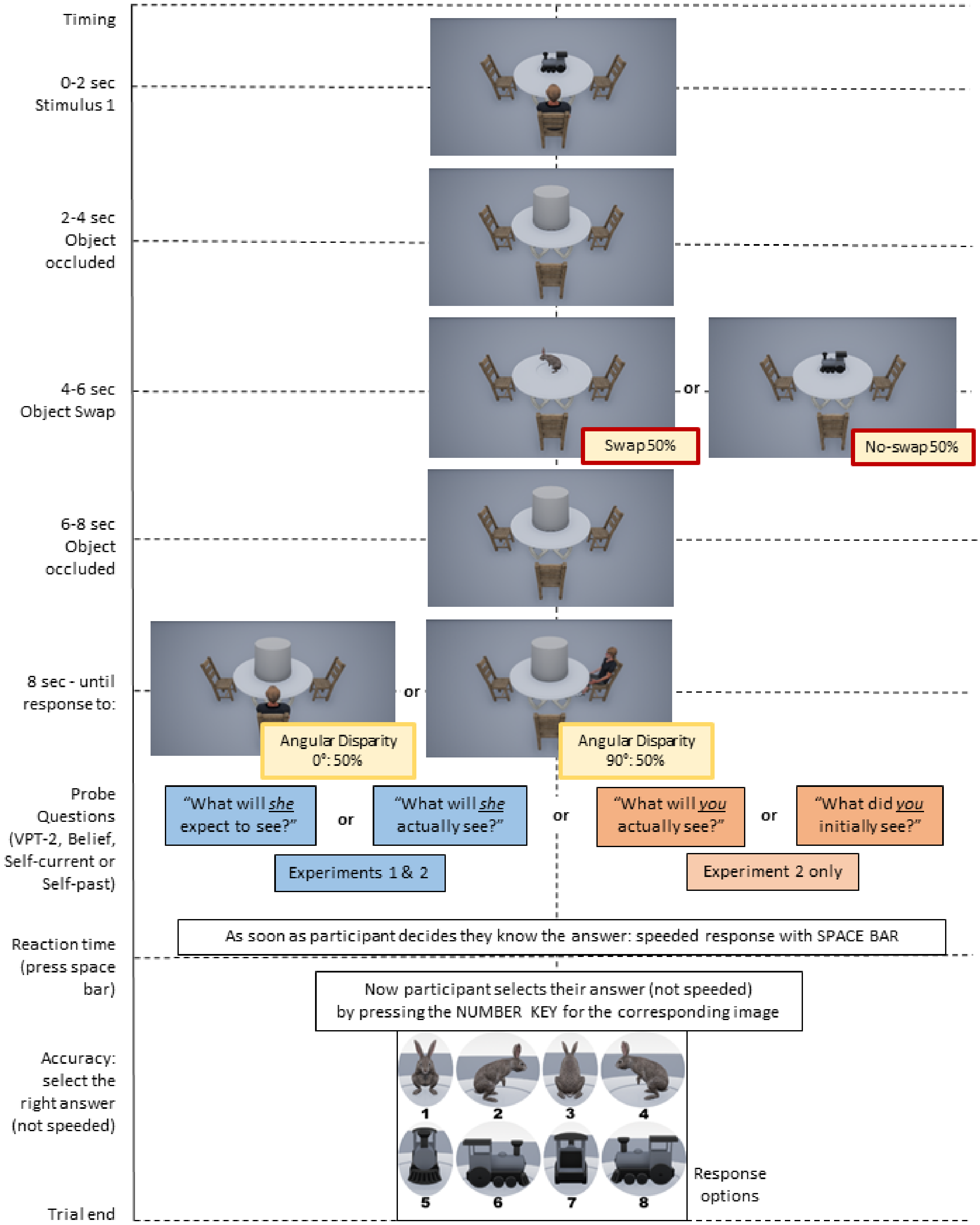


Figure 1. Trial schematic for Experiments 1 and 2.

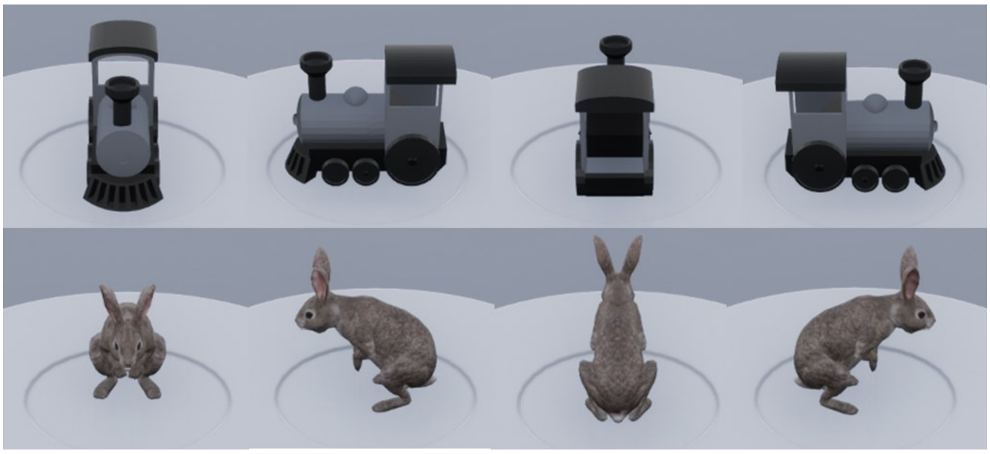


Figure 2. Stimulus options. The target object on the Table in Figure 1 could either be a toy locomotive (top row) or a hare (bottom row), presented in one four different orientations: front, left side, back, and right side.

2.2.4.2. Experiment 2

The second experiment included two additional Self-related questions alongside the two Other-related questions from Experiment 1: “What will *you* actually see?” and “What did *you* initially see?” (see Probe Questions in Figure 1). The first question concerned the participant’s current egocentric perspective and representation of reality, whereas the second was designed to mirror the potential memory demands of the belief question, “What will she expect to see?”, whilst not requiring the participant to make a mental state judgement about the character (see Hypotheses 4 and 5). Note that experimental conditions were only distinguishable at the very end of each trial when a question indicated the required judgement.

This experiment consisted of 16 practice trials and 192 experimental trials split into 4 equal blocks of 48 trials, resulting in 12 trials per condition overall (2 x 2 x 4 design; see Table 1). Each trial lasted approximately 12 seconds, depending on the duration of the participant’s response. RT and error data were collected.

2.2.4.3. Experiment 3

In the third experiment, belief state (TB *vs.* FB) was manipulated by whether or not the character was present to witness the object swap, which occurred in all trials (see Figure 3). The experiment consisted of 16 practice trials and 96 experimental trials split into 3 equal blocks of 32 trials, resulting in 12 trials per condition overall (2 x 2 x 2 design; see Table 2). Each trial lasted approximately 12 seconds, depending on the duration of the participant’s response. RT and error data were collected.

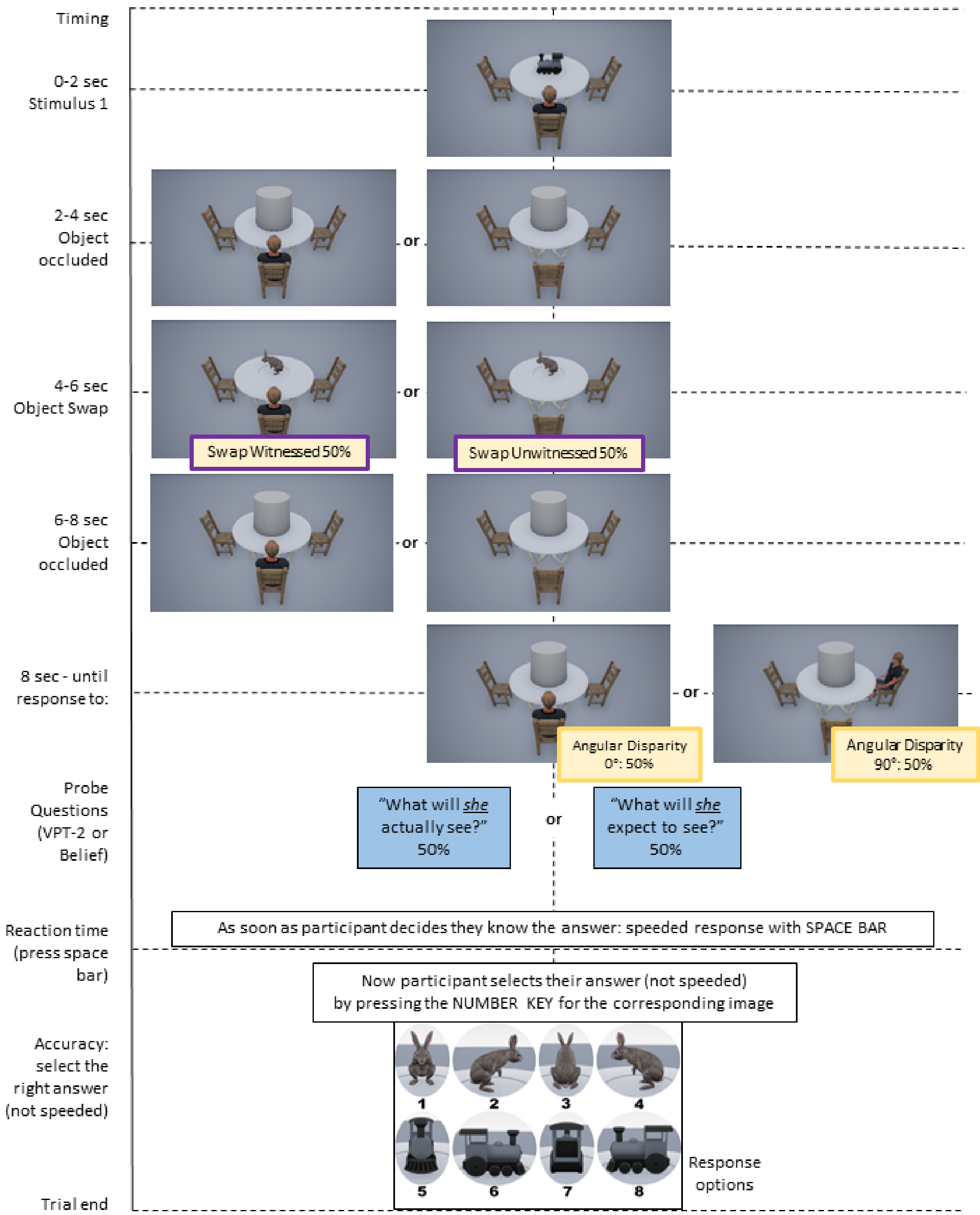


Figure 3. Trial schematic for Experiment 3.

2.2.4.4 Broad Autism Phenotype Questionnaire

The Broad Autism Phenotype Questionnaire (BAPQ; Hurley, Losh, Parlier, Reznick, & Piven, 2007) was used to assess participants' self-reported autistic traits. This instrument consists of 36 items and is derived from gold-standard clinical interview methods (Landa et al., 1992; Piven, Palmer, Jacobi, Childress, & Arndt, 1997). Inclusion alongside our main design factors was deemed to be exploratory yet potentially informative for future research. However, when including BAPQ score as a continuous variable into full design ANOVAs for each experiment, we observed no statistically significant model terms that involved this variable (neither main effects nor interactions), and therefore omit this variable from reporting in Results.

2.2.5 Statistical Analysis

Custom MATLAB (r2019a) code was used to calculate condition averages and remove outliers, and JASP (Version 0.14.1) was used to perform frequentist and Bayesian statistics.

Table 4. Summary of condition RTs and errors in Experiment 1. RTs reported in milliseconds and errors reported as absolute number of errors.

Object Swap (Belief State)	No-swap (TB)				Swap (FB)			
Angular Disparity	0°		90°		0°		90°	
Judgement Type	VPT-2	ToM	VPT-2	ToM	VPT-2	ToM	VPT-2	ToM
RT	1264(461)	1264(412)	1378(462)	1482(563)	1632(*643*)	1605(590)	1793(745)	1914(697)
Errors	.190(.552)	.476(*.804*)	.452(.772)	.667(1.074)	.524(*1.042*)	.1429(2.050)	.833(1.228)	1.929(2.224)

Table 5. Summary of condition RTs and errors in Experiment 2. RTs reported in milliseconds and errors reported as absolute number of errors.

Object Swap (Belief State)	No-swap (TB)							
Angular Disparity	0°				90°			
Judgement Type	VPT-2	ToM	Self-current	Self-past	VPT-2	ToM	Self-current	Self-past
RT	1407(*428*)	1408(*431*)	1472(*447*)	1328(*393*)	1586(*500*)	1703(*563*)	1572(*452*)	1411(*444*)
Errors	.113(*.367*)	.194(*.474*)	.194(*.398*)	.177(*.426*)	.306(*.616*)	.403(*.778*)	.597(*1.166*)	.274(*.657*)
Object Swap (Belief State)	Swap (FB)							
Angular Disparity	0°				90°			
Judgement Type	VPT-2	ToM	Self-current	Self-past	VPT-2	ToM	Self-current	Self-past
RT	1753(*519*)	1736(*553*)	1714(*498*)	1528(*435*)	1991(*682*)	2059(*705*)	1993(*669*)	1634(*468*)
Errors	.468(.783)	.758(*1.112*)	.500(*.825*)	.645(*.943*)	.645(*.943*)	.952(*1.220*)	1.194(*1.377*)	.806(*1.403*)

Table 6. Summary of condition RTs and errors in Experiment 3. RTs reported in milliseconds and errors reported as absolute number of errors.

Object Swap (Belief State)	Witnessed Swap (TB)				Unwitnessed Swap (FB)			
Angular Disparity	0°		90°		0°		90°	
Judgement Type	VPT-2	ToM	VPT-2	ToM	VPT-2	ToM	VPT-2	ToM
RT	1355(*440*)	1543(*528*)	1875(*847*)	2002(*837*)	1777(*589*)	1870(*657*)	2037(*789*)	2215(*908*)
Errors	.569(*1.171*)	.216(*.541*)	.549(*1.064*)	.765(*1.258*)	.824(*1.292*)	.804(*1.249*)	1.000(*1.311*)	1.196(*1.649*)

Note. Values present Mean, (*SD*)

2.3 Results

In the sections that follow, we present the results of analyses that evaluate each experiment in relation to the main pre-registered hypotheses specified in Table 1. For the sake of completeness, we report a full-design ANOVA for each experiment as an initial step before a detailed analysis that evaluates each of our main hypotheses. As per our pre-registration, in specific cases where the alternative hypothesis was abandoned in favour of the null, we performed Bayesian analysis to evaluate the strength of support for the null hypothesis. We present the results of statistics evaluating more minor preregistered hypotheses in Supplementary Material. Tables 4-6 report all means and standard deviations for each of the three experiments.

2.3.1 Experiment 1

We conducted two separate 2x2x2 ANOVAs for RTs and errors with the full experimental designs: Object Swap (Swap [FB], No-swap [TB]), Angular Disparity (0^o, 90^o), and Judgement Type (Belief, VPT-2). For RTs we observed main effects of Object Swap ($F(1,41) = 43.975$, $p < .001$, $n_p^2 = .518$), Angular Disparity ($F(1,41) = 40.455$, $p < .001$, $n_p^2 = .497$), and Judgement Type ($F(1,41) = 4.27$, $p = .045$, $n_p^2 =. 094$). In addition, we observed a significant interaction between Angular Disparity and Judgement Type ($F(1,41) = 7.584$, $p = .009$, $n_p^2 = .156$). For errors we also observed main effects of Object Swap ($F(1,41) = 21.196$, $p < .001$, $n_p^2 = .341$), Angular Disparity ($F(1,41) = 9.72$, $p = .003$, $n_p^2 = .192$), and Judgement Type ($F(1,41) = 18.103$, $p < .001$, $n_p^2 = .306$). In addition we observed a significant interaction between Object Swap and Judgement Type ($F(1,41) = 11.583$, $p = .001$, $n_p^2 = .220$).

2.3.1.1 Hypothesis 1

The central aim of this study was to investigate if VPT-2 and TB reasoning can be dissociated. To this end, belief reasoning trials ("What will *she* expect to see?") were compared to visual perspective trials ("What will *she* actually see?) at both 0° and 90° angular disparity (position on the character's seat upon her return) when the character held a TB (when the object on the table was not swapped). A 2x2 ANOVA applied to RTs revealed a significant main effect of Judgement Type ($F(1,41) = 4.684$, $p =.036$, $n_p^2 = .103$) and a significant Angular Disparity-by-Judgement Type interaction ($F(1,41) = 5.706$, $p = .022$, $n_p^2 = .122$). Planned comparisons between VPT-2 and TB judgements for each angular disparity revealed a significant difference at 90° ($t(41) = 3.068$, $p = .004$, $d = .473$) but not at 0° ($p = .985$). At 90° angular disparity, VPT-2 was significantly faster than TB (Figure 4). Analysis of errors in Experiment 1 revealed a significant main effect of Judgement Type ($F(1,41) = 5.484$, $p = .024$, $n_p^2 = .118$), with TB being more error-prone than VPT-2, but the interaction between Angular Disparity and Judgement Type did not reach significance ($p = .645$). Significant main effects of Angular Disparity were also observed for RTs (F(1,41) = 23.257, p < .001, n_p^2 = .362) and errors (F(1,41) = 4.612, p = .038, n_p^2 = .101), but this feed into Hypothesis 2 (see below).

As illustrated in Figure 4 (left), RT results in Experiment 1 support the alternative hypothesis (H_1) for Hypothesis 1 by indicating a difference between TB reasoning and VPT-2, whereby TB is associated with greater RTs than VPT-2. Furthermore, this is evident at 90° angular disparity, as indicated by a significant interaction between judgement type and angular disparity. The error results in Experiment 1 further support the alternative hypothesis via a main effect, but no interaction. This must be interpreted with caution due to the overall low number of errors.

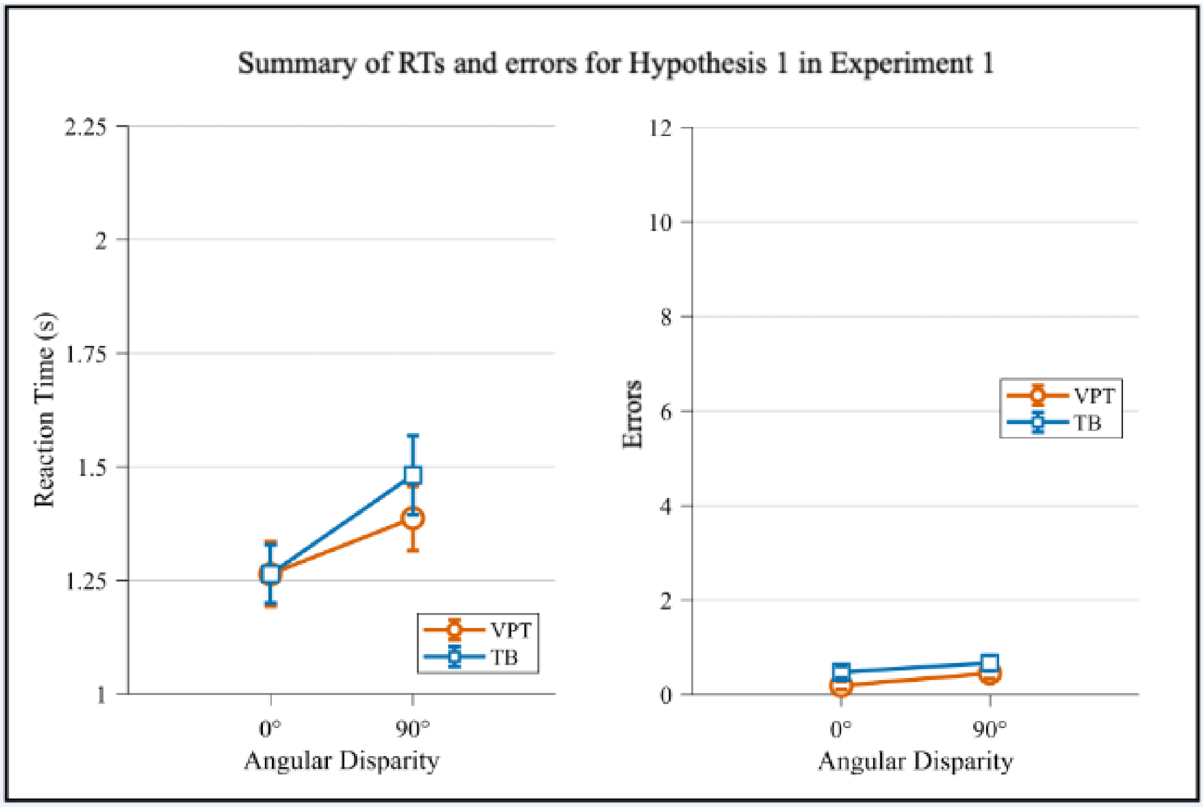


Figure 4. Results for Hypothesis 1 (Table 1) in Experiment 1. Response times (RTs, measured in seconds; correct responses only) are shown on the left and errors (average number of errors per condition and with a maximum of 12) are shown on the right. Error bars are standard error of mean.

2.3.1.2 Hypothesis 2

As a replication of previous findings, it was hypothesised that judgements about another's mental state (belief or perspective) made at 90º angular disparity would be associated with greater RTs and errors than judgements made at 0º angular disparity. Therefore, judgements made at 90° were compared to judgements at 0° angular disparity. Hypothesis 2A was the more stringent test of a main effect of Angular Disparity, while Hypothesis 2B included the possibility of an *ordinal* interaction between Angular Disparity and Judgement Type. As reported above, in the full-design ANOVA of RT data, this was confirmed by a significant main effect of Angular Disparity ($F(1,41) = 40.455$, $p < .001$, =.497) and a significant interaction between Angular Disparity and Judgement Type ($F(1,41) = 7.584$, $p = .009$, =.156). RTs are slower with increasing angular disparity (90° > 0°) for both judgement types, yet with a more pronounced increase for belief compared with VPT-2 judgements. The full-design ANOVA of error data also revealed a significant main effect of Angular Disparity ($F(1,41) = 9.72$, $p = .003$, =.192) but no significant interaction between Angular Disparity and Judgement Type ($p = .763$). Together, these results support Hypothesis 2 (Figure 5).

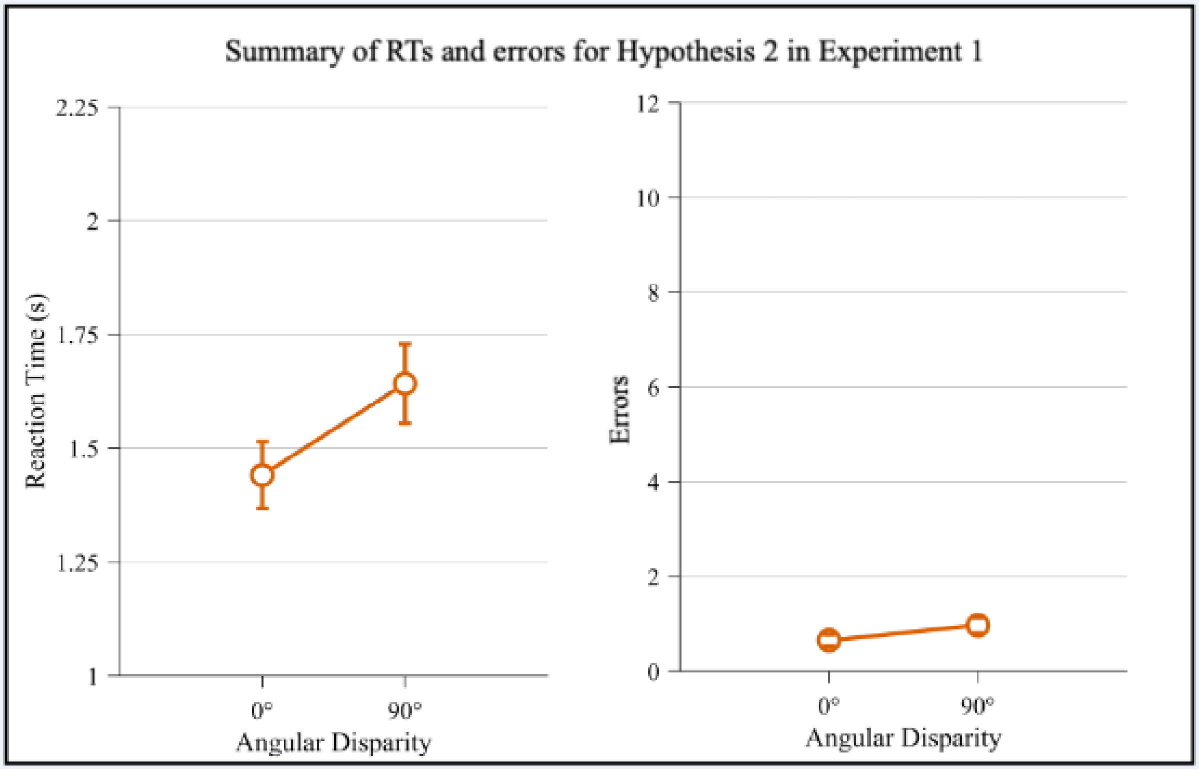


Figure 5. Results for Hypothesis 2 in Experiments 1, with RTs on the left and errors on the right. Error bars denote standard error of mean.

2.3.1.3 Hypothesis 3

It was hypothesised that FB judgements would be associated with greater RTs and errors than TB judgements. This was evaluated by comparing the average of all FB trials (Swap) against the average of all TB trials (No-swap), collapsing across angular disparities. Note that perspective judgments were excluded from this particular analysis. Our novel paradigm also allowed us to assess whether any additional cost for FB is greater at 90° relative to 0° angular disparity between self- and other-perspective. It was therefore informative to analyse the interaction between Object Swap (Swap [FB], No-swap [TB]) and Angular Disparity (90°, 0°). Importantly, however, we did not pre-register Hypothesis 3 in this form. Two 2x2 ANOVAs revealed the expected main effects of Object Swap (RT: ($F(1,41) = 37.176$, $p < .001$, n_p^2 =.476); error: ($F(1,41) = 19.957$, $p < .001$, $n_p^2 = .327$)) and Angular

Disparity (RT: (F(1,41) = 36.193, p < .001, n_p^2 = .469); error: (F(1,41) = 5.663, p = .022, n_p^2 = .121), but no significant interactions in RT (p = .121) or in error (p = .317). As hypothesized, FB judgements were made with significantly greater RTs and errors than TB judgements, replicating previous results (Figure 6). Extending prior findings, Angular Disparity did not significantly interact with FB costs in our novel paradigm.

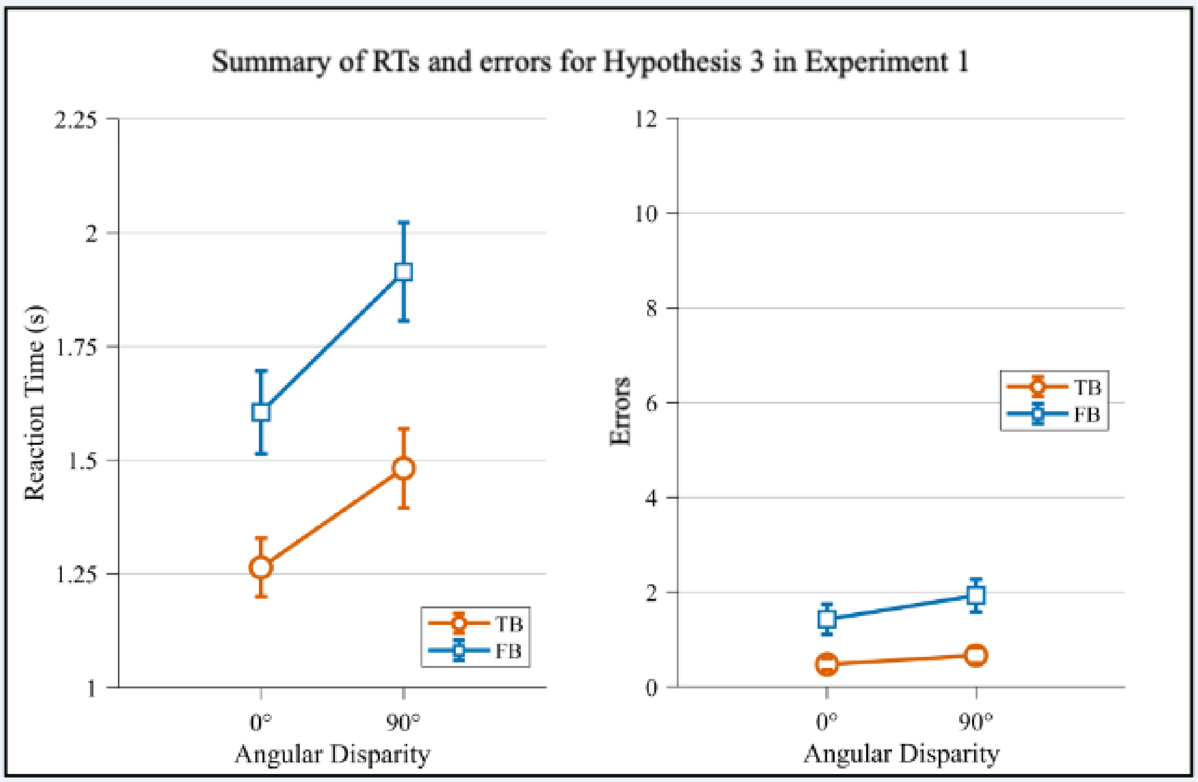


Figure 6. Results for Hypothesis 3 in Experiments 1, with RTs on the left and errors on the right. Error bars denote standard error of mean.

2.3.2 Experiment 2

The aim of the second experiment was to replicate and extend the results of Experiment 1. First, we included Self-judgements to demonstrate that the effects in the initial experiment cannot be explained by an absence of Self-judgements (Quesque & Rossetti, 2020). Second, in addition to asking participants about their current perspective, we also asked them about their memory of the object presented at the start of the trial (Hypotheses 4 and 5). This allowed us to understand whether the increased processing demands observed in Experiment 1 were likely due to mnemonic processing (checking back to the initial object might be more costly for TB) or more likely due to increased complexity of social processing (representing the other's TB might require a more complex representation of their mind). Since experimental conditions were only distinguishable at the very end of each trial it is safe to assume that participants encoded the events in a trial in the same way across conditions, until the question requiring a specific judgement was presented. Thus, any memory effects observed for self-judgements (current vs. past) would be a good indicator for memory effects that may affect other-judgements.

We conducted two separate 2x2x4 ANOVAs for RTs and errors with the full experimental design (Table 2): Object Swap (Swap [FB], No-swap [TB]), Angular Disparity (0º, 90º), and Judgement Type (Other-Belief, Other-Perspective, Self-Current, Self-Past). For RTs we observed main effects of Object Swap (F(1,61) = 110.918, p < .001, n_p^2 = .645), Angular Disparity (F(1,61) = 50.511, p < .001, n_p^2 = .453), and Judgement Type (F(1,61) = 4.539, p = .037, n_p^2 = .069). In addition, we observed a significant interaction between Angular Disparity and Judgement Type (F(1,61) = 8.878, p = .004, n_p^2 = .127). For errors we also observed main effects of Object Swap (F(1,61) = 27.943, p < .001, n_p^2 = .314), Angular Disparity (F(1,61) = 11.634, p = .001, n_p^2 = .160), and Judgement Type (F(1,61) = 6.770, p = .012, n_p^2= .100). No significant interactions were observed. In order to understand this pattern of results, we evaluated each of our five pre-registered hypotheses (Table 1; additional minor Hypotheses 6 and 7 are reported in Supplementary Material).

2.3.2.1 Hypothesis 1

Belief reasoning trials (“What will *she* expect to see?”) were compared to visual perspective trials (“What will *she* actually see?) at both 0° and 90° angular disparity (the character’s seated position upon her return) when the character held a TB (when the object on the table was not swapped). As with Experiment 1, we employed a 2x2 within-subjects ANOVA with the factors Angular Disparity (0º, 90º) and Judgement Type (VPT-2, TB) for Other-judgements and No-swap trials only. The ANOVA applied to RTs in Experiment 2 revealed a significant main effect of Judgement Type F(1,61) = 6.168, p =.016, n_p^2 = .092) and a significant interaction between Angular Disparity and Judgement Type (F(1,61) = 6.871, p = .011, n_p^2 = .101). Planned comparisons between VPT-2 and TB judgements for each angular disparity revealed a significant difference at 90° (t(61) = 3.324, p = .002, d = .422) but not at 0°(p = .976). The ANOVA applied to errors in Experiment 2 revealed that neither the main effect of Judgement Type (p = .109) nor the Angular Disparity-by-Judgement Type interaction reached significance (p = .904). A Bayesian analysis seeking to ascertain the robustness of support for the null hypothesis revealed moderate to weak evidence in favour of null hypothesis (= 0.374). Significant main effects of Angular Disparity were also observed for RTs (F(1,61) = 65.388, p < .001, n_p^2= .517) and errors (F(1,61) = 6.618, p = .013, n_p^2 = .098) but feed into Hypothesis 2 (see below).

As illustrated in Figure 7, RTs further supported the alternative hypothesis by revealing significantly increased RTs for TB compared to VPT-2 judgements, especially at 90° angular disparity. The error results were not significant in the frequentist analysis, and the Bayesian analysis provided only weak evidence for the null hypothesis. These error results are therefore inconclusive, possibly reflecting the low number of overall errors.

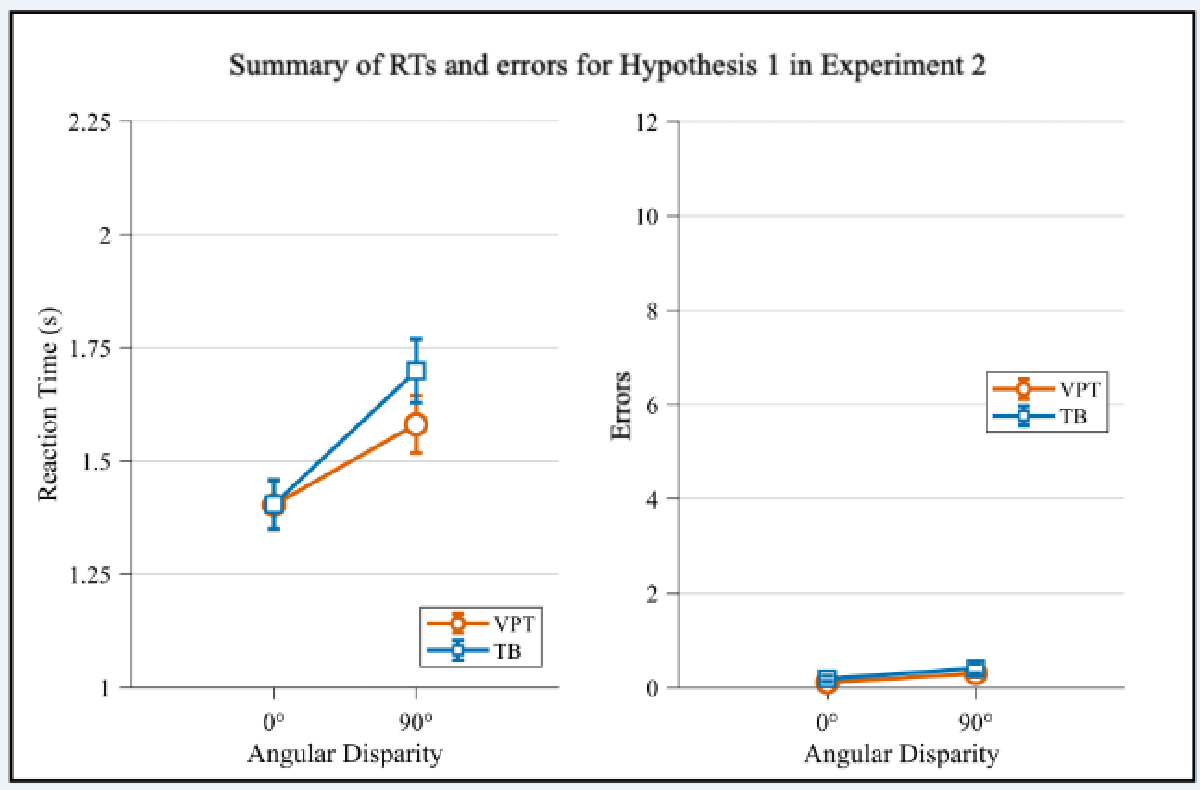


Figure 7. Results for Hypothesis 1 in Experiment 2, with RTs on the left and errors on the right. Error bars are standard error of mean.

2.3.2.2 Hypothesis 2

In the two full design ANOVAs for Experiment 2 reported above, Hypothesis 2 was confirmed through the significant main effect of Angular Disparity in RTs and errors, and the significant interaction between Angular Disparity and Judgement Type in RTs. However, a more precise test of Hypothesis 2 and a direct replication of Experiment 1 requires a further analysis with Other-judgements only, since Self-judgements were not expected to change with angular disparity. This analysis of RT data revealed a main effect of Angular Disparity ($F(1,61) = 50.511$, $p < .001$, $n_p^2 = .453$) and a significant interaction between Angular Disparity and Other-Judgement Type in RTs ($F(1,61) = 8.878$, $p = .004$, $n_p^2 = .127$). RTs are slower with increasing angular disparity (90° > 0°) for both types of Other-judgement, yet with a more pronounced increase for belief compared with VPT-2 judgements. Error data revealed a significant main effect of Angular Disparity ($F(1,61) = 11.634$, $p = .001$, $n_p^2 = .160$), but no significant interaction ($p = .882$). These findings further support Hypothesis 2 that increasing angular disparity between self and other (90° vs 0°) increases cognitive demand for Other-judgements (Figure 8).

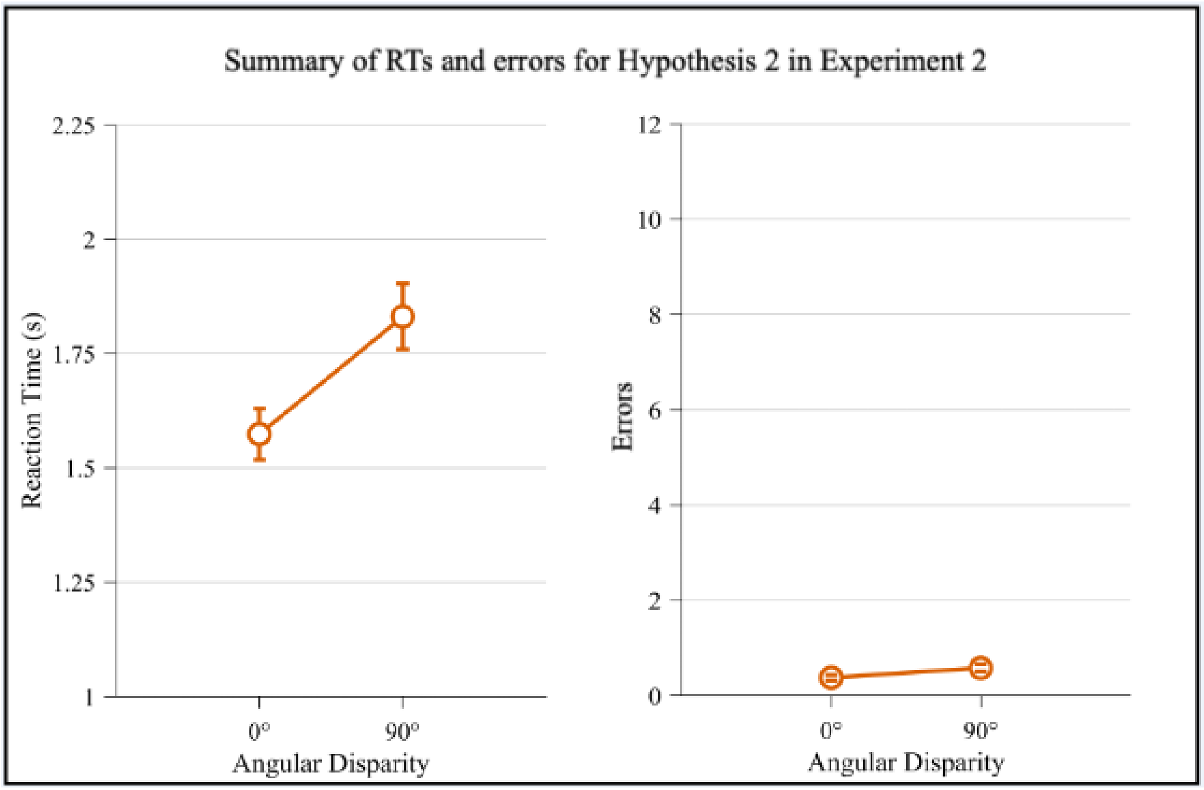


Figure 8. Results for Hypothesis 2 (Table 1) in Experiments 2, with RTs on the left and errors on the right. Error bars denote standard error of mean.

2.3.2.3 Hypothesis 3

As with Experiment 1, it was examined whether FBs were associated with greater RTs and/or errors than TBs. We conducted 2x2 ANOVAs with Object Swap (Swap [FB], No-swap [TB]) and Angular Disparity (0°, 90°) as factors. This analyses revealed the expected main effects of Object Swap (RT: $F(1,41) = 79.416$, $p < .001$, =.566; error: $F(1,41) = 19.198$, $p < .001$, $n_p^2 = .241$) and Angular Disparity (RT: $F(1,41) = 47.991$, $p < .001$, =.440; error: $F(1,61) = 6.915$, $p = .011$, $n_p^2 = .102$), but no significant interactions in either RT (p = .641) nor error (p = .928). As shown in Figure 9, FB judgements were made with significantly greater RTs and errors than TB judgements. Replicating Experiment 1, Angular Disparity did not significantly interact with FB cost.

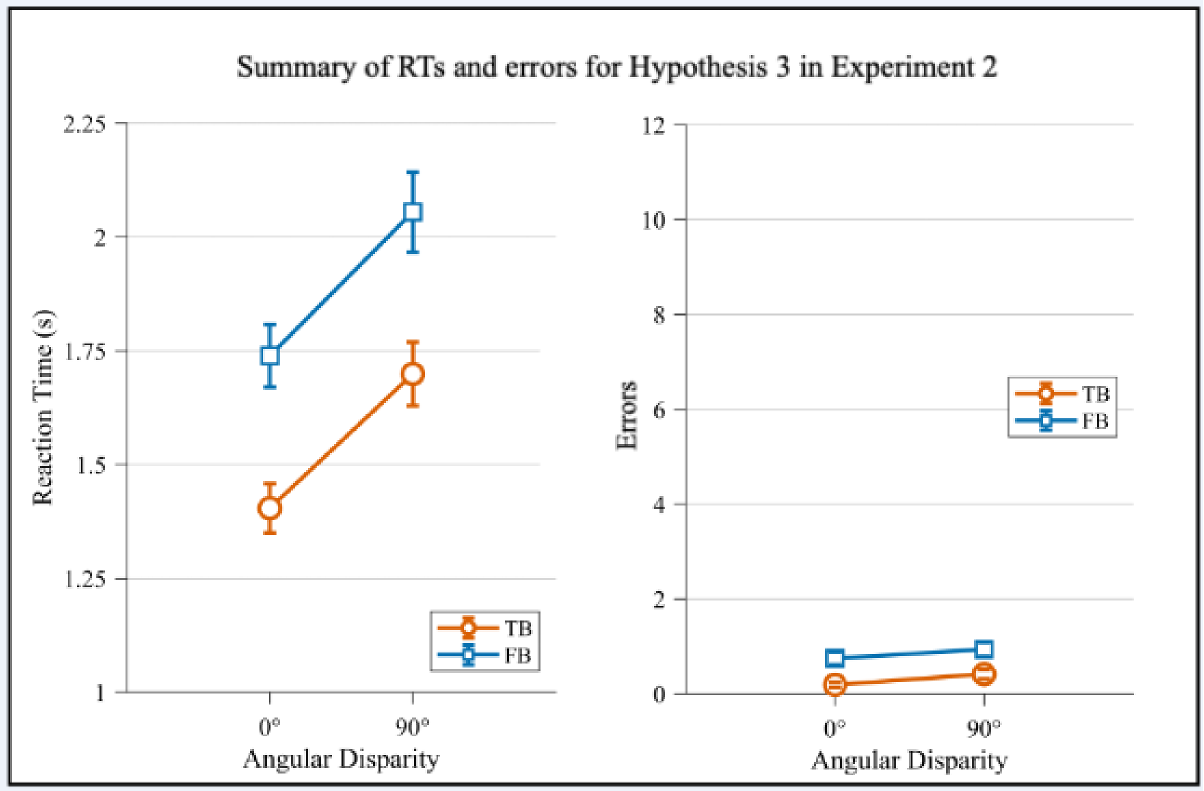


Figure 9. Results for Hypothesis 3 in Experiments 2, with RTs on the left and errors on the right. Error bars denote standard error of mean.

2.3.2.4 Hypothesis 4

Our results so far indicate consistent differences between TB and VPT-2 processing; TB judgements are associated with greater RTs than VPT-2 judgements, especially at 90ºangular disparity (Hypothesis 1). It could be argued that TB trials required an additional memory component, since participants also had to remember the first stimulus, whereas participants only needed to remember the final stimulus and its appearance to respond accurately in VPT-2 trials. It is therefore unclear whether TB judgements were slower because of an additional memory check or because of additional social processing. To address this question, two additional conditions were added in Experiment 2. A self-past question concerning the first stimulus ("What did *you* initially see?") and a self-current question related to the second stimulus ("What will *you* actually see?"). It is important to stress that these two questions concern the participant's own perspective – they are not social in nature. Comparing these two non-social questions allowed us to ascertain the relative contributions of a memory check without confounding social processes. Two-tailed *t*-tests were performed between judgements made about the first stimuli (Self-past) and second stimuli (Self-current).

Contrary to our prediction, Self-past judgements were not associated with increased RTs or errors compared with Self-current judgements; in fact, the former were associated with *lower* RTs and errors than the latter ($t(61) = 7.943$, $p < .001$, $d = 1.009$, and $t(61) = 2.018$, $p = .048$, $d = .256$, respectively; see Figure 10). This indicates that participants may actually anchor their internal representation of the task events to this first stimulus, so they recall the first stimulus (Self-past judgements) faster and more accurately than they can recall the second stimulus (Self-current judgements).

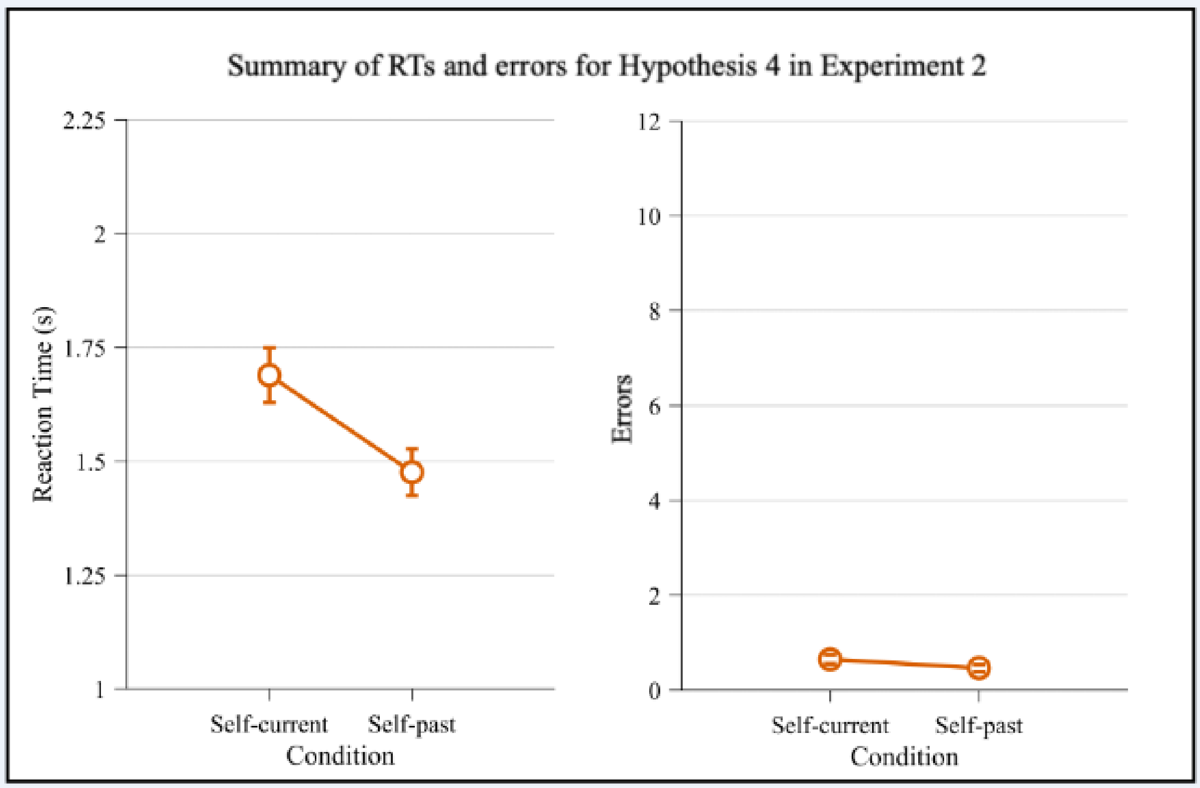


Figure 10. Results for Hypothesis 4 in Experiment 2, with RTs on the left and errors on the right. Error bars denote standard error of mean.

2.3.2.5 Hypothesis 5

As described in Table 1, this hypothesis concerned any potential differences between self-related and other-related judgements and was conditional on Hypothesis 4 being confirmed, which was not the case; in fact, the pattern was reversed in comparison to the hypothesized effect direction. It is therefore unlikely that a memory check may explain the slower responses for TB than VPT-2 judgements in Experiments 1 and 2. Nevertheless, we calculated and compared (Self_Past – Self_Current) vs (Other_TB – Other_VPT-2), conducting one-tailed *t*-tests that resulted in significantly stronger differences for Other- compared to Self-judgements in RTs and errors ($t(61) = 7.267$, $p < .001$, $d = .923$) and ($t(61) = 2.141$, $p = .018$, $d = .272$, respectively; see Figure 11). As previously indicated, these findings suggest that the greater RTs associated with TB calculation relative to VPT-2 processing are more likely to be associated with additional social processes, rather than mnemonic processing (i.e., a check back in memory to the object presented initially).

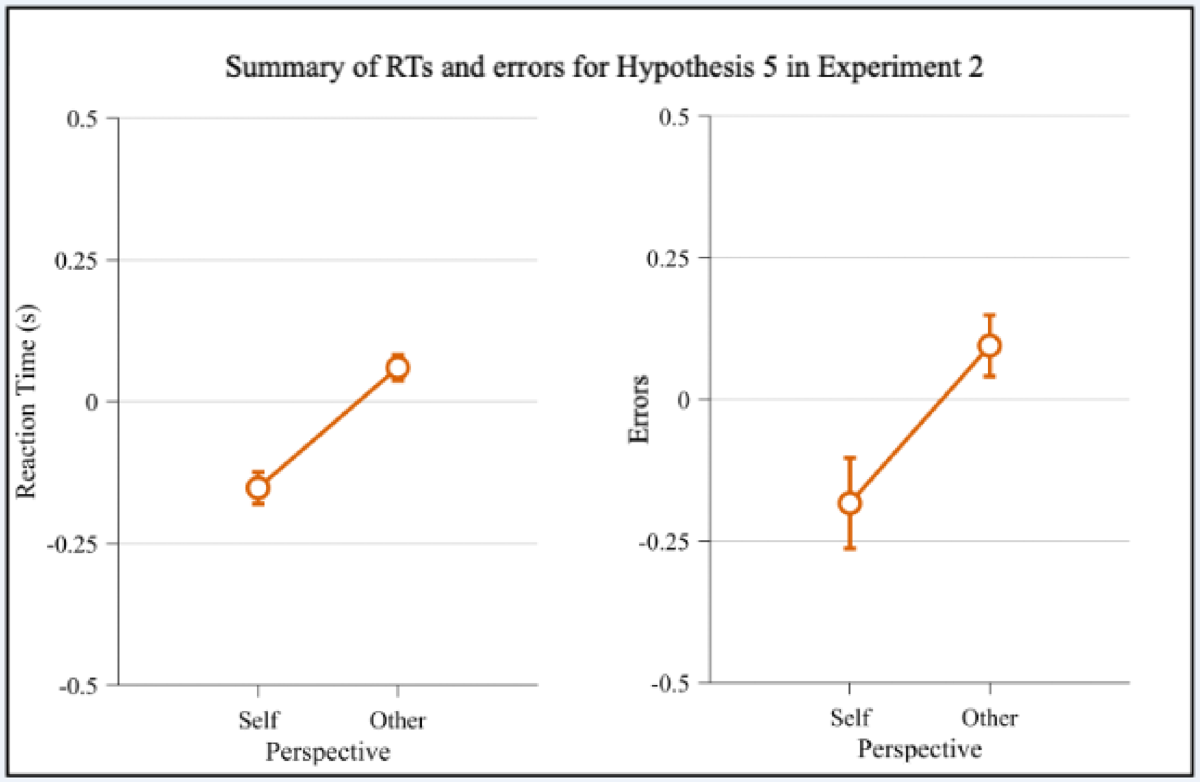


Figure 11. Results for Hypothesis 5 in Experiment 2, with RTs on the left and errors on the right. Error bars denote standard error of mean.

2.3.3 Experiment 3

The central aim of this third pre-registered experiment was to replicate the relationship between VPT-2 and TB reasoning observed in Experiments 1 and 2, using a different manipulation of TB and FB. Frequently, TBs and FBs have been elicited by manipulating whether a change in an object's location is witnessed (TB) or not (FB; e.g., "Sally-Anne" task). Therefore, in Experiment 3 we manipulated belief state by having the character either be present to witness the object swap (TB) or not (FB; see Figure 3). The target object was always swapped in Experiment 3 to equalize cognitive updating demands across conditions.

The 2x2x2 ANOVA for RTs with the full experimental design included the factors Object Swap (Witnessed [TB], Unwitnessed [FB]), Angular Disparity (0^o, 90^o), and Judgement Type (Belief, Perspective). This revealed main effects of Object Swap ($F(1,41) = 46.289$, $p < .001$, $n_p^2 = .481$), Angular Disparity ($F(1,41) = 42.433$, $p < .001$, $n_p^2 = .449$), and Judgement Type ($F(1,41) = 23.329$, $p < .001$, $n_p^2 = .318$). In addition, we observed a significant interaction between Object Swap and Angular Disparity ($F(1,41) = 9.712$, $p = .003$, $n_p^2 = .163$). For errors, we also observed main effects of Object

Swap (F(1,41) = 17.017, p < .001, n_p^2 = .254) and Angular Disparity (F(1,41) = 6.046, p = .018, n_p^2 = .108), but not of Judgement Type (p =.915). In addition we observed a significant interaction between Angular Disparity and Judgement Type (F(1,41) = 7.046, p = .011, n_p^2 = .124).

2.3.3.1 Hypothesis 1

As with Experiment 1 and 2, in Experiment 3 belief reasoning trials ("What will *she* expect to see?") were compared to visual perspective trials ("What will *she* actually see?) at both 0° and 90° angular disparity (the character's seated position upon her return) when the character held a TB (when the object on the table was not swapped). We evaluated this hypothesis with a 2x2 within-subjects ANOVA comprising the factors Angular Disparity (0º, 90º) and Judgement Type (VPT-2, TB; see Figure 4). Analysis of RTs revealed that there was a significant main effect of Judgement Type (F(1,50) = 39.632, p < .001, n_p^2 = .442), but the Angular Disparity-by-Judgement Type interaction was not significant (p = .287). Analysis of errors revealed no significant main effect of Judgement Type (p = .458), but there was a significant interaction between Angular Disparity and Judgement Type (F(1,50) = 7.741, p = .008, n_p^2 = .134). Follow-up analysis of the error results revealed an effect at 0° rather than 90° angular disparity, and in the unpredicted direction (0°: VPT-2 > TB, t(50) = 2.270, p = .028, d = 0.318; 90°: t(50) = 1.851, p = .070, d = .259). Significant main effects of Angular Disparity were also observed for RTs (F(1,50) = 51.072, p < .001, n_p^2 = .505) and errors (F(1,50) = 4.339, p = .042, n_p^2 = .080), but feed into Hypothesis 2 (below).

As illustrated in Figure 12, RT results in Experiment 3 further supported Hypothesis 1 by revealing significantly increased RTs for TBs compared with VPT-2. In this particular paradigm, however, the effect was not significantly more pronounced at 90° compared to 0° angular disparity. Errors revealed an interaction only, showing a small but significant effect in the unpredicted direction at 0°. The latter could be indicative of a speed accuracy trade-off (at 0°), but given the overall low number of errors in this experiment, error findings and possible speed-accuracy trade-offs must be interpreted with care.

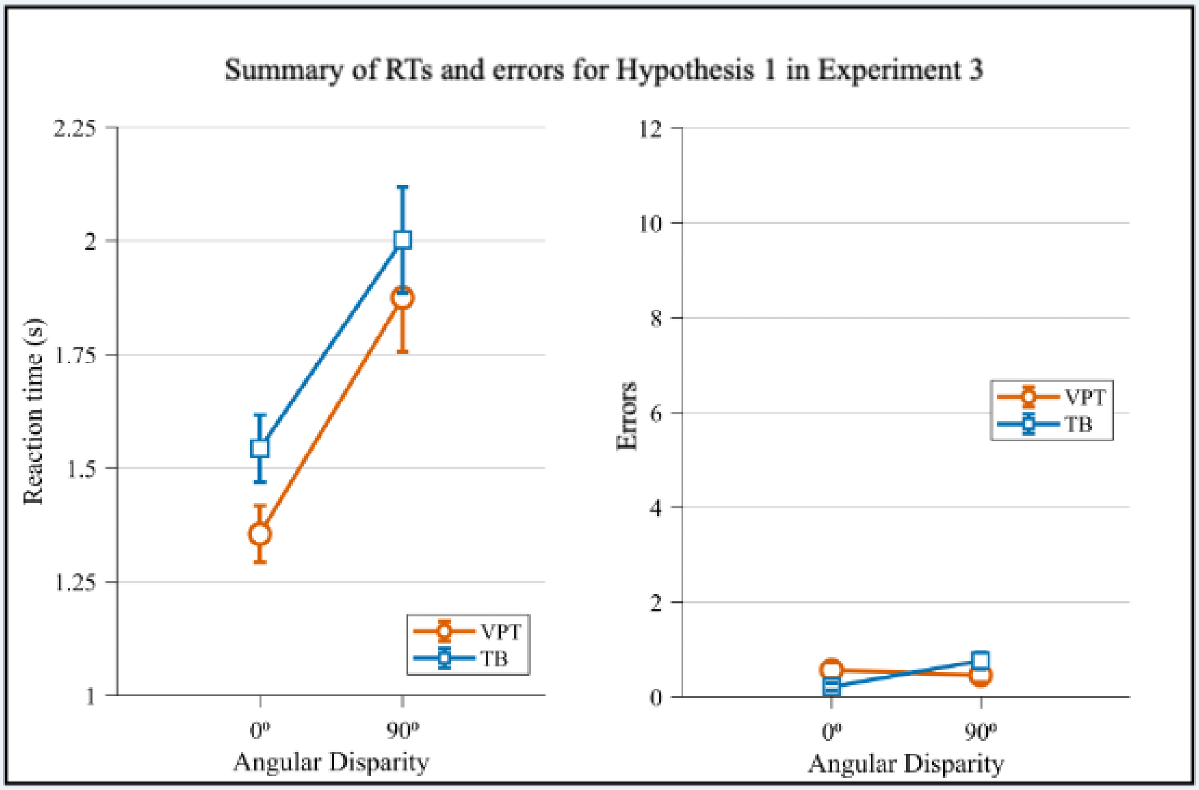


Figure 12. Results for Hypothesis 1 in Experiment 2, with RTs on the left and errors on the right. Error bars denote standard error of mean.

2.3.3.2 Hypothesis 2

This hypothesis concerned differences between making judgements at 0° and 90° angular disparity. Converging with the results of Experiment 1 and 2, full design analyses of Experiment 3 RT data revealed a significant main effect of Angular Disparity ($F(1,50) = 42.433$, $p < .001$, $n_p^2 = .449$) but no significant interaction between Angular Disparity and Judgement Type (p = .807). Error data revealed a significant main effect of Angular Disparity ($F(1,50) = 6.046$, $p = .017$, $n_p^2 = .108$) and a significant interaction between Angular Disparity and Judgement Type ($F(1,50) = 7.046$, $p = .011$, $n_p^2 = .124$). As with Experiments 1 and 2, we urge caution when interpreting these results from errors given the overall low number of errors in this experiment. Together, these results further corroborate the evidence for Hypothesis 2 (Figure 13).

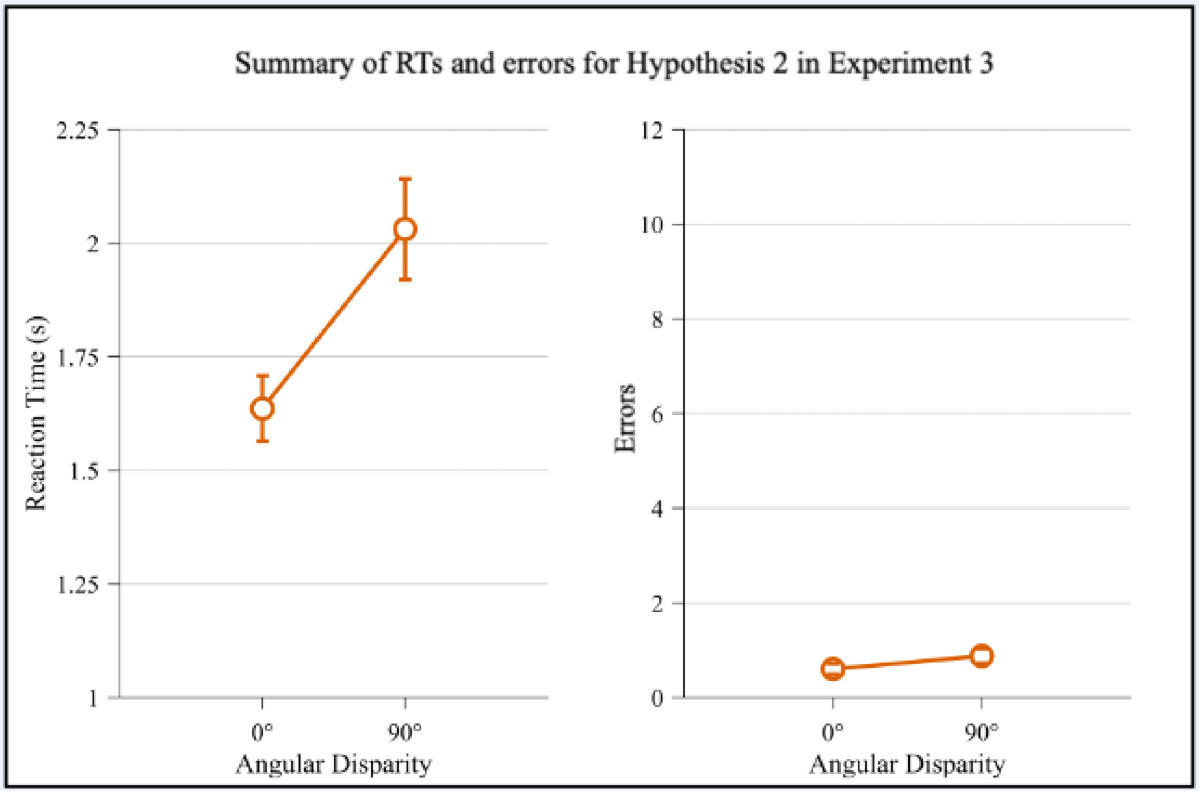


Figure 13. Results for Hypothesis 2 in Experiment 3, with RTs on the left and errors on the right. Error bars denote standard error of mean.

2.3.3.3 Hypothesis 3

This hypothesis compared any differences in RT and/or errors between TB and FB judgements. To evaluate this hypothesis, we conducted 2x2 ANOVAs with the factors Object Swap (Swap [FB], No-swap [TB]) and Angular Disparity (0°, 90°). This analysis revealed the expected main effects of Object Swap (RT: ($F(1,50) = 33.414$, $p < .001$, $n_p^2 = .401$); error: ($F(1,50) = 12.106$, $p = .001$, $n_p^2 = .195$)) and Angular Disparity (RT: $F(1,50) = 38.735$, $p < .001$, $n_p^2 = .437$; error: $F(1,50) = 11.137$, $p = .002$, $n_p^2 = .182$), but no significant interactions in neither RT ($p = .091$) or error ($p = .410$). Again, FB judgements were made with significantly greater RTs and errors than TB judgements (Figure 14), replicating previous findings. Replicating Experiments 1 and 2, angular disparity did not significantly interact with FB costs.

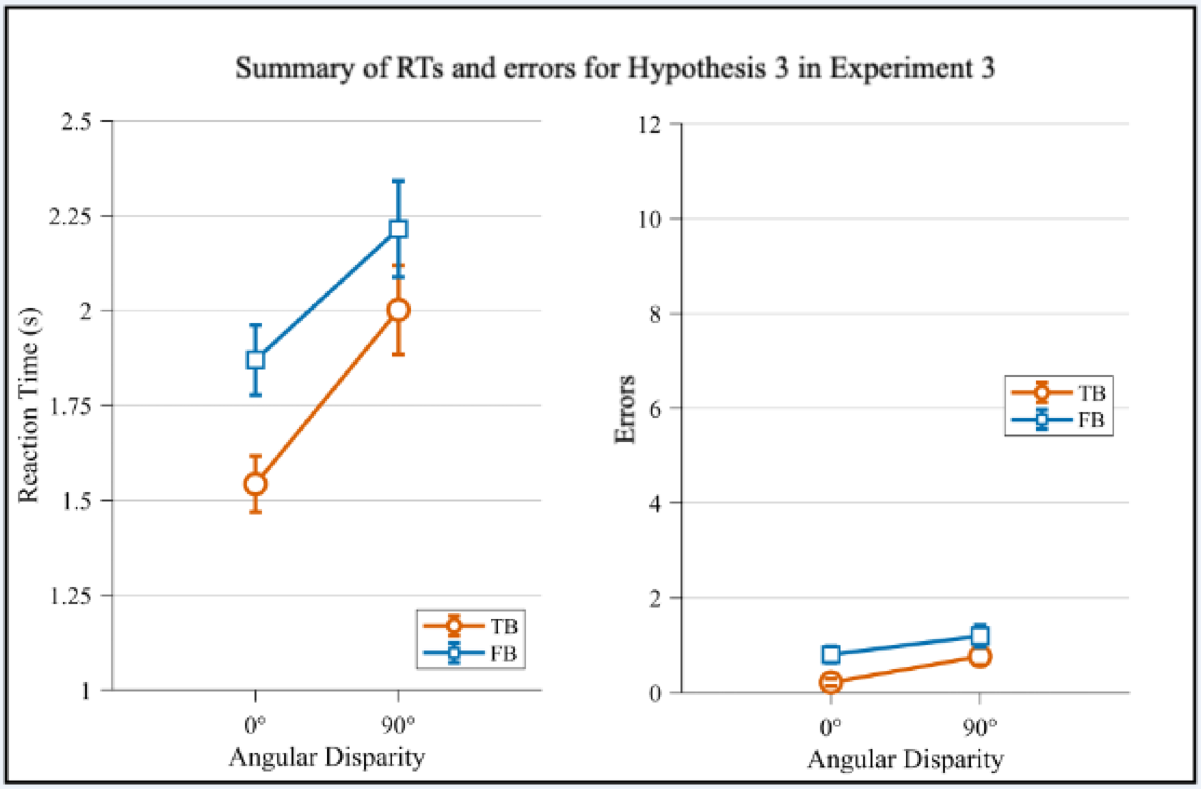


Figure 14. Results for Hypothesis 3 in Experiments 3, with RTs on the left and errors on the right. Error bars denote standard error of mean.

2.4 Discussion

We present a novel paradigm, the "Seeing-Believing Task", designed specifically to investigate differences between cognitive processes that allow us to infer another's belief state and their visual perspective of the world. This is a crucial question in ToM research (Gunia et al., 2021; Hamilton et al., 2009; Schurz et al., 2013); insights into which would afford a more precise neurocognitive categorisation of the processing mechanisms involved. Previously, research has focused on false belief (FB) rather than true belief (TB) reasoning (Baron-Cohen et al., 1985) because a more complex understanding of another's mental representation is required when their belief is known to the observer to be false (Apperly et al., 2008). Indeed, representing another's FB has been shown reliably to be slower and more error prone than representing a TB that is consistent with the observer's own representation of reality (Apperly et al., 2008; Apperly et al., 2011). Here, we replicate and extend this finding consistently across three pre-registered online experiments.

Given these considerations about added costs for processing FBs, it would be unsurprising if FB judgements also lead to slower and more error-prone processing compared to VPT-2 judgements. For our primary hypothesis (Hypothesis 1), we therefore compared judgements about another's perspective ("What will she actually see?") with judgements about their TB – and not their FB – ("What will she [correctly] expect to see?") since in our paradigm, both, VPT-2 and TB, concern representations of the actual state of reality, as it is known to the participant. We considered two alternative theoretical notions. The first predicted identical or largely overlapping cognitive processing for VPT-2 and TB judgments in light of strong correlations between independent performance indices of VPT-2 and ToM (e.g., Hamilton et al., 2009; Quesque & Rossetti, 2020; Złotogórska-Suwińska & Putko, 2019) and overlap in associated neural substrates (e.g., Gunia et al., 2021 for review; Schurz et al., 2013). Furthermore, both reflect the same (true) state of reality and required exactly the same responses in our novel paradigm.

In contrast, our alternative hypothesis predicted that there would be a significant performance difference when making VPT-2 and TB judgements, because the two types of mentalising might rely – at least in part – upon psychologically distinct mechanisms. Firstly, another's visuospatial perspective can be dissociated from their belief if they close their eyes, thus, a simple perceptual manipulation affecting their perspective but not their belief. It was further argued earlier that representing another's (true) belief might require additional or more sophisticated processing of their mental states than merely representing their visuospatial perspective (e.g., Howlin et al., 1999). For instance, the latter could be resolved by imagining the self-occupying another virtual viewpoint, rather than fully representing the other's mental state in relation to their viewpoint. Indeed, Kessler and Thomson (2010) reported that the same embodied mental self-rotation was also employed when participants imagined themselves in a different viewpoint that was defined by an empty chair rather than another person. A wealth of research conducted in the context of "spatial updating" further suggests that VPT-2 mechanisms are widely employed in non-social, spatial contexts (for review see Hamilton et al., 2014; Kozhevnikov, Motes, Rasch, & Blajenkova, 2006; Wang et al., 2006; Zacks & Michelon, 2005).

Our primary hypothesis (Hypothesis 1) also predicted that if TB imposed greater cognitive load than VPT-2, this difference would be more pronounced when the other's perspective differed from the participant's egocentric perspective (90° angular disparity); that is, when the other's perspective could not be merely assimilated into the participant's own perspective. More precisely, Hypothesis 1 assumed that a mental transformation into the other's viewpoint was required for all other-related judgements at 90° angular disparity, but additional processing would then be needed for TB compared with VPT-2 judgements. Importantly, the required mental transformation for all other-related judgements at 90° angular disparity (Hypothesis 2) was also evaluated. Both hypotheses received consistent support in RT and error analyses across all three experiments, replicating previous findings in relation to Hypothesis 2 (Kessler & Thomson, 2010; Michelon & Zacks, 2006).

Regarding Hypothesis 1, in all three experiments, TB judgements were associated with greater cognitive effort than VPT-2 judgements (larger RTs and, more inconsistently, number of errors). Further, Experiments 1 and 2 also revealed that the difference in RTs was greater when Self- and Other-perspectives differed (90° angular disparity). Experiment 3, however, revealed equally higher RT costs for TB compared to VPT-2 at 0° and 90° angular disparity. This is likely due to the more costly manipulation in this paradigm, where the target object was always swapped but was either witnessed by the character or not. RTs were generally longer in Experiment 3, confirming these added costs (Tables 4-6). The required object update and the need for keeping track of the character's perspective in the scene (what they had witnessed or not) may have prevented participants from assimilating the other's perspective and belief into the egocentric perception of reality at 0° angular disparity as effectively as in Experiment 1. This would explain the additional cost of TB over VPT-2 judgements at 0° angular disparity in Experiment 3, which was nullified in Experiments 1 and 2. Future research should address these considerations.

Error data presented a somewhat inconsistent pattern, where Experiment 1 revealed a significant main effect of Judgement Type but no interaction with Angular Disparity, Experiment 2 showed no effects, while Experiment 3 revealed a significant interaction between Judgement Type and Angular Disparity but no main effect of Judgement Type. In a Bayesian follow-up analysis of Experiment 2 weak to medium support for the H0 (no difference between VPT-2 and TB) was found, which is the only piece of evidence in the entire study that supports the notion that TB and VPT-2 might not be distinct processes. Error findings have to be interpreted with care due to the overall low number of errors, but more importantly, error data did not indicate speed-accuracy trade-offs, which could have jeopardised the interpretation of the RT findings. Therefore, in the light of overwhelming evidence in RT data we conclude that inferences concerning another's TB require additional resources as compared to judgements about their visual perspective.

What exactly is the difference between VPT-2 and TB? Given that perspective judgements always referred to the final object in a trial, while FB judgments related to the initial object in a trial, other non-social variables may have influenced processing throughout belief trials, for FB as well as TB. For example, as FB judgements depended on a larger number of events in a trial, participants may have also been more uncertain about making their decision and taken more time on TB trials. Such uncertainty when making a belief judgement might have resulted in a check back in memory to the beginning of a trial (to determine if the object really was swapped or not). This was investigated directly in Experiment 2 by including past and current judgements from the participant's egocentric perspective (self-judgements).

Crucially, including self-judgements did not change the basic pattern of difference between Other-related VPT-2 and TB judgements observed in Experiment 1, indicating that the initial results did not simply reflect an absence of Self-judgements (Quesque & Rossetti, 2020). Surprisingly, however, Self-related judgements did not reveal the hypothesised processing advantage for current- relative to past-judgements ("What will you actually see" compared with "What did you initially see?"; Hypothesis 4). Instead, Self-past judgements were significantly faster than Self-current judgements, ruling out the possibility of a memory check for the former. While surprising and worth further pursuit in future research, this effect suggests that participants anchor their representation of trial events to the initially presented scene rather than updating their representation as the trial unfolds. We contend that an extrapolation of this conclusion from Self- to Other-judgements is legitimate because experimental conditions were only distinguishable at the very end of each trial when the different judgements were required. Thus, given the lack of any early distinguishing features, it is valid to conclude that all trials were encoded in the same way until the final question.

As discussed, we considered the possibility that, on TB trials, participants might alleviate their uncertainty by initiating an unnecessary check back in memory to confirm whether or not the target object had been swapped (Hypothesis 5). In the light of the surprising result for Self-related judgements, this now appears unlikely. However, while we can rule out a memory check, other sources of uncertainty should be considered in future studies as possible explanations for the difference between VPT-2 and TB. Uncertainty is often the reason for slower decisions, and TB might involve more uncertainty than VPT-2. However, it is important to understand what the source of uncertainty might be. Considering “what the other ought to know” during belief judgments might increase “representational” uncertainty (we know less about the other’s belief and desires) compared with mere judgements of reality from another’s perspective. In other words, belief reasoning is likely to involve more complex and/or uncertain representations in the sense that more sources of information are available to the other to inform their beliefs as compared to their visual perspective of reality. There is more uncertainty about what exactly may inform the other’s belief, but we (as participants) may settle for the assumption that what they have seen will be their primary source for informing their belief. The process of settling for the latter could then result in longer processing times.

In addition to “representational” uncertainty that might be perceived as inherent to the other’s true beliefs (“She is uncertain about her belief”), participants might also be more uncertain about their correct processing of all events on trials that require belief representation (“I am uncertain about my judgement of her belief”). Future research could address these sources of uncertainty through distinct confidence scales after each trial (e.g., “How certain is She?” vs “How certain are You?”).

Importantly, the notion of uncertainty that may emerge from various sources of information being available to the other to inform their belief ties in with a more mechanistic interpretation of our main result. We conjecture that the added effort for TB compared to VPT-2 judgements indexes a transition from minimal to full-blown ToM processing, as described by Apperly and Butterfill (also 2009; Butterfill & Apperly, 2013). Minimal ToM is defined as relational, whereby objects and their locations are registered with another agent (e.g., what the other can or cannot see at any given time, and whether their last registration of an object is correct or false with respect to the object’s current location), thus enabling goal-directed actions that allow participants to complete ToM tasks quickly and efficiently without the need for slower, more effortful, full-blown ToM. Apperly and Butterfill conceived of the latter as a full representation in propositional format, allowing inferences about the other's mental states and future actions (Butterfill & Apperly, 2013). This is further underpinned by philosophical distinctions between perceptual and inferential mentalizing, where only the latter requires propositional processing (e.g., McNeill, 2012; Michael & De Bruin, 2015).

While the embodied transformation engaged for VPT-2 requires substantial processing effort when angular disparity is high, in contrast to line-of-sight mechanisms involved in Level-1 perspective tracking (e.g., Kessler & Rutherford, 2010; Michelon & Zacks, 2006), due to its analogue embodied nature (Kessler & Thomson, 2010). This transformation would not automatically generate a propositional representation of the other's visual experience (Kessler, 1999). The outcome of the transformation could still be a relational representation of the target perspective – conforming to minimal ToM – that simply registers the correct perceptual orientation of the object from the mentally embodied viewpoint (also McNeill, 2012). It is therefore not strictly required to generate a propositional mental representation of the other's experience for resolving a perspective judgement correctly (e.g., Kessler & Thomson, 2010; Experiment 3; same embodied transformation without an avatar).

However, when explicitly asked to take another's belief into account, participants might feel compelled to generate a propositional representation of the other's belief at the expense of additional, inferential processing resources (i.e., full-blown ToM). This seems plausible when considering the details of our paradigm. The question "What will she expect to see?" might not only depend on what she last saw. While she was away, she may have obtained further information about what to expect, or she may have become aware that the object has been swapped in the past while she was away, or she may have forgotten what object she initially saw. These considerations, akin to considering counterfactual possibilities (see Rafetseder, O'Brien, Leahy, & Perner, 2021 for a developmental relationship between belief- and counterfactual reasoning), tie in with considerations of uncertainty as described above. As indicated by their responses, participants settle for what she initially saw as the best source of information for her belief, but such a decision process would come at extra costs.

The crucial point here is that considering various sources of information that may inform the other's (true) belief, akin to considering counterfactual possibilities, requires inferential processing (full-blown ToM), while a factual judgement about the object's identity and orientation from the other's viewpoint (VPT-2) can be resolved through relational processing (minimal ToM). Of course, further findings are required to corroborate this conjecture and future studies should aim at testing this interpretation of our effects.

Note that Apperly and Butterfill's framework (2009; Butterfill & Apperly, 2013) includes the possibility that belief judgements could also be resolved using minimal ToM. However, a relational representation that simply registers objects and their locations with another observer's past and current viewpoints would not differ between VPT-2 and TB judgements in our paradigm. Therefore, our findings speak against this possibility.

Finally, the angular disparity manipulation in our novel paradigm allowed us to determine possible effects of overlapping vs disparate self and other perspectives on the processing costs of FB vs TB (Hypothesis 3). Recently, overlapping self and other perspectives have been identified as a common confound in typical “false location belief reasoning tasks” (e.g., Rahman et al., 2021). However, when we included Angular Disparity as a factor in the analysis of the difference between FB and TB, we did not observe any significant interactions between Belief State (TB, FB) and Angular Disparity (0°, 90°). Thus, an overlapping perspective between self and other does neither increase nor decrease the added costs for FBs compared to TBs. We therefore conclude that the observed differences are likely to reflect the additional demands of inhibiting one’s own perspective-unspecific privileged representation of reality (i.e., object identity under the bucket) in FB tasks, unlike TB tasks where the other’s belief is congruent with the participants’ privileged representation (but not necessarily identical in perspective).

2.4.1 Developmental considerations

VPT-2 judgements were consistently quicker than TB judgments. One could therefore argue that perspective taking might be a developmental stepping-stone towards more sophisticated forms of mentalizing such as full-blown belief reasoning (Gunia et al., 2021; Kessler et al., 2014; Kessler & Thomson, 2010; Michelon & Zacks, 2006). However, several objections will have to be considered. In our task, TB judgements had to be made based on the other’s viewpoint. Thus, a viewpoint transformation was required at 90º in any case and while longer processing times for TBs may indicate additional/different processing compared to VPT-2, it does not necessarily indicate that TB processing depends on fully developed perspective taking abilities. In other words, TBs that do not rely in their content on a VPT-2 transformation, e.g., TBs about the correct location of an object (rather than its viewpoint-dependent orientation), could actually develop before VPT-2.

Indications that children may pass simple forms of TB (around the age of 3+) before FB (e.g., Fabricius et al., 2010) and VPT-2 (around the age of 4-5; e.g., Hamilton et al., 2009) have indeed been reported. However, a debate has ensued whether TB processing is the same in all age groups. That is, TB processing at an early age, before FB tests are passed, could be different to processing at a later age, when FB tests are also passed (e.g., Fabricius et al., 2010; but see Huemer et al., 2023). Young children may pass TB tests in a simpler way, potentially using minimal ToM, while older children may process them in a similar fashion to FBs and counterfactual thinking, eventually engaging full-blown ToM. VPT-2 could therefore be a stepping-stone for FB more specifically, which in turn may affect the way children process beliefs altogether, i.e., using inferential reasoning. An interesting implication would be that children, who can complete VPT-2 and TB tasks, but have not yet mastered FB reasoning, would not show a difference between VPT-2 and TB judgements in our Seeing-Believing Task, as they might process VPT-2 and TB judgements in the same relational fashion, using minimal ToM. We hope that our novel paradigm may benefit developmental research as well as further research with adults.

2.4.2 Limitations and Outlook

This study is the first to employ the newly developed Seeing-Believing Task and must therefore be treated as preliminary. This is reflected in our suboptimal pre-registration of Hypothesis 3, for instance, where we did not maximise the possibilities of our novel paradigm. We pre-registered three experiments to address some of the most obvious experimental questions, such as the influence of self vs other judgements, memory (Experiment 2) and different ways of manipulating TBs and FBs (Experiment 3). We further chose to pre-register our study given that experimentation and data collection was conducted online. While we believe that the presented results are consistent and powerful, a replication in more controlled laboratory settings might reveal further subtleties of this novel paradigm.

A surprising observation across all three experiments was that average number of errors were so low that variability was limited, affecting analysis and interpretation of this dependent measure. This is surprising, given that a substantial number of participants in each experiment failed to achieve our minimal performance criterion in at least one condition. It appears that these participants may not have understood the instructions fully. This is perhaps understandable given the lack of interactive explanation and instruction in this online version of a complex paradigm. However, the majority of participants who understood the instructions committed low numbers of mistakes. As this may reflect a selection bias in terms of levels of motivation and attention in these successful participants, a replication under laboratory conditions might help achieve more realistic estimates of errors.

A further surprising outcome that would warrant further investigation was the strong effect favouring Self-past judgments over Self-current judgements in Experiment 2. This indicates that participants anchor their trial representation to the initial scene rather than update their representations continuously as the trial unfolds. A new version of Experiment 2, where Self and Other judgments are presented in separate blocks might shed light on effects induced by the complexity of having to maintain the possibility of four different judgement types until the very end of each trial. Differences between Self-past and Self-current judgements might be diminished in such a paradigm (see Hypothesis 6 in Supplementary Material). It would also be of interest to replicate the observed difference between Self-past and Self-current in the context of Experiment 3 (e.g., adding Self-past and Self-current judgements), in order to understand if the more difficult manipulation of un/witnessed object swaps changes participants' representational anchoring and updating during trials.

2.4.3 Conclusions

Using a novel Seeing-Believing Task, the experiments comprising this study provide consistent evidence that inferences concerning another's visual perspective (how the world appears visually to them) involves, at least in part, psychologically distinct processes to those supporting inferences about their beliefs (what they believe to be true about the visual world). This is the case even when the other's belief is true, referring to the same true state of reality and requiring identical responses in the paradigm we developed. Perspective judgements were found to be reliably faster and less error prone when compared to those concerning beliefs, indicating that the former involves representations of another's mental states that are easier to generate. We propose that the observed differences could reflect higher demands in social processing (rather than mnemonic processing) for representing another's mind when generating their TB as compared to merely imagining another's visual viewpoint. The higher processing demands could be indicative of a transition from relational (perspectives) to propositional (beliefs) processing. The presented work supports future research endeavours by providing a novel but replicated paradigm along with open materials and data (https://osf.io/57wa9/).

3. Comparing Visual Perspective Taking and Belief Reasoning in Autism Spectrum Condition

3.1 Introduction

Humans are equipped with the capacity to represent others' mental states and experiences, referred to commonly as "mentalizing" or "theory of mind", which is essential for effective social interaction and communication. A crucial developmental stepping stone in our understanding that others' experiences may differ from our own is the emergence of visuospatial perspective taking – the mental process of seeing the world through another's eyes. So far, however, this capacity has been studied separately from other mentalizing abilities, such as belief reasoning. The latter requires the representation of others' beliefs about reality rather than their actual experiences as such and might therefore require a higher level of complexity. Recently, by developing a novel integrated paradigm we delineated high-level perspective taking from belief reasoning, showing consistently higher costs for the latter even if another's belief about reality is true and therefore coincide with their visual perspective (Green, Shaw, & Kessler, 2022). In the present study, we aimed to extend these new insights into the segregation of mentalizing sub-processes, and investigate these processes in Autism Spectrum Condition (ASC). Utilising our novel paradigm, we investigated whether more subtle differences exist between autistic and non-autistic adults in these mentalising sub-processes that may have been missed in prior research, and that might provide more nuanced insights into the cognitive phenotype of ASC. In the following sections, we first describe central concepts before specifying our methods and hypotheses.

3.1.1 Autism Spectrum Condition

Autism Spectrum Condition (ASC; also referred to commonly as Autism Spectrum Disorder) is a complex, multifaceted and heterogeneous condition that affects ~1% of the global population (American Psychiatric Association, 2013). According DSM-5, ASC diagnoses are based on two core symptoms: atypical social interaction and communication (e.g., responding inappropriately in conversation), and restricted, repetitive behaviours (e.g., strict adherence to routines and highly specific interests of unusual intensity; American Psychiatric Association, 2013). Autistic individuals exhibit a full range of intellectual and language abilities, from severe intellectual disability to superior intelligence (Grzadzinski, Huerta, & Lord, 2013) and non-verbal to no language impairments (American Psychiatric Association, 2013). The exact presentation of ASC varies with age and ability (American Psychiatric Association, 2013; Fakhoury, 2015), contributing to the complexity of the behavioural phenotype and heterogeneity of the condition.

3.1.2 Theory of Mind

Theory of Mind (ToM) refers to the ability to impute mental states to others and oneself. The ToM hypothesis of autism suggests that atypical social interaction and communication in ASC arise from variations in the capacity for ToM specifically (e.g., Rajendran & Mitchell, 2007). Alternatively, these variations may arise from more general non-social differences to processes common to both ToM and VPT-2, which may reflect differences in executive functioning. Perhaps the most well-known assessment of ToM ability employed in ASC research is the Sally-Anne task (Baron-Cohen et al., 1985; see Wellman et al., 2001 for review). In this task, a participant watches a scenario unfold between two characters, Sally and Anne. Sally places a ball into a red box and leaves the room. In Sally's absence, Anne moves the ball from the red box to a blue box. As Sally is unaware of the change to the location of the ball, she now holds a *false belief* (FB; i.e. that the ball is in the red box). The participant is then asked "Where will Sally look for the ball?" To answer this question correctly, participants must inhibit their own understanding of reality (that the ball is in the blue box) in order to represent FB. Baron-Cohen and colleagues (1985) observed that autistic children tended to fail this test of FB reasoning, whereas non-autistic children and those with Down's syndrome tended to pass. Subsequent research suggests that typically developing children tend to begin passing FB tasks between the ages of four and five (Hogrefe et al., 1986; Perner, Leekam, & Wimmer, 1987; Wellman et al., 2001), while autistic children typically start to pass them at much later ages (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001; Charman & Baron-Cohen, 1995; Happé, 1994b). Importantly, although they pass these tasks at a later age, many autistic children do pass them eventually. This suggests either that many autistic children do possess some capacity for ToM or that they are capable of employing compensatory strategies.

For a long time, ASC was regarded as a childhood condition. However, many autistic adults continue to report ToM difficulties (Spek, Scholte, Berckelaer-Onnes, & Ina, 2010) despite being able to pass experimental tests of this capacity – measures of both first-order (inferring a person's mental state) and second-order ToM (inferring a mental state about a mental state; Kaland et al., 2002; Tager-Flusberg et al., 2000). This represents a need to develop ToM tasks that are appropriately difficult for adults whilst able to measure more subtle features of ToM. In response to this, 'advanced ToM' tasks have been developed with the aim of capturing more accurately the demands of everyday social interactions. For example, in the Strange Stories (Happé, 1994a) and Faux Pas tasks (Baron-Cohen, O'riordan, Stone, Jones, & Plaisted, 1999) participants are presented with short vignettes describing social situations and asked to explain characters' behaviour by inferring their mental states. Using such tasks, some studies have reported lower accuracy in autistic compared to non-autistic adults (Happé, 1994a; Kaland et al., 2002; Zalla et al., 2009), whereas other studies report no such differences in performance (Ponnet et al., 2004; Roeyers et al., 2001). These tasks are regarded as more difficult than first- and second-order ToM tasks because they probe a range of ToM concepts, requiring an appreciation of subtler contextual information and an understanding of the emotional impact of behaviours. Furthermore, the Strange Stories and Faux Pas tasks require participants to read passages of written text, thereby introducing different verbal and executive demands compared with first- and second-order ToM tasks. As such, it is difficult to isolate social (ToM) from other non-social (executive) processes.

3.1.3 Visual Perspective Taking

Visual Perspective Taking (VPT) refers to our capacity to understand that an object viewed simultaneously by the self and another will create different visual experiences if the viewing circumstances differ; this includes both *what* is visible (Level-1) and *how* something appears from another's viewpoint (Level-2; Flavell et al., 1981). For example, Hamilton et al. (2009) investigated Level-2 Visual Perspective Taking (VPT-2) in children with ASC by showing them a toy panda at a specific orientation before covering it and asking them how the panda would appear from the perspective of a doll positioned 90^{o} to the left or right of the (occluded) panda. The children were then given a picture card containing images of the panda from the front, back, left side and right side, and asked to choose the image that the doll would see when the cover was removed. Similar to the Sally-Anne task, responding correctly requires the child to inhibit their own perspective in order to represent the viewpoint of the doll. Although this highlights a process common to ToM (FB reasoning) and VPT-2, the type of information being represented differs between the two types of mentalising; the former involves another's belief about reality, whereas the actual state of reality from the another's perspective is represented during VPT-2. Some studies report that children with ASC are less accurate relative to those without in VPT-2 tasks (Hamilton et al., 2009; Ni et al., 2021; Yirmiya et al., 1994), whereas others report no such differences (Tan & Harris, 1991). Studies assessing adults with autistic traits, rather than those diagnosed formally with autism, suggest that VPT-2 may be more challenging for autistic than non-autistic individuals because they struggle to mentally embody another's perspective (Brunyé et al., 2012; Kessler & Wang, 2012). For example, Kessler and Wang reported that individuals with a greater number of autistic traits were less inclined to complete tasks by mentally rotating their body schema to the target orientation, whereas individuals with fewer autistic traits were more inclined to mentally rotate their body schema into the target orientation. In addition, Kessler and Wang (2012) reported that individuals reporting greater number of autistic traits were more likely to select an alternative method to embodied transformation, such as mentally rotating the target object instead.

3.1.4 Comparing Belief Reasoning and Visual Perspective Taking

From the discrepant findings reviewed above, it remains unclear if and how alterations in belief reasoning, VPT-2 or processes common to both forms of mentalising contribute to the atypical social interaction and communication that characterise ASC. This might be due to the aforementioned limitations of existing belief-based mentalizing tasks, or fundamental differences in the tasks employed to assess these sub-processes independently. For example, the Sally-Anne task involves a change in the physical location of a target object that is likely to involve an attentional shift, which is unlike the panda task described above to assess VPT-2, which may limit comparison of these tasks.

In a recent study Green, Shaw and Kessler (2022), a novel experimental paradigm that overcomes these limitations and permits direct comparisons between the two sub-processes was introduced, allowing us to advance our understanding of mentalising in ASC. This Seeing-Believing Task resembles classic FB tasks (e.g., the previously mentioned Sally-Anne task), but is appropriately demanding for adults, whilst also minimising the non-social verbal and executive demands imposed by 'advanced ToM' tasks (e.g., Faux Pas stories). In the Seeing-Believing Task, participants are required to infer either a character's belief about, or visual perspective of a target object, which either remained unchanged (no swap), or was changed whilst the character was not looking (swap). Each trial begins with an image of an object (either a toy rabbit or train) on a table, and a character, Kim, sitting at the table on a chair with their back to the participant. As such, there is no difference between the visual perspective of Kim and the participant in this initial image. In subsequent images, Kim leaves the room and in their absence the object on the table is either swapped with another (e.g., the rabbit swapped for the train) or remains unchanged (Swap or No-swap condition). A bucket was then placed over the object before Kim returns. On their return, Kim sat either in her original seat or one positioned 90º to its left or right. This results in either a 0º or 90º angular disparity, respectively, in the visual perspectives of Kim and the participant. Participants are then asked "What will she [Kim] expect to see [when the bucket is lifted]?", assessing their understanding of Kim's belief, or "What will she actually see?", assessing their understanding of Kim's visual experience from her current viewpoint (belief or VPT-2 judgement). With this single task, then, Kim's belief or visual experience differs systematically from the participant's. This allows us to measure belief reasoning and VPT-2 in tandem, thereby eliminating any between-task differences and controlling for overlap with the egocentric experience. Further, in our previous study we made a range of adjustments to reduce non-ToM demands often present in experimental tasks: a single target object was used (i.e. rabbit or train) rather than an array, reducing visuo-spatial demands (Hamilton, Brindley & Firth, 2009), and the target stimulus was occluded when participants were asked questions about its identity, reducing inhibitory demands (Leslie, German, & Polizzi, 2005). Additionally, participants were asked to indicate their answer using a key press to select an image rather than a verbal response, thereby reducing language demands.

Using this novel task, our previous study revealed that *true* belief (TB) reasoning was associated consistently with increased response times (RTs) compared with VPT-2 judgements, despite their conceptual overlap and identical responses. Since questions probing belief reasoning concerned the identity of the first (former) object on the table while those probing VPT-2 concerned the second (current) object, possibly presenting a memory confound, we incorporated Self-current ("What will you [the participant] actually see [when the bucket is lifted]?") and Self-past questions ("What did you initially see [on the table]?") to equate memory demands. This revealed that Self-past judgements were associated with lower RTs than Self-current judgements, suggesting that additional cognitive demands associated with (true) belief reasoning relative to VPT-2 was unlikely to reflect additional memory processes. Rather, we suggest that belief reasoning relies upon more complex social representations compared with VPT-2 (Green, Shaw and Kessler, 2022).

3.1.5 The current investigation

To investigate if ASC reflects a specific difficulty in forming complex social representations, as suggested by the ToM hypothesis, or difficulties in processes common to both ToM and VPT-2, in this pre-registered study we employed our novel Seeing-Believing Task to compare belief reasoning and VPT-2 performance in a group of autistic adults. We also compare their performance to non-autistic adults (ASC and non-ASC group, respectively). If autistic adults find it more difficult than non-autistic adults to form the complex social representations required for ToM, but are equally capable of representing another's visual representation, it was predicted that the poorer performance (increased RTs and errors) on belief reasoning relative to VPT-2 trials that we observed previously would be more pronounced in the autistic compared to non-autistic adults.

3.1.6 Hypotheses

All hypotheses were pre-registered on the OSF (https://osf.io/xwjub/). Hypotheses 1 and 2 broadly concern comparisons between (true) belief reasoning and VPT-2, based upon the findings of our former study. First, in line with our previous findings, we predicted that the non-ASC group would demonstrate greater RTs and/or errors for (true) belief reasoning in the No-swap condition compared with VPT-2 judgements, and this difference would be greater at 90º than 0º angular disparity (Hypothesis 1) as executive demands are greater at greater angular disparities. Since it is unclear whether ASC reflects specific differences in ToM (ToM hypothesis) or more general differences in processes common to both ToM and VPT-2 (executive functioning), we formulated two alternative hypotheses for adults with ASC. Hypothesis 2a is based on the ToM hypothesis, predicting that, as for the non-ASC group, the ASC group would produce greater RTs and/or errors for (true) belief judgements in the No-swap condition compared to VPT-2 judgements, and this difference would be greater at 90º relative to 0º angular disparity. More importantly, these increases in RTs and/or errors for TB compared with VPT-2 judgements were predicted to be greater in the ASC compared with the non-ASC group. If, however, ASC is associated with a difference in processes common to ToM and VPT-2 (executive functioning), we predicted that TB and VPT-2 judgements would be equally more difficult for the ASC compared with the non-ASC group (Hypothesis 2b). In other words, we hypothesised a main effect of Group but no Group-by-Judgement interaction. In addition, we predicted that both groups would show an increase in RTs and/or errors across both true belief and VPT-2 judgements made at 90º angular disparity compared with those made at 0º angular disparity, but with an overall steeper increase for the ASC relative to the non-ASC group given the increased executive demands imposed by increasing angular disparity.

Hypotheses 3 and 4 concern the relationship between FBs, TBs and VPT-2. Previously Green, Shaw and Kessler (2022), in individuals without ASC it was revealed greater RTs and errors for FB judgements compared to both TB and VPT-2 judgements, which was most pronounced at 90º angular disparity. It was predicted that the non-ASC group would replicate this finding (Hypothesis 3). Regardless of whether ASC reflects specific differences in ToM (ToM hypothesis) or more general differences in processes common to both ToM and VPT-2 (executive functioning; see Rajendran & Mitchell, 2007 for review), we predicted that the ASC group would also exhibit greater RTs and/or errors for FB compared with TB and VPT-2 judgements. Given the additional demands imposed by increasing angular disparity, it was also hypothesised that these differences between judgement types would, again, be most pronounced at 90° relative to 0° angular disparity. More importantly, we hypothesised that larger differences in RTs and/or errors for FB compared with TB and VPT-2 judgements with increasing angular disparity would be greater in magnitude for the ASC compared with the non-ASC group (Hypothesis 4). However, given the mixed results reported in the literature regarding explicit FB reasoning in adults, we acknowledge that this prediction is contentious.

Hypotheses 5 and 6 concern the relationship between Self-past and (“what did you initially see?”) Self-current judgements (“what will you actually see [when the bucket is lifted]?”). In our previous study, we observed the counter-intuitive effect that Self-current judgements were associated with greater RTs and/or errors than Self-past judgements. We interpreted this as evidence that participants anchored their judgements on the initial state of the target object (probed by Self-past judgements) instead of continuously updating their representations according to their knowledge of reality (the object currently hidden under the bucket). In the present study, we predicted that the non-ASC group would replicate this finding (Hypothesis 5). For the ASC group, we formulated two hypotheses: One possibility is that individuals with ASC also anchor their perspective to the initial stimulus, evidenced by greater RTs and/or errors on Self-current relative to Self-past judgements. To evaluate this, we predicted no difference between the ASC and non-ASC group for this contrast (Hypothesis 6a). Another possibility is that adults with ASC focus more on their current perspective and update their representations continuously as the trial unfolds, in which case Self-past perspectives would be associated with greater RTs and/or ERs than Self-current judgements (Hypothesis 6b). Should adults with and without ASC encode the sequence of events in a trial differently to one another, this would have implications for the interpretation of any observed differences between belief reasoning and VPT. Differences in the ASC group might reflect mnemonic rather than social processes, for example, which is opposite to the interpretations we made from our previous study of individuals without ASC.

3.2 Methods

3.2.1 Design

The hypotheses, study design and planned analyses were pre-registered on the OSF (https://osf.io/xwjub/). The experiment comprised a 2 (Group: ASC, non-ASC) x 2 (Object Swap: No-swap, Swap) x 2 (Angular Disparity: 0^{o}, 90^{o}) x 4 (Judgement Type: VPT-2, Belief Reasoning, Self-current, Self-past) full factorial mixed design.

3.2.2 Materials

3.2.2.1 The Seeing Believing Task

The present study employed a version of the Seeing-Believing Task used in Experiment 2 Chapter 2. There were two practice blocks, one of twelve trials and another of eleven trials, with a recap of the task instructions placed in between. This was followed by three blocks of 64 trials, each with self-paced breaks in between. See Figure 15 for a trial schematic.

3.2.2.2 Raven's Progressive Matrices

Since studies have cited intelligence as a factor that affects ToM performance (e.g., Hamilton et al., 2009) and so we administered the Raven's Progressive Matrices (RPM; Raven & Court, 1938) to measure non-verbal intelligence. The RPM consists of a series of puzzles, wherein participants are asked what picture will come next in a series of black and white shapes. For each of 60 trials, participants are asked to choose their answer from eight options. For each correct puzzle, participants scored one point. Scores across the 60 puzzles are summed to create an overall score (maximum = 60). The RPM is a test of non-verbal intelligence, which assess the ability to infer rules, manage a hierarchy of goals and form high-level abstractions (Carpenter, Just, & Shell, 1990). Burke (1985) reported a Spearman-Brown reliability coefficient of .96, demonstrating the reliability of the RPM. In relation to other cognitive tests, Snow, Kyllonen, and Marshalek (1984) regarded RPM as the most complex and general single test of intelligence. The RPM were chosen over more common verbal measures of intelligence because they appear to be more appropriate for individuals with ASC; for example, (Dawson, Soulières, Ann Gernsbacher, & Mottron, 2007) reported that Wechsler scales of intelligence

Three (WISC-III; Wechsler & Kodama, 1949) underestimate intelligence in those with ASC by an average of 30 points.

3.2.2.3 Autism Spectrum Quotient (AQ; Baron-Cohen et al., 2001)

This version of AQ is a self-administered questionnaire designed to measure the degree to which an adult with normal intelligence has traits associated with the autism spectrum, with higher scores indicating more associated traits. This scale consists of 50 items on a 4-point Likert scale ranging from 1 (Definitely agree) to 5 (Definitely disagree). The AQ assesses five domains: social skill, attention switching, attention to detail, communication, and imagination. Cronbach's alpha of these domains range from .63 to .77. The maximum score on this instrument is 50. Baron-Cohen et al. (2001) recommend cut-off of 32 for discriminating between ASC and non-ASC groups, as this achieves the highest true- and lowest false-positive rate. In the present study, this recommended cut-off was used for inclusion into the ASC group but values of 26 (one standard deviation below the ASC cut-off) or lower were used for inclusion into non-ASC group.

3.2.3 Participants

Sample size calculations performed with G*Power (Faul et al., 2007) suggested a sample of 120 participants (60 ASC, 60 non-ASC) was required to achieve a small effect size ($f = 0.15$) with 95% power with a 2x2x4 mixed ANOVA (16 variables across 3 factors). Calculations were computed with correlations of r =. 81 among repeated measures, based on our previous data. All participants (see *Table 1*) were aged between 18 and 40 years and fluent in written and spoken English. Those in the ASC group self-reported a formal diagnosis of ASC and had an AQ score equal to or greater than 32. Those in the non-ASC group reported to have never been diagnosed with an ASC and provided AQ scores less than 26.

Table 7. Summary of sample demographic information after applying exclusion criteria.

n = 102	ASC (n = 58)	non-ASC (n = 65)
Age, M(*SD*)	27.193 (*6.19*)	24.359 (*5.38*)
Females:Males ratio	28:29	31:33
Autism Quotient, M(*SD*)	39.25 (*4.79*)	17.05 (*5.81*)
Raven's Progressive Matrices, M(*SD*)	46.97 (*9.68*)	44.00 (*8.74*)
No. of participants removed due to low accuracy on experimental task	8	9

Note. M = mean, SD = standard deviation. Descriptive statistics were calculated after the removal of participants with low accuracy on the Seeing-Believing Task.

3.2.4 Procedure

This experiment was conducted online. First, participants were recruited to the study via Prolific (https://www.prolific.co/) and were then directed to Qualtrics (https://www.qualtrics.com/uk/) to the participant information sheet and consent form. After providing consent, participants were given instructions to the experimental task and then directed back to Pavlovia to complete the task implemented in PsychoPy (Peirce, 2007). Next, participants were asked to complete the Raven’s Progressive Matrices, also administered via Pavlovia. Finally, participants were asked to complete the AQ and read a debrief form on Qualtrics. Participants were compensated with £12 via Prolific. Aston University’s Research Ethics Committee approved this experiment, and all participants provided informed consent before taking part.

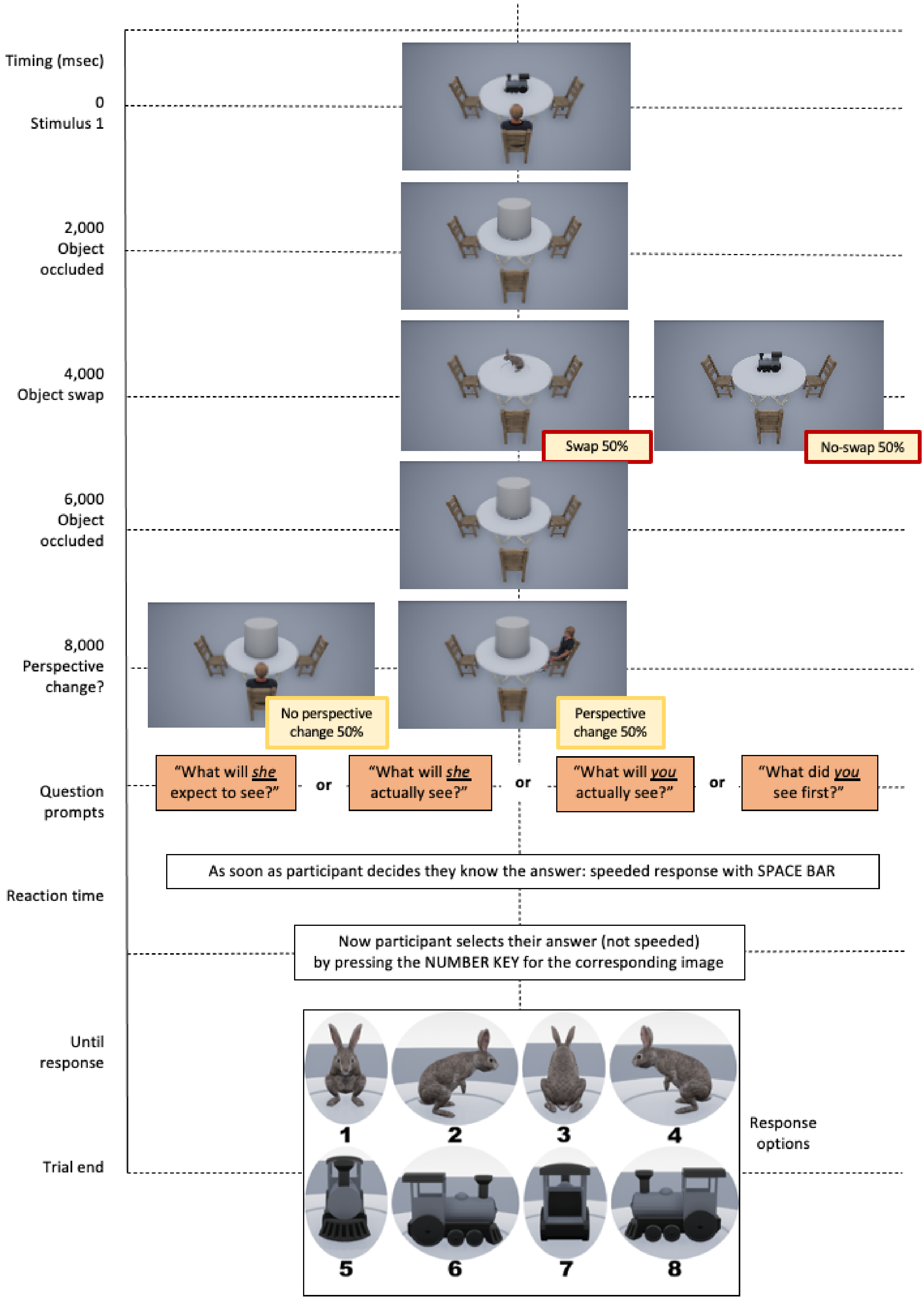


Figure 15. Trial schematic of the experimental task.

3.2.5 Statistical Analysis

Custom MATLAB (r2019a) code (https://osf.io/wcvba/) was used to calculate condition averages and remove outliers, and JASP (Version 0.14.1) was used to perform inferential statistics. Planned analyses and predicted results can be found in the pre-registration. Outlier trials were defined as two SDs beyond each participant's condition mean. Due to violations of normality, RTs were log-scaled and two participants were removed for scoring greater than three SDs above the overall mean RT for all participants over all conditions in at least 4/16 conditions, in addition to those removed due to low accuracy on the Seeing-Believing Task. Of those removed, one was in the ASC group and the other in the non-ASC group. All participants included in statistical analyses answered at least 3/12 trials of each type correctly in line with Green, Shaw and Kessler (2022). Incorrect trials were not included in mean RT calculations, and errors were analysed separately to RTs. Hypotheses were evaluated using within-subjects and mixed model analysis of variances (ANOVAs), and paired and independent samples *t*-tests for planned comparisons.

3.3 Results

As per our pre-registration (see https://osf.io/3dgpy), we used a two-tailed independent samples *t*-test to assess if the ASC and non-ASC group differed in their non-verbal intelligence, as assessed by RPM, but no significant difference was observed ($t(119) = 1.771$, $p = .079$, $d = 0.323$; see Table 1). Therefore, RPM scores were not included as a covariate in subsequent statistical analyses.

3.3.1 Hypothesis 1

3.3.1.1 Non-ASC

In line with Green, Shaw and Kessler (2022), it was hypothesised that true belief reasoning will be associated with greater RTs and/or errors than VPT-2 and any differences will be greater at 90° relative to 0° angular disparity. A 2x2 within-subject ANOVA, with the factors Angular Disparity (0°, 90°) and Judgement Type (VPT-2, TB) was applied to No-swap (i.e., TB) trials only. RTs and errors were analysed separately. Replicating our previous findings, analyses of RTs did not reveal a statistically significant main effect of Judgement Type ($F(1,63) = .195$, $p = .660$, $n_p^2 = .003$), but did reveal a statistically significant main effect of Angular Disparity ($F(1,63) = 8.136$, $p = .006$, $n_p^2 = .114$) and a significant Judgement Type-by-Angular Disparity interaction ($F(1,63) = 6.024$, $p = .017$, $n_p^2 = .087$; Figure 3A, upper left). Further, a planned comparison of the difference between TB and VPT-2 judgements at 90° angular disparity, performed with a one-tailed paired samples *t*-test, revealed a statistically significant difference ($t(63) = 1.789$, $p = .039$, $d = .224$); TB reasoning was associated with greater RTs than VPT-2. Analysis of error data did not reveal a statistically significant main effect of

Judgement Type (F(1,63) = 3.864, p = .054, n_p^2 = .058), nor an interaction between Judgement Type and Angular Disparity (F(1,63) = .740, p = .393, n_p^2 = .012), but did reveal a statistically significant main effect of Angular Disparity (F(1,63) = 6.689, p = .012, n_p^2 = .096; see Figure 3A, lower left). Additionally, a one-tailed paired-samples t-test comparing TB and VPT-2 judgements made on No-swap trials with 90° angular disparity revealed a statistically significant difference (t(63) = 2.009, p = .024, d = .251), where TB judgements were associated with greater errors. RT findings support Hypothesis 1, whereas error findings do not. These findings replicate our previous work (Green, Shaw and Kessler, 2022).

3.3.1.2 ASC

Hypothesis 2 aimed to understand if there is a difference between TB reasoning and VPT-2 (in terms of RTs and/or errors) in adults with ASC, and if any differences are affected by increasing angular disparity from 0° to 90°. A 2x2 within-subjects ANOVA was with the factors Angular Disparity (0°, 90°) and Judgement Type (TB, VPT-2) was performed on No-swap trials only (i.e., TB). RTs and errors were analysed separately. Analysis of RT data did not reveal a statistically significant main effect of Judgement Type (F(1,56) = 1.208, p = .276, n_p^2 = .021), nor an interaction between Judgement Type and Angular Disparity (F(1, 56) = 1.974, p = .166, n_p^2 = .034). There was, however, a main effect of Angular Disparity (F(1,56) = 46.257, p < .001, n_p^2 = .452; see Figure 3A, upper right). Corresponding to the analysis of the non-ASC group, a two-tailed paired-samples t-test was conducted as a planned comparison to compare TB and VPT-2 belief judgements at 90° angular disparity. This test did not reveal a statistically significant difference (t(56) = 1.540, p = .065, d = .204). Analysis of error data did not reveal a statistically significant main effect of Judgement Type (F(1,56) = .586, p = .447, n_p^2 = .010), nor an interaction between Judgement Type and Angular Disparity (F(1,56) = .150, p = .700, n_p^2 = .003), but did reveal main effect of Angular Disparity (F(1,56) = 7.992, p = .007, n_p^2 = .125; see Figure 3A, upper right). Again, as a final planned comparison, a two-tailed paired-samples t-test comparing VPT-2 and true belief judgements at 90° angular disparity was performed. This test did not find a statistically significant difference (t(56) = .726, p = .235, d = .096).

3.3.1.3 Group comparison

To assess if the relationship between belief reasoning and VPT-2 judgements differs between the ASC and non-ASC group, a three-way mixed ANOVA was performed for the between-groups factor Group (ASC, non-ASC) and within-subjects factors Judgement Type (TB, VPT-2) and Angular Disparity (0°, 90°). Analysis of RTs revealed a statistically significant interaction between Group and Angular Disparity (F(1,119) = 4.906, p = .029, n_p^2 = .040). However, there was no significant main effect of Group (F(1,119) = .049, p = .825, n_p^2 < .001), nor a Group-by-Judgement Type (F(1,119) = .148, p =

.701, n_p^2 = .001) or Group-by-Judgement Type-by-Angular Disparity interaction (F(1,119) = .001, p = .970, n_p^2 < .001; see Figure 3A). The analysis of error data revealed no significant interaction between Group and Angular Disparity (F(1,119) = .151, p = .699, n_p^2 = .001), Group and Judgement Type (F(1,119) = 1.066, p = .304, n_p^2 = .009), nor Group-by-Judgement Type-by-Angular Disparity (F(1,119) = .167, p = .684, n_p^2 = .001). However, there was a significant main effect of Group (F(1,119) = 7.729, p = .006, n_p^2 = .061) and Judgement Type (F(1,119) = 3.918, p = .05, n_p^2 = .032; see Figure 3A). Those in the ASC group made fewer errors than those in the non-ASC group, and TB judgments were associated with greater errors than VPT-2 judgements. These error findings do not clearly support any of our hypotheses, but they do support a distinction between TB reasoning and VPT-2 judgements.

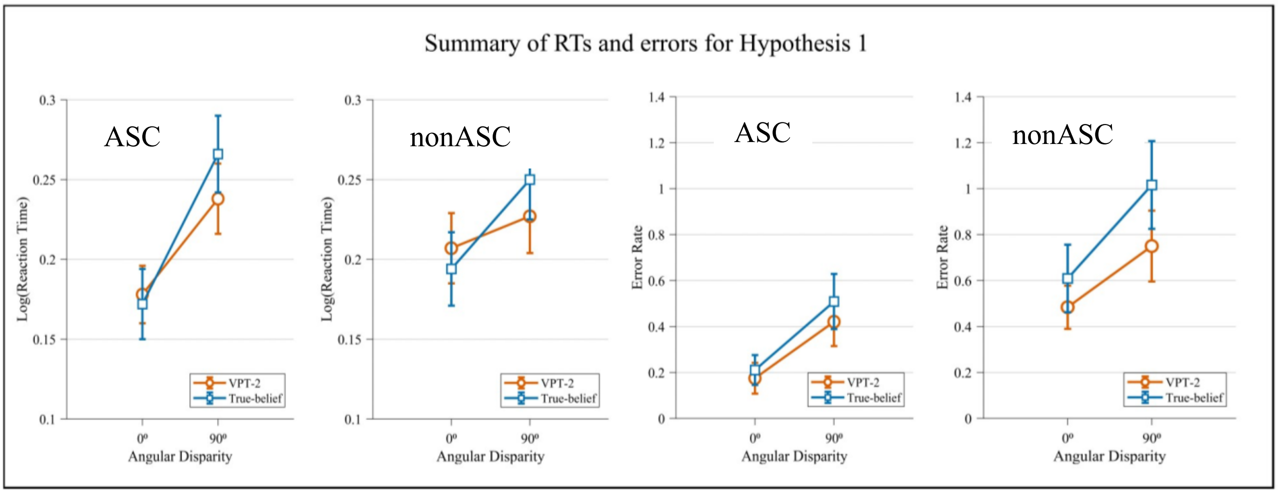


Figure 16. Results for Hypothesis 1, Response times (RTs, measured in seconds; correct responses only) are shown on the left and errors (average number of errors per condition and with a maximum of 12) are shown on the right. Error bars are standard error of mean.

3.3.2 Hypothesis 2

3.3.2.1 Non-ASC

On the basis of previous findings (Green, Shaw and Kessler, 2022), we predicted that FB judgements made at 90° angular disparity would be associated with greater RTs and/or errors than TB and VPT-2 judgments made at 90° angular disparity in the non-ASC group. To assess this hypothesis, a series of two-tailed paired-samples t-tests were performed: First, FB judgements were compared with TB judgements at 90° angular disparity and revealed statistically significant differences in RTs (t(63) = 7.143, p < .001, d = .893; see Figure 3B, upper-right) and errors (t(63) = 7.881, p < .001, d = .985; see Figure 3B, lower right). Second, FB judgements were compared with VPT-2 judgements (No-swap trials) made at 90° angular disparity, which also revealed statistically significant difference in RTs (t(63) = 4.145, p < .001, d = .518; Figure 3B, upper-right) and errors (t(63) = 4.691, p < .001, d = .586; Figure

3B, lower right). These results support Hypothesis 3, suggesting greater cognitive demands for FB judgements relative to TB reasoning and VPT-2 judgements.

3.3.2.2 ASC

Hypothesis 4 concerns the relationship between FB, TB and VPT-2 judgements all made at 90° angular disparity in the ASC group. It is possible that FB judgements will be associated with greater RTs and/or errors than TB *and* VPT-2 judgements, as observed in the non-ASC group, but it also possible that the cognitive demand associated with changing perspective may be so great that differences are indiscernible. Like in the non-ASC group, this hypothesis was assessed using a series of paired-samples *t*-tests: First, FB and TB judgements made at 90° angular disparity were compared, revealing statistically significant differences in RTs ($t(56) = 10.062$, $p < .001$, $d = 1.333$; Figure 3B, upper left) and errors ($t(56) = 7.356$, $p < .001$, $d = .974$; Figure 3B, lower left). In addition, FB judgements made at 90° angular disparity were compared with VPT-2 judgements made at 90° angular disparity under the No-swap conditions, which also revealed statistically significant difference in RTs ($t(56) = 5.467$, $p < .001$, $d = .724$; Figure 3B, upper left) and errors ($t(56) = 5.229$, $p < .001$, $d = .693$; Figure 3B, lower left). As with the non-ASC group, these findings demonstrate the cognitive demand for FBs relative to TBs and VPT-2 judgements at 90° angular disparity.

3.3.2.3 Group comparison

The aim of this hypothesis is to assess whether the ASC group exhibits a larger difference between FB judgements and both TB and VPT-2 judgements at 90° angular disparity than the non-ASC group. This hypothesis was examined by averaging the RTs and errors (separately) of TB and VPT-2 judgments made at 90° angular disparity and then subtracting this value from the score associated with FB judgement at 90° angular disparity. An independent samples *t*-test assessed if there was a difference in this relative measure between the ASC and non-ASC group. Analysis of RTs did not reveal a statistically significant difference ($t(119) = .488$ $p = .626$, $d = .089$), nor did an analysis of errors ($t(119) = 1.063$, $p = .290$, $d = .194$; see Figure 3B). In other words, ASC and non-ASC participants exhibited approximately similar magnitudes of slowing and errors in response to FB judgments made at 90° angular disparity, relative to the average of TB and VPT-2 judgments made at 90° angular disparity. This suggests that the ASC group did not find FBs more difficult than the non-ASC group in comparison to TB.

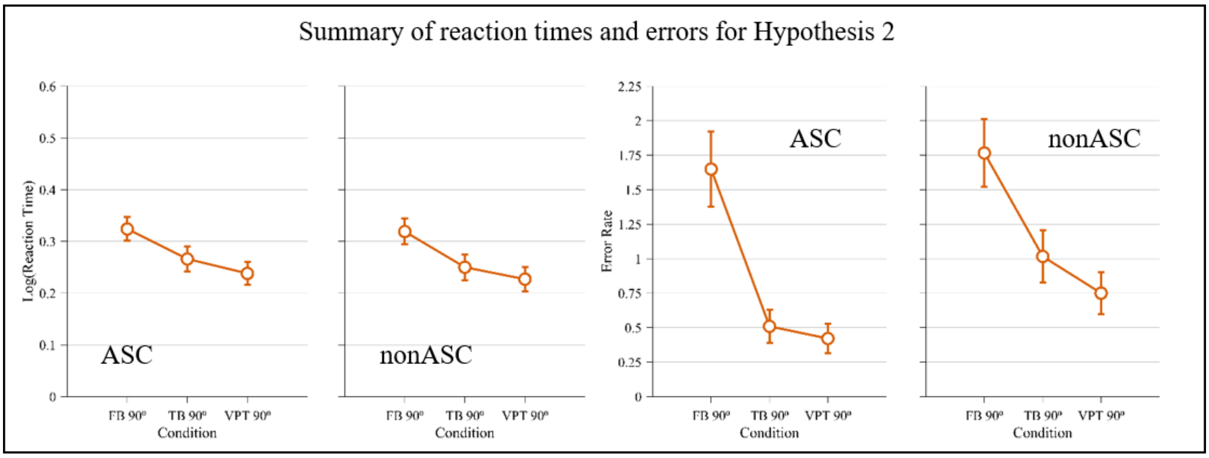


Figure 17. Results for Hypothesis 2, Response times (RTs, measured in seconds; correct responses only) are shown on the left and errors (average number of errors per condition and with a maximum of 12) are shown on the right. Error bars are standard error of mean.

3.3.3 Hypothesis 3

3.3.3.1 Non-ASC

In line with our previous findings (Green, Shaw and Kessler, 2022), it was predicted that Self-current judgements would be associated with greater RTs and/or errors than Self-past judgements. This planned comparison was examined by performing one-tailed paired-samples *t*-test comparing RT and error data separately between Self-current and Self-past trials. Analysis of RTs revealed a significant difference, where Self-current judgements were associated with greater RTs than Self-past judgements ($t(63) = 3.258$, $p < .001$, $d = .407$ (Figure 3C, upper right). This was not true for error data, however, which did not reveal a significant difference between Self-current and Self-past judgements ($t(63) = 1.093$, $p = .139$, $d = .137$; Figure 3C, lower right). The RT data therefore converge with our previous observations, but error data did not. Together, these findings still suggest that when performing the Seeing-Believing Task, participants anchored their mental representation of task events to the first rather than the second stimulus, which lead to faster recall of Self-past judgements.

3.3.3.2 ASC

It was unclear whether individuals with ASCs would anchor their experience of the task to the first stimulus like those without ASC, or to the second stimulus that aligned to their experience during the question phase of the task. To investigate this, Self-current and Self-past judgements in the ASC group were compared using two-tailed paired samples *t*-tests. Analysis of RTs revealed a significant difference, where Self-current judgements were slower than Self-past judgements ($t(56) = 6.521$, $p < .001$, $d = .864$; Figure 3C, upper left), similar to the non-ASC group. Likewise, analysis of errors revealed a significant difference where Self-current judgements were more error prone than Self-past judgements ($t(56) = 2.387$, $p = .010$, $d = .316$; Figure 3C, lower left). As with the non-ASC group, these findings suggest that those in the ASC group also anchored their task experience to first stimulus (Self-past judgements rather than the second (Self-current judgements).

3.3.3.3 Group comparison

The final hypothesis assessed whether adults in the ASC group performed the task with a similar strategy to those in the non-ASC group. As reported above, both the ASC and non-ASC group performed Self-past judgements faster than Self-current judgments. To assess this, the RTs and errors associated with Self-current judgements were subtracted from scores associated with Self-past judgements (separately for RT and error) to create difference scores. These difference scores were compared between groups using a two-tailed independent samples *t*-tests. We observed no significant difference in RTs ($t(119) = 1.622$, $p = .108$, $d = .295$; Figure 3C) or errors ($t(119) = .825$, $p = .411$, $d = .150$; Figure 3C). Overall, this pattern of results suggests that adults in both the ASC and non-ASC group anchor their experience of the task to the first object on the table, rather than the second.

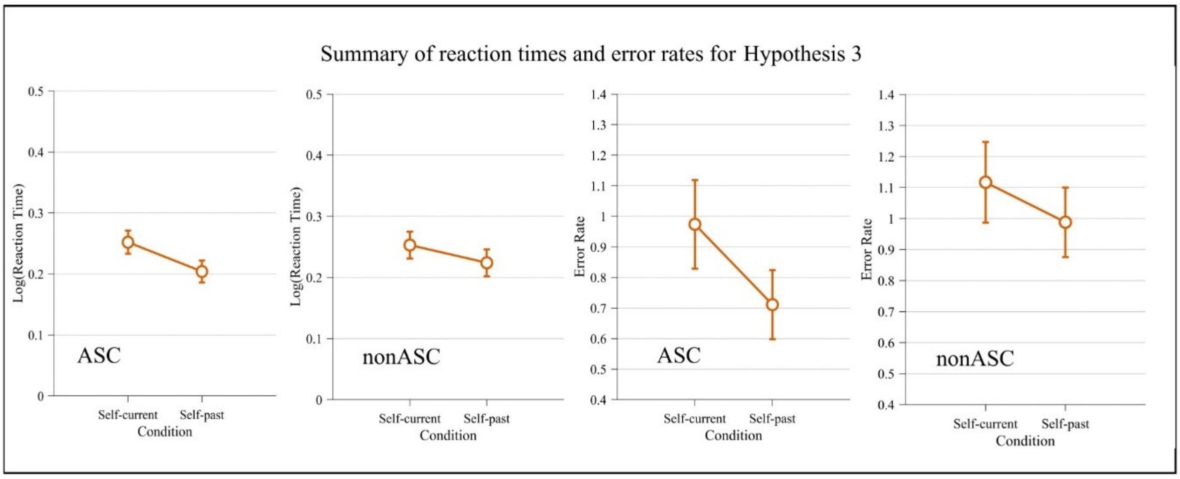


Figure 18. Results for Hypothesis 3, Response times (RTs, measured in seconds; correct responses only) are shown on the left and errors (average number of errors per condition and with a maximum of 12) are shown on the right. Error bars are standard error of mean.

Table 8A, Summary of descriptive statistics for no-swap trials, RTs are seconds and errors are average number of errors.

	No-swap (true belief)							
	0º Angular Disparity				90º Angular Disparity			
	VPT-2	ToM	Self-current	Self-past	VPT-2	ToM	Self-current	Self-past
ASC, RT	178 (*139*)	172 (*167*)	190 (*153*)	158 (*159*)	238 (*167*)	266 (*184*)	235 (*143*)	190 (*172*)
Non-ASC, RT	207 (*178*)	194 (*181*)	196 (*182*)	193 (*234*)	227 (*182*)	250 (*202*)	236 (*185*)	219 (*184*)
ASC, error	.175 (*.504*)	.211 (*.491*)	.158 (*.368*)	.298 (*.886*)	.421 (*.801*)	.509 (*.909*)	1.123 (*1.680*)	.649 (*.954*)
Non-ASC, error	.484 (*.756*)	.609 (*1.177*)	.359 (*.698*)	.578 (*.956*)	.750 (*1.234*)	1.016 (*1.527*)	1.094 (*1.256*)	.734 (*.930*)

Note. M = Mean, SD = Standard Deviation, VPT-2 = Visual Perspective Taking Level 2, ToM = Theory of Mind.

Table 8B, Summary of descriptive statistics for swap trials, RTs are seconds and errors are average number of errors.

	Swap (false belief)							
	0º Angular Disparity				90º Angular Disparity			
	VPT-2	ToM	Self-current	Self-past	VPT-2	ToM	Self-current	Self-past
ASC, RT	261 (*151*)	253 (*160*)	275 (*163*)	221 (*144*)	304 (*173*)	324 (*176*)	309 (*171*)	248 (*152*)
Non-ASC, RT	276 (*193*)	292 (*201*)	265 (*187*)	228 (*178*)	301 (*195*)	319 (*203*)	131 (*193*)	253 (*176*)
ASC, error	.912 (*1.286*)	.895 (*1.332*)	.860 (*1.076*)	.684 (*1.183*)	.877 (*1.001*)	1.649 (*2.057*)	1.754 (*2.115*)	1.211 (*1.645*)
Non-ASC, error	1.156 (*1.556*)	1.391 (*1.399*)	1.078 (*1.418*)	1.422 (*1.531*)	1.516 (*1.764*)	1.766 (*1.950*)	1.938 (*2.069*)	1.238 (*1.653*)

Note. M = Mean, SD = Standard Deviation, VPT-2 = Visual Perspective Taking Level 2, ToM = Theory of Mind.

3.4 Discussion

This study utilised Seeing-Believing Task to assess if ASC reflected a specific difficulty in forming complex social representations, or difficulties in processes common to both ToM and VPT-2. To this end, we compared belief reasoning and VPT-2 performance in groups of autistic and non-autistic adults.

First, it is important to stress that the present findings for the non-ASC group replicate our previous observations very closely (Green, Shaw and Kessler, 2022); they were slower to make TB compared with VPT-2 judgements at 90° angular disparity despite both types of judgment requiring the exact same responses. That is, asking these individuals about another's TB of reality is identical in content to their visuospatial perspective, but different in the psychological processing of this content. We further replicated an additional RT cost for FB judgements relative to TB and VPT-2 judgements. Finally, we replicated a speed and accuracy advantage for Self-past compared with Self-current judgements, emphasising the relevance of the starting stimulus for anchoring any given trial. Since participants are unable to anticipate what type of judgement will be required at the end of a trial, it is safe to assume that the same encoding and updating strategy is applied to all trials. These findings of the present study therefore provide support for our previous conclusion that simple mnemonic explanations of the difference between true belief and perspective processing are unlikely.

A key feature of ASC is the difference in social interaction and communication relative to non-autistic social norms. The ToM hypothesis of ASC suggests that these alterations arise from a domain-specific variation in ToM ability (Rajendran & Mitchell, 2007). On the other hand, these alterations arise from a more general differences in processes common to both ToM and VPT-2 (Denckla, 1996; Pellicano, Maybery, Durkin, & Maley, 2006). Comparing belief reasoning and VPT-2 performance provides a means with which to test the specificity of ToM variations in ASC because both sub-processes of mentalizing require the suppression of one's own egocentric perspective to simultaneously process and control two opposing representations. Arguably, the executive demands in terms of suppression and control can be regarded as similar, while the major remaining difference appears to be social in terms of the complexity of representing another's mind (Green, Shaw and Kessler, 2022). That is, representing another's belief about reality (true or false) may require a more sophisticated representation of the other's mind than merely representing reality from their visuospatial viewpoint. This is supported by research showing that a similar embodied transformation processes is employed when adopting the visual perspective of another person and a viewpoint indicated by an inanimate object (e.g., sitting in an empty chair; Kessler & Thomson, 2010), the latter not necessarily taking another's mind into account. Further, our previous study revealed that differences between TB and perspective judgements were not simply mnemonic in nature (no check back to the initially presented object) but likely to be social (Green, Shaw and Kessler, 2022), a finding that was replicated in the current experiment for both autistic and non-autistic individuals.

In light of these findings, should the differences in social interaction characterising ASC arise from alterations in domain-general executive functioning, we hypothesised the following: (i) belief reasoning and VPT-2 would be impaired equally in adults comprising the ASC group; (ii) any difference between the sub-processes would be similar or smaller in the ASC compared to the non-ASC group; and (iii) the ASC group would show greater overall increased processing difficulty (larger RTs and Errors) compared with the non-ASC group. Conversely, if the social dimension of the ASC phenotype arises from social-specific variations in ToM ability, adults in the ASC group should have exhibited a greater difficulty with TB reasoning than VPT-2 judgements when compared with adults in the non-ASC group on our Seeing-Believing Task. We also considered that any differences between TB reasoning and VPT-2 might be masked by a large increase in cognitive demand in the ASC group (not tied directly to the executive function demands of the judgements themselves), indicated by a strong effect of increasing angular disparity. This alternative was regarded as conceptually closer to an executive function explanation than to a ToM explanation, since a general increase in processing demands - so much so that ceiling performance is reached - would be more likely to reflect domain-general processing deficits.

Comparison of TB reasoning and VPT-2 for the ASC group in isolation (Hypothesis 2) did not reveal any statistically significant differences between VPT-2 and belief reasoning; however, there was a main effect of angular disparity. At first glance, these results neither clearly support a ToM nor an executive functioning interpretation; instead, they seem to best fit Hypothesis 2b, suggesting that any differences between belief reasoning and VPT-2 may have been masked by increased RTs and errors associated with increasing overall effort as indicated by a strong angular disparity effect. Furthermore, this notion is supported by group comparisons, which revealed an interaction between group and angular disparity in RTs where there was a greater difference between 0º and 90º angular disparity in autistic adults compared to non-autistic adults. While the non-ASC group was not generally faster than the ASC group, the latter showed a stronger effect of angular disparity that further supports the notion of generally increased demands.

Interestingly, however, there was a main effect of group in errors, where the ASC group were more accurate than the non-ASC group in both belief reasoning and VPT-2. With no group differences in overall RTs, this effect does not seem to reflect a speed-accuracy trade-off in the ASC group. Still, it should be considered that errors were very low overall in both groups (see Table 2). This pattern may suggest that autistic individuals had not reached ceiling performance after all, raising doubts about our interpretation of Hypothesis 2. In addition, we observed significantly slower RTs for FB compared to TB and VPT-2 judgements in the ASC group, which might further indicate that RTs could slow down further. The final conclusion might therefore be that the overall pattern of results supports an executive functioning interpretation of differences in the ASC group. It is further possible that non-autistic individuals conceive of TB and VPT-2 judgements as being socially different tasks, manifesting as a significant difference (now replicated four times), while those with ASC may not. Autistic individuals might be trying to perform both belief reasoning and VPT-2 in the same way, therefore showing no difference between these judgements, but an overall increased demand for executive functioning resources when the other's viewpoint differs from their egocentric perspective (as reflected by the enhanced angular disparity effect). Thus, somewhat counterintuitively, in addition to supporting a general executive functioning involvement in ASC differences, a lack of differentiation between VPT-2 and TB judgements in our data might also hint at an overall less differentiated mentalizing capacity in ASC. It must be noted, however, that there were no significant group differences in RT between participants with and without autism.

Studies investigating FB reasoning in autistic children have reported that they tend to struggle with these tasks in comparison to typically developing children (e.g., Baron-Cohen et al., 1985; Hamilton et al., 2009). On the other hand, research investigating belief reasoning in autistic adults is less consistent. Previous studies using explicit paradigms typically report no differences in performance (Bowler, 1992; Peterson, Slaughter, & Paynter, 2007). It has been suggested that once individuals develop sufficient verbal abilities, they develop compensatory strategies or rules to cope with such scenarios (Bradford, Hukker, Smith, & Ferguson, 2018; Schneider, Slaughter, Bayliss, & Dux, 2013). The results of our study support this theory, in that the difference between FB judgements (at 90º angular disparity) and the average of TB and VPT-2 judgements (at 90º angular disparity) did not differ between autistic and non-autistic individuals. This suggests that autistic adults did not find explicit belief reasoning judgement any more difficult than their counterparts, supporting the notion that autistic adults have at least some ToM abilities or develop compensatory strategies.

The results of this experiment also support our previous research using this paradigm in the general population (Green, Shaw and Kessler, 2022). Firstly, we again observed that VPT-2 and belief reasoning are at least partially distinct processes in non-autistic individuals, and belief reasoning is the more cognitively demanding of the two. In addition, we replicate our previous finding that Self-current judgements are associated with greater RTs than Self-past judgements for non-autistic individuals (as well as in the ASC group). We interpret this as further evidence that individuals anchor their experience of each trial to the first (Self-past judgement) rather than the second stimulus (Self-current judgement). In addition, we suggested previously that if Self-past judgements are associated with less cognitive effort than Self-current judgements, then it is unlikely that the additional cognitive effort required for TB judgments relative to VPT-2 is due to additional memory processes. Findings from the non-ASC group in the present study support this suggestion. We proposed initially that autistic adults might adopt a different strategy when performing the task, but our results indicated that this was not the case; similar to the performance of non-autistic individuals in the present and previous study, Self-past judgements in autistic adults were associated with less cognitive effort (as evidenced by RTs and/or errors) than Self-current judgements.

It is important to point out that, to the best of our knowledge, this is the first study to investigate genuine VPT-2 in autistic adults, and so it is particularly interesting that we have observed greater RTs with increasing angularity in the ASC relative to the non-ASC group. Previous studies have compared performance on spatial perspective taking (or laterality) paradigms in autistic adults. These studies have not reported any differences (David et al., 2010; Zwickel et al., 2011). We suggest that such tasks require lower-level cognitive processing and can be resolved by visual discrimination alone. In contrast, the task we have developed requires participants to either perform a mental self-rotation, or rotation of the target stimuli (referred to typically as mental object rotation), both of which are arguably more difficult than simple visual discrimination. It is unclear whether autistic adults used embodied self-rotation or object-rotation to complete these tasks (for a discussion see Kessler & Wang, 2012), but previous research has reported that adults reporting high autistic traits struggle with embodied self-rotations (Brunyé et al., 2012; Kessler et al., 2014), yet not with object rotations (Hamilton et al., 2009). Therefore, it follows that autistic adults will find VPT-2 judgements at increasing angular disparities more difficult than non-autistic adults. Our findings also align with several studies reporting differences in VPT-2 between non-autistic and autistic children (Hamilton et al., 2009; Ni et al., 2021; Yirmiya et al., 1994). However, not all studies assessing VPT-2 in autistic children have reported variations (Tan & Harris, 1991), and so further research into VPT-2 performance in autistic adults is necessary to assess whether they demonstrate consistent difficulties with VPT-2.

Unlike many other experiments investigating ASC, the present sample of autistic adults were not recruited through clinical services. We recruited adults with through Prolific (https://www.prolific.co/). Unlike clinical services, Prolific does not diagnose individuals with ASC or require them to provide evidence of a formal diagnosis. Instead, participants self-reported whether they had previously been diagnosed with ASC. We acknowledged that this does leave room for error, therefore we also added inclusion criteria based on participant's AQ scores. All participants in the ASC group scored at least 32 on the AQ – a criterion associated with maximal true-positives (73%) and minimal false-positives (2%; Baron-Cohen et al., 2001). Therefore, it is likely that this sample reflects at least part of the autism spectrum. As outlined above, ASC is a highly heterogeneous condition; autistic individuals exhibit a full range of intellectual abilities, from severe intellectual disability to superior intelligence. The ASC sample in the present study achieved scores on the RPM comparable to the non-ASC group, suggesting the sample is composed primarily of high-functioning individuals. The findings of the present study might not generalise well to lower-functioning autistic individuals. However, the Medical Research Council report that 75% of autistic individuals perform within normal intelligence ranges (MRC, 2001), so these findings may be applicable to a large number of autistic adults.

At first glance, the results of the present study support neither the ToM nor the executive functioning hypothesis of altered social cognition in ASC. The increase in cognitive demand associated with increasing angular disparity was large (larger than in non-autistic adults) and may have masked differences between belief reasoning and VPT-2. However, lower errors in autistic adults overall and an equivalent difference between FB and TB/VPT-2 judgements compared with non-autistic adults raises doubts as to whether the ASC group was performing at ceiling level. An alternative view is one of a less differentiated mentalizing capacity - this would account much better for a lack of difference between TB and perspective judgements alongside generally higher demands on executive functioning in autistic adults in our paradigm. In addition, our findings indicate that autistic adults have more difficulty with VPT-2 than non-autistic adults, but further research is required as this is the only investigation to study VPT-2 in autistic adults. No differences were observed between autistic and non-autistic adults in terms of explicit belief reasoning, converging with most previous research. However, we stress that the majority of the present ASC sample were likely to be high functioning, as evidenced by their numerically higher RPM score than non-autistics adults, so these findings may not generalise to all individuals with ASC. Findings from the non-ASC group replicated those of our previous study (Green, Shaw and Kessler, 2022), suggesting that belief reasoning and VPT-2 are at least partially distinct processes and belief reasoning is the more cognitively demanding of the two. Furthermore, increased cognitive demand associated with belief reasoning compared to VPT-2 is unlikely to be due to additional memory processes, but further research is required to determine the exact social nature of the difference. Future research should also aim to specify this relationship further using multiple groups with ASC stratified by level of functioning.

4. Does lying involve belief reasoning?

4.1 Introduction

Lying and deception are common in everyday life (DePaulo et al., 2003) and may be used for prosocial and antisocial purposes (Ding et al., 2014). Abe (2009) defined *deception* as a psychological process by which an individual deliberately attempts to convince another person to accept as true something that the deceiver knows to be false. In the literature, this same process has also been termed *lying* (e.g., Lee, 2013; Sai, Ding, Gao, & Fu, 2018), and the terms "lying" and "deception" tend to be used interchangeably in the literature. More recently, however, Sobel (2020) proposed that *lying* involves giving information to the receiver that the liar believes to be untrue, regardless of the liar's intent or expected consequences, while *deception* refers to acts performed with the intention of creating a FB in the receiver. The key distinction between lying and deceiving being the liar/deceiver's intention to deceive.

Intentionally deceiving someone has been likened to purposefully creating a FB in the mind of another and therefore FB reasoning is regarded as a prerequisite for deception (Ding et al., 2015; Sodian & Frith, 1992). FB reasoning is the most common index of *Theory of Mind* (ToM), and ToM refers to the ability to represent another's intentions and beliefs (Baron-Cohen et al., 2001). *Belief Reasoning* refers to the representation of beliefs more broadly (disregarding whether these are true or false). ToM is typically assessed using FB tasks (e.g., the object transfer false belief task; Wimmer & Perner, 1983). To pass these tests, participants must understand that someone else's beliefs might not reflect reality as it is known to the participant. It is unclear whether lying requires belief reasoning, as an understanding of the receiver's mind is not strictly necessary when making a statement that is simply untrue, i.e. without the goal to deceive. To understand whether lying involves belief reasoning, we will compare lying and deception. Most research on deception or lying using adults has focused on lie detection, which does not shed light on the potential difference between lying and deception in terms of belief reasoning; therefore, it is more informative to focus on the development of lying and deception in children.

It is generally agreed that children begin to understand FBs between the ages of four and five years (e.g., Hogrefe et al., 1986), but lying/deceptive behaviour has been reported in children as young as 30 months of age (Newton, Reddy, & Bull, 2000). For example, Talwar and Lee (2008) used a temptation resistance task to study deception in children aged three to eight years. Children were instructed not to peek at a toy as part of a game. When the researcher left the room, however, most children broke the rules and peeked at the toy. Upon the researcher's return, the child was asked if they had peeked at the toy and Talwar and Lee reported that 64% of children deceived the researcher by saying they did not peek at the toy. Talwar and Lee (2008) reported that children as young as three years deceived the researcher, but older children deceived the researcher more than younger children did. In light of Sobel's (2020) suggestion, this task should be re-classified as a lying task, rather than a deception task. Evans and Lee (2013) proposed that when younger children (2-3 years) lie, they tend to make statements that are untrue and do not take into account the receiver's mental states. Evans and Lee referred to these as *primary lies*. Evans and Lee (2013) also proposed that slightly older children (4-5 years) tell *secondary lies,* which involves giving false information to a receiver who is unlikely to be aware of the true state of affairs and therefore more susceptible to lies. Secondary lies could be referred to as deception under Sobel's (2020) dichotomy because the child considers whether the receiver is aware of the true state of affairs, thus, implying some level of belief reasoning. According to Evans and Lee (2013), the age range for observing the use of secondary lies/deception appears to coincide with the onset of FB reasoning.

Russell, Mauthner, Sharpe, and Tidswell (1991) used the 'windows task' to study deceptive behaviour in children aged three to four years. In this task, the child competes with the experimenter to win sweets. In each trial, there are two boxes, one of which contains a sweet. The child is asked by the experimenter to point to the box where the experimenter should look for the sweet. If the experimenter looks in the correct box, the experimenter receives the sweet. Alternatively, if the experimenter chooses the incorrect box, then the child receives the sweet. The windows allow the child to see which box the sweet is in. Russell and colleagues (1991) reported that most four year old children chose to deceive the experimenter and told them to look in the incorrect box, whereas three year old children and autistic children did not. This supports that notion the FB understanding is necessary to deceive others. In addition, it has been reported that ToM training, including belief reasoning training, can promote deceptive behaviour in children (Ding et al., 2015). Ding and colleagues recruited two groups of three year old children who could not lie. One group was given ToM-belief reasoning training, whereas the other group was given training on the properties of physical objects. After training, the ToM group began to deceive the experimenter on a 'hide-and-seek task', whereas the other group of children who were trained on the physical properties of objects did not. Ding and colleagues followed-up the children after one month and the ToM training group still exhibited an increased tendency to deceive. Ding and colleagues (2015) interpreted these results as evidence for a causal link between belief reasoning and deception.

Whether there is a link between lying and belief reasoning is less clear. Technically speaking, lying involves making a statement that is untrue and therefore it may only involve consideration of reality and not the receiver's beliefs. To understand whether lying involves consideration of reality *and* beliefs, we have adapted the Seeing-Believing Task (Green, Shaw and Kessler, 2022; see Chapter 2 for more information). The Seeing-Believing Task was originally developed to compare reasoning about beliefs and reality in the context of belief reasoning and visual perspective taking, two ToM abilities. In this task, participants viewed a series of images which depicted a story about a character, Kim, and which object (hare or locomotive) was on the table in front of her. Each trial began with Kim sat a table with one of the two objects on with her back to the participant, so her perspective of the object on the table matched the participant's. Next, Kim left the room and the object was covered with a bucket. In Kim's absence, either the object was swapped (e.g., if it was the hare, then it was swapped for a locomotive), or the object remained the same. The object was covered with a bucket again and Kim returned. Kim either sat in her original seat at 0° angular disparity from the participant or at one of two chairs ±90° from the participants' perspective. Participants were then asked "what will see expect to see [when the bucket is lifted]?" or "what will she actually see [when the bucket is lifted]?". The first questions required participants to reason about Kim's belief, whereas the second probed participants' understanding of Kim's reality. By varying the angular disparity between Kim and the participant, we were able to distinguish between the participant's own egocentric perspective and representation of reality from their representations of another's perspective and their beliefs. Additionally, manipulating angular disparity also serves as a method of increasing the task difficulty, so it appropriately difficult for adults. Our previous study (Chapter 2) revealed that *TB* reasoning was associated consistently with increased RTs compared with VPT-2 judgements, despite their conceptual overlap and identical responses (i.e., correct answers). The aim of this study is the compare lying and deception, which can also be conceptualised as comparing reasoning about reality and beliefs (like Chapter 2), therefore the Seeing-Believing Task will be adapted to compare lying and deception.

Our adaptation of the Seeing-Believing Task to measure lying and deception will be referred to as the Lying-Deception Task. Like in the Seeing-Believing task, we varied whether the character held a TB or FB (whether the object is swapped or not) and the character's angular disparity from the participant (i.e., the chair Kim sits in when returns), conforming to Green and colleagues (2022). However, instead of questions at the end of each trial, participants were instructed to explicitly confirm or disconfirm (deceive) the character's belief or to confirm or disconfirm the state of reality (lie). Note that only the former explicitly referred to the character's belief, while the latter did not, thus, any potential involvement of belief reasoning in the latter would be implicit. A simple example for the former would be to ask a participant to "deceive their [the character's] (true) belief", which would result in deception, whereas to "confirm their [the character'] (true) belief" would result in telling them the truth. In contrast, a simple example for disconfirming the state of reality would be to "tell them [the character] a lie (about the state of reality)" and for confirming the state of reality would be to "tell them [the character] the truth (about the state of reality)". As it is generally accepted that deception involves belief reasoning, which was further reinforced here through an explicit instruction, these conditions are regarded as *explicit belief reasoning* and form a reference point for investigating potentially *implicit belief reasoning* when lying. It is important to note that we can also deceive others by confirming their FBs (i.e., to "confirm their [the character's] (false) belief" results in a lie) or vice versa, tell others the truth by disconfirming (deceiving) their FB (i.e., to "deceive their [the character's] (false) belief" results in telling them the truth). These additional belief conditions provided further data points for comparing explicit and implicit belief reasoning recruitment.

It is generally accepted that belief reasoning is required to deceive someone (e.g., Ding et al., 2015) and here we explicitly asked participants to either confirm or deceive another's belief. If there is no difference between implicit belief reasoning (i.e., lying and truth telling) and explicit belief reasoning conditions (i.e., confirming or deceiving the character's belief), we will interpret this as evidence that lying does require belief reasoning. Conversely, if performance in explicit belief reasoning trials is slower or more error prone than implicit belief reasoning trials, we will take this as evidence that lying is unlikely to require belief reasoning, but is simply conveying untrue facts about reality, instead (e.g. Sobel, 2020). Furthermore, employing this complex design, will also allow us to explore an interaction between *state of reality* (i.e., confirmed or disconfirmed) and belief reasoning (i.e., implicit or explicit). We will focus on four specific comparisons detailed in our hypotheses below (see Table 1 for more details).

4.1.1 Hypotheses

Hypotheses were pre-registered and can be found online (https://osf.io/cqtrk).

Hypothesis 1: Under TB conditions (when the target object is not swapped in Kim's absence), there will be a statistically significant difference between deceiving the character's TB and telling the character a lie – especially at 90° angular disparity, where Kim's perspective is different from the egocentric perspective. Specifically, it is predicted that deceiving the character's TB might be associated with greater RTs (and/or errors) because telling a lie might just require the participant to say the opposite of what is true, whereas deceiving the character's TB requires additional belief reasoning (Sobel, 2020). We expect this effect to be present at 0° (where self (participant) and other (Kim) are aligned), as well as 90° (where self and other (Kim) are *not* aligned), but to be more pronounced at 90° angular disparity. However, if no difference is found (i.e. Bayesian statistics show support for H_0), then telling a lie would appear to involve belief reasoning rather than simplistic reasoning about reality.

Hypothesis 2: Under FB conditions (when the target object is swapped whilst Kim is away), a statistically significant difference is expected between trials where the participant is asked to confirm the participant's FB (deception) and trials where the participant is asked to tell the character a lie – especially at 90° angular disparity. It is expected that confirming the character's FB might still be associated with greater RTs (and/or errors) because telling a lie just requires the participant to convey the opposite of what is true, whereas confirming the character's FB might require additional ToM operation in processing the FB We expect this effect to be present at 0° (where self and other (Kim) are aligned) and 90° angular disparity, but more pronounced at 90°. Again, if no difference is found (i.e. Bayesian statistics show support for H_0), then telling a lie would appear to involve belief reasoning.

Hypothesis 3: Under TB conditions (no swap), there will be a statistically significant difference between confirming the character's TB and telling them the truth, especially at 90° angular disparity. It is predicted that confirming their belief will be associated with greater RTs (and/or Errors) than telling the character the truth about the state of reality because the participant will be required to use belief reasoning, as well as perform a perspective transformation at 90° angular disparity. This would replicate Green, Shaw and Kessler's (2022) dissociation of visual perspective taking (state of reality) from TB judgements (true belief > perspective at 90° angular disparity) in a different task context.

Hypothesis 4: Under FB conditions (swap), a statistically significant difference is expected between trials where the participant is asked to deceive the character's FB and trials where the participant is asked to the tell Kim the truth. The double negative alongside explicit belief reasoning for the former is expected to take longer than merely conveying the state of reality (truth). This condition may therefore serve as a "reality check" for whether the paradigm works as expected.

4.2 Method

4.2.1 Design

The experiment had a 2 (belief reasoning: Explicit, Implicit) x 2 (Reality State: Confirmed, Disconfirmed) x 2 (Belief Type: False Belief [Swap trials], True Belief [No-swap trials]) x 2 (Angular Disparity: 0°, 90°).

Table 9. Shows logically equivalent (i.e., confirming/disconfirming the state of reality) but psychologically (potentially) distinct instructions and associated hypotheses.

Explicit Belief processing Confirm/Deceive Belief:		**Implicit** Belief processing Truth/Lie:		State of Reality	Hypothesis H_1
"Confirm Kim's (TRUE) belief about reality"		"Tell Kim the truth about reality"		**Confirmed**	**explicit** > **implicit**
"Confirm Kim's (FALSE) belief about reality"			"Tell Kim a lie about reality"	**Disconfirmed**	**explicit** > **implicit**
	"Deceive Kim's (TRUE) belief about reality"		"Tell Kim a lie about reality"	**Disconfirmed**	**explicit** > **implicit**
	"Deceive Kim's (FALSE) belief about reality"	"Tell Kim the truth about reality"		**Confirmed**	**explicit** > **implicit**

Note. The character is referred to as Kim.

4.2.2 Materials

4.2.2.1 Lying-Deception Task (modified from Green, Shaw and Kessler's (2022) Seeing-Believing Task)

The Lying-Deception Task was split into four blocks of trials, two Implicit and two Explicit blocks (see Table 9 for definition of Explicit vs Implicit). These two types of blocks are differentiated only by the instructions at the end of each trial. As shown in Figure 19, all trials began with a character, Kim, sitting at a table with either a hare or toy locomotive placed on it. Kim was sitting with their back to the participant, so initially; Kim and participant had identical visual perspectives of the item on the table. There were two empty chairs at the table at ±90º from the avatar. On all trial types, the item on the table was then occluded by a bucket and Kim left the room (i.e., her chair was shown empty). In 50% of trials, the object was then exchanged (i.e., if it was the locomotive initially, then it is exchanged for the rabbit, and vice versa) and in the remaining 50% of trials the object remains the same in Kim's absence. Upon Kim's return, she is unaware if the object has been swapped or not during her absence. At the end of each trial Kim returned to either their previous chair (in front of participant at 0º angular disparity), or to one of the other two chairs at either side of the table, i.e., at ±90º angular disparity. In the Explicit blocks, the participant were given one of two instructions on an equal number of trials:

1. Deceive their belief
2. Confirm their belief

These instructions require the participant to consider which object Kim believes is on the table (under the bucket) and confirm or deceive that belief. Alternatively, in the Implicit blocks, the participant is given one of two instructions on an equal number of trials:

1. Tell them a lie
2. Tell them the truth

These instructions require the participant to consider the object they know is on the table (under the bucket) and use this information to tell Kim the truth or a lie. It should be noted that this tasks aims to probe strategic lying/deceiving ability – when participants are asked to "tell them a lie" or "deceive their belief", the correct answer is the incorrect object in the correct orientation, rather than just any answer other than the correct one. This means that there will only be one correct response when telling a lie. This bears more similarity to real life, wherein one is more likely to try to tell a believable lie rather than anything that is untrue. Once the participant imagined their answer, they then pressed the space bar (conforming to Green, Shaw and Kessler, 2022). Participants then selected their answer from a choice of eight options depicting the hare and locomotive from four distinct orientations (front, left side, right side, back). Participants completed 192 trials split evenly across the four blocks (48 trials per block). The order of Implicit and Explicit blocks were counter-balanced. Participants completed two Implicit blocks followed by two Explicit blocks, or vice versa. Participants also completed eight Implicit and eight Explicit practice trials at the beginning of the respective blocks.

Green, Shaw and Kessler (2022) made a range of adjustments to reduce non-ToM demands, using a single target object (i.e., hare or locomotive), rather than an array, reducing visuo-spatial demands (Hamilton et al., 2009), and the target stimulus was occluded when participants were asked questions about its identity, reducing inhibitory demands (Leslie et al., 2005). Additionally, participants were asked to indicate their answer using a key press to select an image rather than a verbal response, thereby reducing language demands. Language demands cannot be eliminated because the participant must be asked questions to probe their understanding of the trial, but questions were approximately matched on sentence length and word complexity.

4.2.3 Participants

Participants were recruited to the study via Prolific (https://www.prolific.co/), which has been shown to produce high quality data (Jones et al., 2022). Sample size calculations performed with G*Power (Faul et al., 2007) estimated that a sample of 48 participants was required to achieve a small effect size (f = 0.15) with 95% power in a 2x2x2 mixed ANOVA (8 variables across 3 factors). Calculations were computed with correlations of r =. 81 among repeated measures, based on our previous data (Green, Shaw and Kessler, 2022). All participants (n = 46; females = 27) were aged between 18 and 40 years (mean [M] = 26.578, standard deviation [SD] = 5.619) and fluent in written and spoken English. A total of 79 participants were recruited (33 participants were removed due to low accuracy on the Lying-Deception Task) to obtain 46 datasets with a minimum of three out of twelve correct responses for each trial type on the Lying-Deception Task.

4.2.4 Procedure

This experimental procedure was conducted entirely online. First, participants were directed to Qualtrics (https://www.qualtrics.com/uk/) to the participant information sheet and consent form. After providing consent, participants were given instructions and then directed back to Pavlovia to complete the Lying-Deception task implemented in PsychoPy (Peirce, 2007). Finally, participants read a debrief form on Qualtrics. Participants were compensated with £6.50 via Prolific. Aston University's Research Ethics Committee approved the experiment.

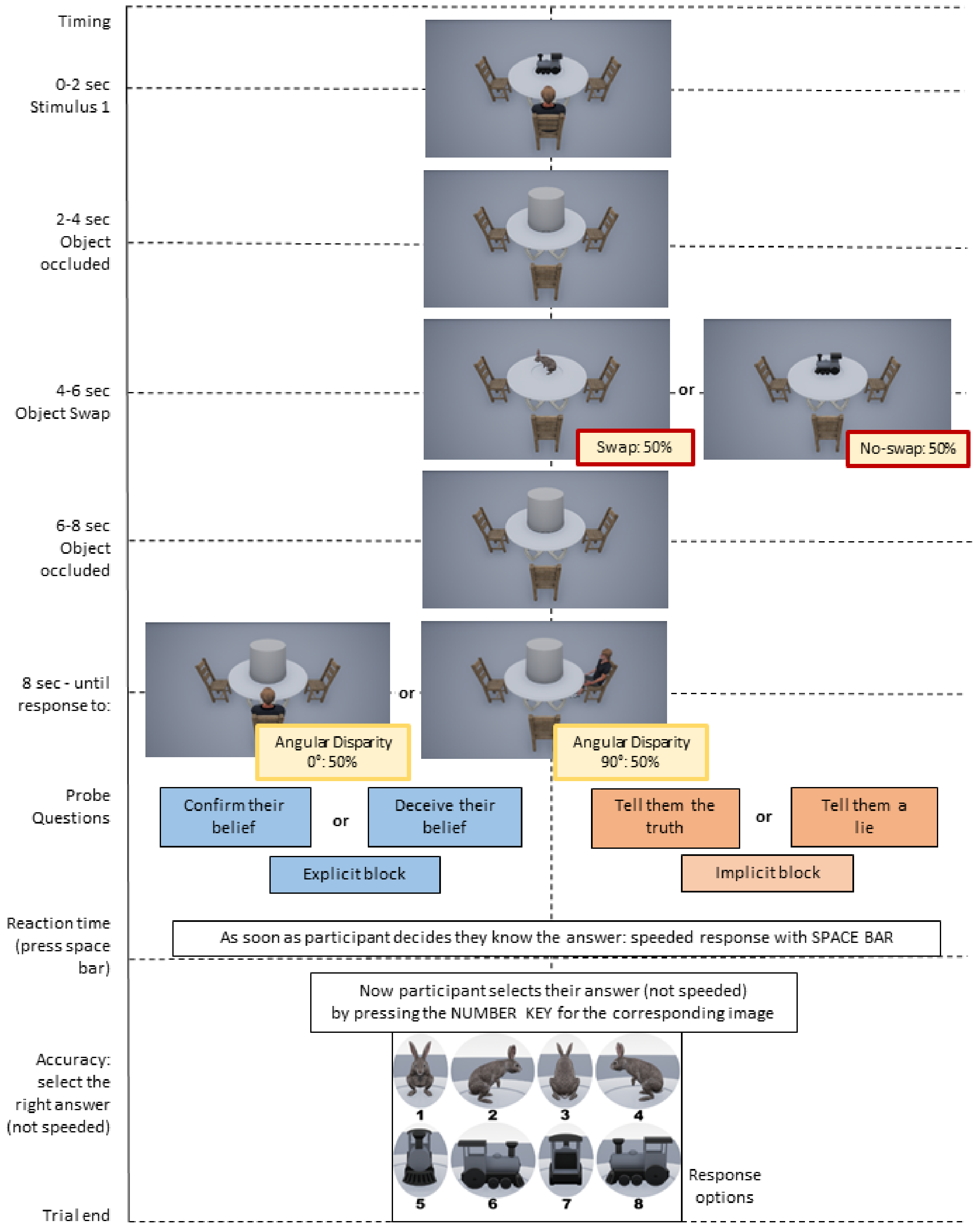


Figure 19. Trial schematic for Lying-Deception Task

4.2.5 Statistical Analysis

Custom MATLAB (r2019a) code was used to calculate condition averages and remove outliers, and JASP (Version 0.14.1) was used to perform inferential statistics. Planned analyses and predicted results can be found in the pre-registration (https://osf.io/cqtrk). Outlier trials were defined as two SDs beyond each participant's condition mean. All participants included in statistical analyses answered at least 3/12 trials of each type correctly in line with Green, Shaw and Kessler, (2022). Incorrect trials were not included in mean RT calculations, and ERs were analysed separately to RTs. Hypotheses were evaluated using within-subjects and mixed-model analysis of variances (ANOVAs), with paired- and independent-samples *t*-tests for planned comparisons.

4.3 Results

4.3.1 Full design

The Lying-Deceiving Task (based on the Seeing-Believing Task by Green, Shaw and Kessler, 2022) had a multifactor repeated-measures design: 2 (Belief Reasoning: Explicit, Implicit) x 2 (Reality State: Confirmed, Disconfirmed) x 2 (Belief Type: FB [Swap trials], TB [No-swap trials]) x 2 (Angular Disparity: 0°, 90°). In the first instance, this was examined with a full-design, four-way repeated-measures ANOVA and subsequently refined based on the four pre-registered Hypotheses. Analysis of RTs revealed statistically significant main effects of Belief Reasoning ($F(1,45) = 13.667$, $p < .001$, $n_p^2 = .223$), State of Reality ($F(1,45) = 36.222$, $p < .001$, $n_p^2 = .446$), Belief Type ($F(1,45) = 24.430$, $p < .001$, $n_p^2 = .352$) and Angular Disparity ($F(1,45) = 35.032$, $p < .001$, $n_p^2 = .438$), and a significant Belief Reasoning x Belief Type interaction ($F(1,45) = 5.530$, $p = .023$, $n_p^2 = .109$). No other interactions were significant: Belief Reasoning x State of Reality ($F(1,45) = 1.809$, p = .185, $n_p^2 = .039$), State of Reality x Belief Type ($F(1,45) = .011$, $p = .918$, $n_p^2 < .001$), Belief Reasoning x Angular Disparity ($F(1,45) =1.156$, $p = .288$, $n_p^2 = .025$), Belief Type x Angular Disparity ($F(1,45) = .076$, $p = .784$, $n_p^2 = .002$), State of Reality x Angular Disparity ($F(1,45) = 3.189$, $p = .081$, $n_p^2 = .066$), Belief Reasoning x State of Reality x Belief Type ($F(1,45) = .978$, $p = .328$, $n_p^2 = .021$), Belief Reasoning x State of Reality x Angular Disparity ($F(1,45) < .001$, $p = .983$, $n_p^2 < .001$), Belief Reasoning x Belief Type x Angular Disparity ($F(1,45) = 1.081$, $p = .304$, $n_p^2 = .023$), State of Reality x Belief Type x Angular Disparity ($F(1,45) = .444$, $p = .509$, $n_p^2 = .010$), and Belief Reasoning x State of Reality x Belief Type x Angular Disparity ($F(1,45) = .009$, $p = .925$, $n_p^2 < .001$).

Analysis of errors revealed statistically significant main effects of Belief Reasoning ($F(1,45) = 10.716$, $p = .002$, $n_p^2 = .192$), State of Reality ($F(1,45) = 16.501$, $p < .001$, $n_p^2 = .268$), Belief Type ($F(1,45) = 10.287$, $p = .002$, $n_p^2 = .186$) and Angular Disparity ($F(1,45) = 18.362$, $p < .001$, $n_p^2 = .290$). Significant interactions of Belief Reasoning x Belief Type ($F(1,45) = 5.530$, $p = .023$, $n_p^2 = .109$), State of Reality x Angular Disparity ($F(1,45) = 4.558$, $p =.038$, $n_p^2 = .092$), State of Reality x Belief Type x Angular Disparity ($F(1,45) = 5.624$, $p = .022$, $n_p^2 = .111$) were also observed. The Belief Reasoning x Angular Disparity interaction was not statistically significant ($F(1,45) = 3.031$, $p =.089$), nor were the interactions between Belief Reasoning x State of Reality ($F(1,45) = .420$, $p = .520$, $n_p^2 = .009$), State of Reality x Belief Type ($F(1,45) = 1.566$, $p =.217$, $n_p^2 = .034$), Belief Type x Angular Disparity ($F(1,45) = 2.429$, $p = .126$, $n_p^2 = .051$), Belief Reasoning x State of Reality x Belief Type ($F(1,45) = 1.373$, $p = .247$, $n_p^2 = .030$), Belief Reasoning x State of Reality x Angular Disparity ($F(1,45) = 1.602$, $p = .212$, $n_p^2 = .034$), Belief Reasoning x Belief Type x Angular Disparity ($F(1,45) = .053$, $p = .819$, $n_p^2 = .001$) and Belief Reasoning x State of Reality x Belief Type x Angular Disparity ($F(1,45) = 2.579$, $p = .115$, $n_p^2 =. 054$) interactions did not reach significance. See Table 10A and 10B for directionality of reported effects.

Table 10A. Summary of Descriptive Statistics for Explicit conditions, RTs given in milliseconds and errors refers to average number of errors, M (*SD*)

	Confirmed				Disconfirmed			
	TB		FB		TB		FB	
	0 Degrees	90 Degrees	0 Degrees	90 Degrees	0 Degrees	90 Degrees	0 Degrees	90 Degrees
RT	1286 (*412*)	1485 (*582*)	1654 (*577*)	1992 (*778*)	1551 (*629*)	1912 (*931*)	2027 (*1191*)	2450 (*1331*)
Errors	.391 (*.469*)	.587 (*.832*)	1.065 (*1.555*)	1.522 (*1.773*)	.935 (*1.451*)	1.587 (*1.950*)	1.283 (*1.655*)	2.042 (*2.139*)

M = Mean, SD = standard deviation, VPT-2 = visual perspective taking level 2, ToM = Theory of Mind.

Table 10B. Summary of Descriptive Statistics for Implicit conditions

	Confirmed				Disconfirmed			
	TB		FB		TB		FB	
	0 Degrees	90 Degrees	0 Degrees	90 Degrees	0 Degrees	90 Degrees	0 Degrees	90 Degrees
RT	1194 (*330*)	1377 (*480*)	1352 (*430*)	1525 (*615*)	1408 (*550*)	1764 (*1683*)	1530 (*649*)	1772 (*803*)
Errors	.457 (*.751*)	.391 (*.802*)	.261 (*.535*)	.804 (*1.128*)	.609 (*1.358*)	1.109 (*1.853*)	.891 (*1.552*)	1.043 (*1.490*)

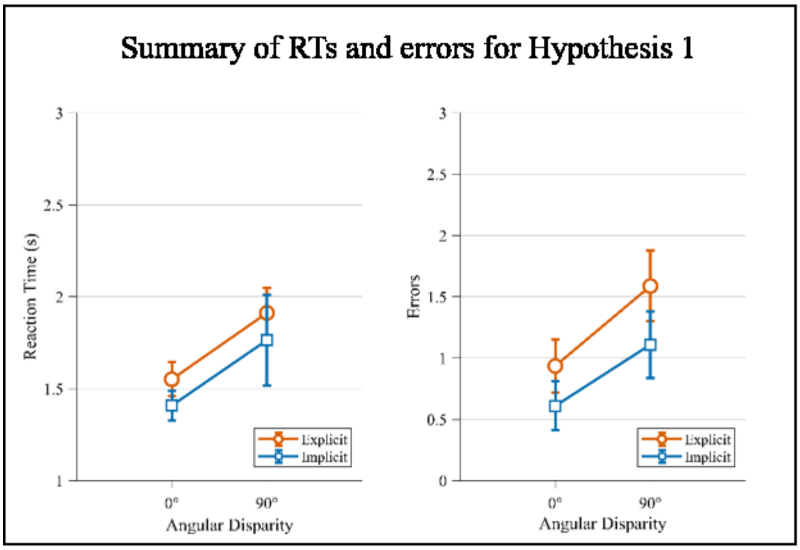
M = Mean, SD = standard deviation, VPT-2 = visual perspective taking level 2, ToM = Theory of Mind.

4.3.2 Hypothesis 1

Hypothesis 1 was evaluated by performing a 2x2 repeated-measures ANOVA, with the factors Belief Reasoning (Explicit, Implicit) and Angular Disparity (0°, 90°) on trials where Kim holds a TB (No swap) and the participant is asked to deceive Kim's true belief/disconfirm reality (with "deceive their [true] belief" or "tell them a lie" instructions). Analysis of RTs revealed a statistically significant main effect of Angular Disparity ($F(1,45) = 9.416$, $p = .004$, $n_p^2 = .173$), but no significant main effect of

Belief Reasoning (F(1,45) = 1.060, p = .309, n_p^2 = .023), or Belief Reasoning x Angular Disparity interaction (F(1,45) < .001, p = . 982, n_p^2 < .001). As a final test of difference, paired-samples t-tests were performed at 0° and 90° angular disparity to compare implicit and explicit instructions. The t-test performed at 0° was not statistically significant (t(45) = 1.858, p = .070, d = .274; BF_{10}= .776, weak evidence for H_0), nor was the test performed at 90° (t(45) = .567, p = .573, d = .084; BF_{10}= .186, strong to moderate evidence for H_0). Similarly, analysis of errors revealed a statistically significant main effect of Angular Disparity (F(1,45) = 15.799, p < .001, n_p^2 = .260), but the main effect of Belief Reasoning was not statistically significant (F(1,45) = 2.693, p = .108, n_p^2 = .056), nor was the Belief Reasoning x Angular Disparity interaction (F(1,45) = .348, p = .558, n_p^2 = .008). Trials in which Kim sat at a 90º angular disparity from the participant's perspective were associated with greater RTs and errors than trials where there was no perspective difference between Kim and the participant; however, there was no difference between trials where the participant was asked to "tell [Kim] a lie" or "deceive [Kim's] belief". As for RTs, paired-samples t-tests were performed at 0° and 90° angular disparity to compare implicit and explicit instructions as a final test of difference. These tests did not reach significance (0°: t(45) = 1.281, p = .207, d = .189; BF_{10}= .344, moderate to weak evidence for H_0; 90°: t(45) = 1.606, p = .115, d = .237; BF_{10}= .526, weak evidence for H_0).

Figure 20. Results for Hypothesis 1, Response times (RTs, measured in seconds; correct responses only)

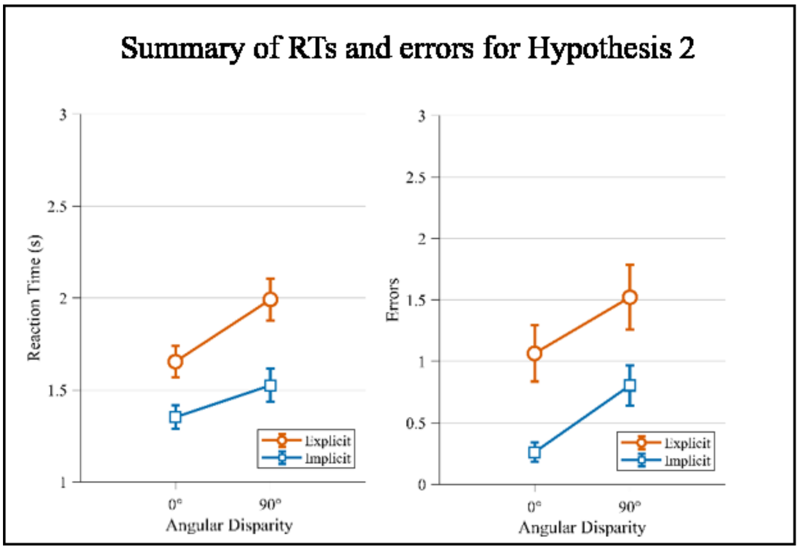


are shown on the left and errors (average number of errors per condition and with a maximum of 12) are shown on the right. Error bars are standard error of mean.

4.3.3 Hypothesis 2

Hypothesis 2 was evaluated by performing a 2x2 repeated-measures ANOVA with factors Belief Reasoning (Explicit, Implicit) and Angular Disparity (0º,90º) on trials where Kim holds a FB (Object swap), and the participant is asked to confirm Kim's false belief/disconfirm reality (with "confirm their [false] belief" or "tell them a lie" instructions). Analysis of RTs revealed a significant main effect of Belief Reasoning ($F(1,45) = 27.749$, $p < .001$, $n_p^2 = .381$) and Angular Disparity ($F(1,45) = 29.276$, $p < .001$, $n_p^2 = .394$), however the interaction between Belief Reasoning x Angular Disparity interaction was not statistically significant ($F(1,45) = 3.622$, $p = .063$, $n_p^2 = .074$). Analysis of errors revealed a significant main effects of Belief Reasoning ($F(1,45) = 12.974$, $p < .001$, $n_p^2 = .224$) and Angular Disparity ($F(1,45) = 16.967$, $p < .001$, $n_p^2 = .274$), and Belief Reasoning ($F(1,45) = 1.354$, $p = .251$, $n_p^2 = .029$), but not a Belief Reasoning x Angular Disparity interaction ($F(1,45) = .106$, $p = .746$, $n_p^2 = .002$). Trials in which Kim sat at a 90º angular disparity from the participant's perspective were associated with greater RTs and errors than trials where there was no perspective difference between Kim and the participant and trials were belief reasoning was explicit were associated with greater RTs and errors than trials were belief reasoning was implicit.

Figure 21. Results for Hypothesis 2, Response times (RTs, measured in seconds; correct responses only)

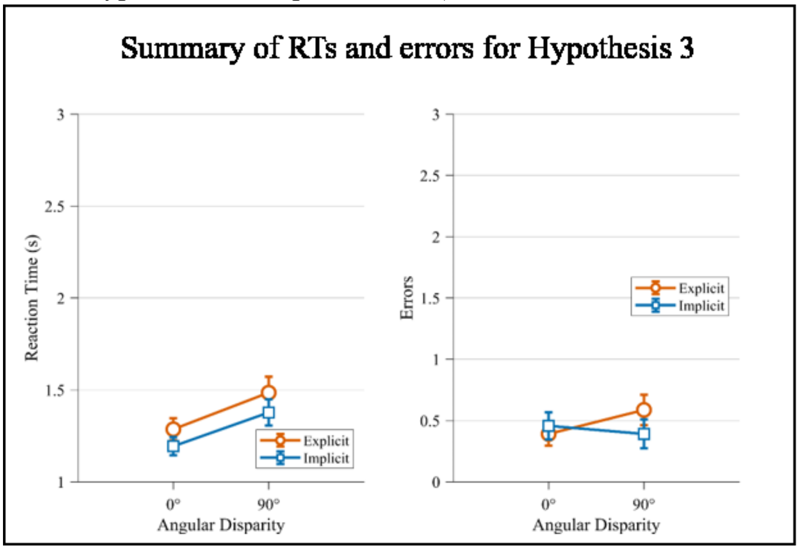


are shown on the left and errors (average number of errors per condition and with a maximum of 12) are shown on the right. Error bars are standard error of mean.

4.3.4 Hypothesis 3

Hypothesis 3 was evaluated by performing a 2x2 repeated-measures ANOVA with factors Belief Reasoning (Explicit, Implicit) and Angular Disparity (0º, 90º) on trials where Kim holds a TB (No object Swap), and the participant is asked to confirm Kim's true belief/confirm reality (with "confirm their [true] belief" or "tell them the truth" instructions). Analysis of RTs revealed significant main effects of Belief Reasoning ($F(1,45) = 5.410$, $p = .025$, $n_p^2 = .107$) and Angular Disparity($F(1,45) = 27.469$, $p < .001$, $n_p^2 = .379$), but no significant Belief Reasoning x Angular Disparity interaction ($F(1,45) = .150$, $p = .700$, $n_p^2 = .003$). Trials where Kim sat at a 90º angular disparity from the participant's perspective were associated with greater RTs than trials where there was no perspective difference between Kim and the participant. In addition, explicit trials ("confirm their belief" instructions) were associated with greater RTs than implicit trials ("tell them the truth" instructions). Conversely, analysis of errors revealed no significant main effects of Angular Disparity ($F(1,45) = .395$, $p = .533$, $n_p^2 = .009$) or Belief Reasoning ($F(1,45) = .335$, $p = .566$, $n_p^2 = .007$), nor a significant Belief Reasoning x Angular Disparity interaction ($F(1,45) = 2.107$, $p = .154$, $n_p^2 = .045$). Trials where Kim sat at a 90° angular disparity from the participant's perspective were associated with greater RTs than trials where there was no perspective difference between Kim and the participant. RTs were significantly faster for implicit belief reasoning trials, as compared to explicit belief reasoning trials. This difference was not mirrored in error data.

Figure 22. Results for Hypothesis 3, Response times (RTs, measured in seconds; correct responses only)



are shown on the left and errors (average number of errors per condition and with a maximum of 12) are shown on the right. Error bars are standard error of mean.

4.3.5 Hypothesis 4

Hypothesis 4 was examined by performing a 2x2 repeated-measures ANOVA with factors Belief Reasoning (Explicit, Implicit) and Angular Disparity (0° ,90°) on trials where Kim holds a FB (Object Swap), and the participant is asked to deceive Kim's false belief/confirm reality (with "deceive their [false] belief" or "tell them the truth" instructions). Analysis of RTs revealed significant main effects of Belief Reasoning ($F(1,45) = 13.949$, $p < .001$, $n_p^2 = .237$) and Angular Disparity ($F(1,45) = 17.515$, $p < .001$, $n_p^2 = .280$), but not Belief Reasoning x Angular Disparity interaction ($F(1,45) = 1.729$, $p = .195$, $n_p^2 = .037$). Similarly, analysis of errors revealed significant main effects of Belief Reasoning ($F(1,45) = 5.589$, $p = .022$, $n_p^2 = .110$), Angular Disparity ($F(1,45) = 8.643$, $p = .005$, $n_p^2 = .161$) and a Belief Reasoning x Angular Disparity interaction ($F(1,45) = 5.014$, $p = .030$, $n_p^2 = .100$). Trials in which Kim sat at a 90° angular disparity from the participant's perspective were associated with greater RTs and errors than trials where there was no perspective difference between Kim and the participant and trials were belief reasoning was explicit were associated with greater RTs and errors than trials were belief reasoning was implicit. Increasing angular disparity from 0° to 90° was associated with a greater increase in RTs and errors in explicit conditions compared to implicit conditions.

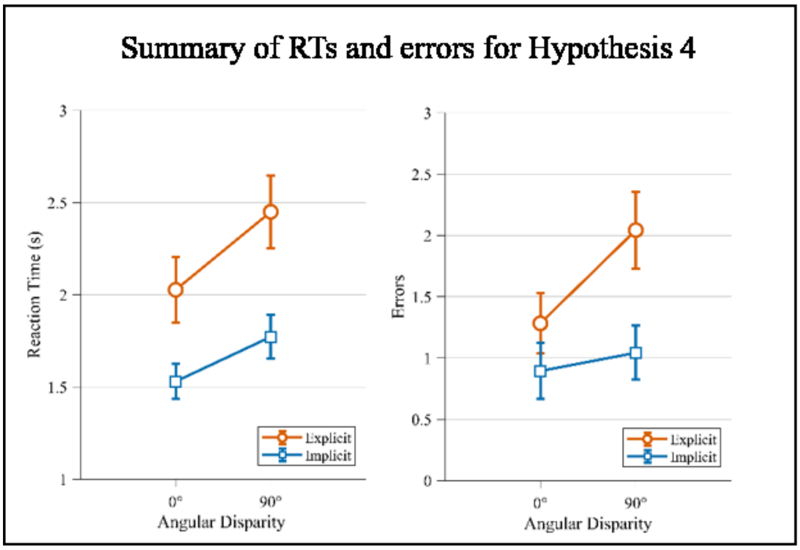


Figure 23. Results for Hypothesis 4, Response times (RTs, measured in seconds; correct responses only) are shown on the left and errors (average number of errors per condition and with a maximum of 12) are shown on the right. Error bars are standard error of mean.

4.3 Discussion

In this study, we developed a novel *Lying-Deception Task* to compare lying and deception to explore whether lying involves belief reasoning. Sobel (2020) proposed that *lying* refers to giving information to the receiver that the liar believes to be untrue, regardless of the liar's intent or expected consequences. Alternatively, *deception* refers to acts performed with the intention of creating a FB in the receiver. The key distinction between lying and deception being whether liar or deceiver reasons about the receiver's mental state (i.e., belief reasoning). Given the causal link between belief reasoning and deception (Ding et al., 2015), it thought that deception involves belief reasoning. It is not clear whether lying involves belief reasoning, however, as understanding of the receiver's mind is not strictly necessary when making a statement that is untrue. The Lying-Deception Task was developed to compare lying and deception without the complication of between-task differences. The Lying-Deception Task involved manipulation of a character's (Kim's) Belief Type (i.e., True of False) and the Angular Disparity between the participant and the character (0° or 90°), as well as the type of Belief Reasoning (i.e., Implicit or Explicit) and State of Reality (i.e., instruction to Confirm or Disconfirm Kim's belief/reality). This complex design created a series of logically equivalent scenarios (i.e., had the same correct answer) allowing exploration of the interaction between belief processing and state of reality.

Hypothesis 1 focused on the comparison of deceiving Kim's TB and telling Kim a lie (Disconfirm TB and Reality). This revealed no difference in RTs or errors at 0° or 90° angular disparity. Follow-up frequentist and Bayesian statistics were performed, which did not reach significance and provided varying degrees of evidence for the null hypothesis. This suggests that there is no difference between lying and deception and these findings do not support Sobel's (2020) distinction between lying and deception. Instead, the results suggest that participants were reasoning about the character's belief regardless of whether belief reasoning was implicit or explicit. It is possible that under some circumstances participants will choose to use belief reasoning when lying to someone even if it is not strictly necessary.

However, an alternative explanation is conceivable. Apperly and Butterfill (2009; Butterfill and Apperly, 2013) proposed a two-system approach to ToM, where standard belief reasoning tasks can also be resolved using efficient but constrained minimal ToM, instead of flexible but more costly full-blown ToM. If deceiving a TB does not engage full-blown ToM but only minimal ToM, then RTs and errors could indeed be comparable to lying. However, using a very similar paradigm, Green and colleagues (2022) demonstrated reliably that TB processing engaged higher cognitive costs than level-2 perspective taking (VPT-2), suggesting that while VPT-2 only engaged minimal ToM, TB required full-blown ToM (see also Hypothesis 3). This speaks against the alternative explanation that deceiving a TB might have only recruited minimal ToM in the current experiment. One factor that may have affected the Lying-Deception Task's ability to detect a difference between implicit and explicit belief reasoning is the way TBs and FBs were manipulated. In TB trials, participants only viewed one of the two objects (i.e., hare or locomotive), but when telling the character a strategic lie, they had to select the other object. Thinking about the object that had not seen in that trial may have incurred an additional time cost. This is in comparison to FB trials where they see both objects as one is swapped for the other. In Hypothesis 3, the character also held a FB, but the participant was asked to confirm the character's belief or tell them the truth, so they did not need to think about the alternative object. One way to examine this would be to create another iteration of the Lying-Deception Task where the object is always swapped and whether the character witnesses the object swap is manipulated, like in Chapter 2 Experiment 3. This would ensure that the participant sees both objects in all trials and would allow us to ascertain if only seeing one of the two objects affect the Lying-Deception Task's ability to detect a difference between lying and deception.

Hypothesis 2 compared confirming a FB and telling Kim a lie (Confirm FB, Disconfirm Reality) and revealed significant differences in RTs and errors, where confirming a false belief (explicit belief reasoning) was associated with greater RTs and errors than lying (implicit belief reasoning). This suggests that lying does not require belief reasoning to the same extent as a deception that was induced by confirming a FB and therefore supports Sobel's (2020) philosophical argument for a distinction between deception and lying, as well as Evans and Lee's (2013) account of the development of lying and deceptive behaviour in young children. Previous studies have reported that FBs are associated with greater RTs and errors than TBs (e.g., Green, Shaw & Kessler, 2022; Apperly et al., 2008), so it follows that additional demands associated with FB reasoning could explain the presence of a difference in Hypothesis 2, but not Hypothesis 1. With this is mind, confirming a FB was compared with deceiving a TB at 0° and 90° angular disparity. These paired samples *t*-tests did not reach significance for RTs (0°: $t(45) = 1.572$, $p = .123$, $d = .232$; 90°: $t(45) = .868$, $p = .390$, $d = .128$) or errors (0°: $t(45) = .539$, $p = .593$, $d = .079$; 90°: $t(45) = .215$, $p = .831$, $d = .032$). This suggests that it is not as simple as there just being an extra processing cost associated with processing FBs compared to TB. These findings suggest it is likely there are other factors at play too, such as only seeing one of the two objects in FB trials, but not TB trials as mentioned previously.

Hypothesis 3 compared confirming Kim's TB and telling her the truth (Confirm TB and Reality), which revealed differences in RTs, where confirming Kim's TB (explicit belief reasoning) was associated with greater RTs than telling her the truth (implicit belief reasoning). This suggests that belief reasoning is not required to the same extent in truth telling as it is in belief confirming. In some ways, these findings mirror those of Green, Shaw and Kessler (2022) in showing that it is more demanding (increased RTs and/or errors) to reason about another's beliefs than it is to reason about a shared reality. Confirming Kim's TB in this investigation is comparable to calculating Kim's TB in Green, Shaw and Kessler's (2022) Seeing-Believing Task and telling Kim the truth in this investigation is comparable to calculating Kim's visual perspective in Green, Shaw and Kessler's (2022) Seeing-Believing experiment. It is possible that reasoning about another's (true) belief requires one to manipulate complex social representations, which are more demanding than manipulating components of reality. This further corroborates our conclusion above (Hypothesis 1) that deceiving a TB in this experiment engaged what Apperly and Butterfill conceived of as full-blown ToM.

Finally, Hypothesis 4 compared deceiving Kim's FB and telling her the truth (Disconfirm FB, Confirm Reality) and revealed a difference in RTs where confirming Kim's FB (explicit belief reasoning) was associated with greater RTs and errors than telling her the truth (implicit belief reasoning). Like Hypothesis 3, this suggests that it is more demanding to reason about another's beliefs than it is to reason about a shared reality. Deceiving a FB involves a double negative and it is possible that some of the additional processing associated with deceiving a FB compared to telling the truth reflects decoding this instruction. This is supported by the fact that average RTs are numerically the slowest of the conditions and errors were not greater than those reported in other conditions.

Together, these results suggest that a distinction between explicit and implicit belief reasoning can be demonstrated in some contexts, but perhaps not others. Explicit belief reasoning was associated with greater RTs than implicit belief reasoning for Hypotheses 2-4, which supports the suggestion that belief reasoning is not strictly necessary when telling a lie. On the other hand, the lack of difference reported for Hypothesis 1 suggests that in some instances people may opt to employ belief reasoning when lying, although it also possible this can be explained by the characteristic of the task. From these data, it is not clear why a distinction between lying and deception was reported for Hypothesis 2, but not for Hypothesis 1. It is possible that something about the scenario investigated in Hypothesis 1 that encouraged participants to recruit *more* belief reasoning processes during lying despite it not being strictly necessary. Alternatively, the fact the participants viewed both objects in FB trials, but not TB trials may have affected results, but further experimentation is required to clarify this.

It has been proposed that ToM and therefore belief reasoning is comprised of two distinct processes, an efficient process and a flexible process (Apperly & Butterfill, 2009). The efficient process tracks simple relations between agents and objects, whereas the flexible process tracks and manipulates more complex propositional attitudes, therefore the efficient process is regarded as fast and automatic, whereas the flexible process is slow and effortful (Edwards & Low, 2019). In this investigation belief reasoning and particularly deception in form of confirming a FB appears to have recruited the flexible process, rather than the efficient one. However, as argued above, Green and colleagues' (2022) findings warrant the conclusion that full-blown ToM was also employed for deceiving a TB. It is therefore conceivable that lying recruits costly full-blown ToM in some cases whereas in other cases it may fall back on efficient but minimal ToM. As of yet it remains unclear what conditions may trigger the strategic use of flexible or more efficient ToM processing.

We acknowledge that the Lying-Deception Task presents a very specific scenario and therefore these results may not generalise to other lying or deception tasks. The current findings suggest that individuals may choose to recruit more/less belief reasoning processes when lying/deceiving under some circumstances, however given the limited number of scenarios investigated here; it is not clear what it is about disconfirming Kim's TB that altered participant's belief reasoning inclination. To understand this process, future research should create an iteration of the Lying-Deception Task where the object is always swapped, so that this factor does not differ between TB and FB trials. Additionally, this is the first study to compare lying and deception, therefore we should seek to replicate the findings presented here. It is also recognised that experimental tasks, such as the Lying-Deception Task, are limited in their generalisability to real life scenarios. For example, it is unlikely or uncommon that one would be instructed to lie or deceive by another. In addition, people are likely to choose to lie or deceive to gain a reward or avoid punishment, whereas in this experiment, there are no benefits for lying. With these factors in mind, these findings should be generalised to real-life behaviour with extreme caution. Future research, could investigate the difference between lying and deception using a more realistic scenarios.

4.3.1 Conclusion

The novel Lying-Deception Task was used to compare lying and deception in adults with the aim of exploring whether lying involves belief reasoning. In three of the four hypotheses, explicit belief reasoning was associated with greater RTs than implicit belief reasoning. In one hypothesis, however, there was no difference between implicit and explicit belief reasoning. This suggests that there may be factors that affect individual's inclination to perform belief reasoning, or characteristics of the task may have incurred additional processing in some trial types, but not others. Together, these indicate that reasoning about beliefs (i.e., deception) may be more complex than reasoning about reality (i.e., lying). Future research should explore whether viewing both objects in every trial affects performance and to explore potential factors that may affect individual's inclination to perform belief reasoning. Given the specific nature of this task, future research could also compare lying and deception using a broader range of tasks, including tasks that might better mirror the demands of real life social interactions.

5. General Discussion

The aim of this thesis was to investigate the social cognitive processes involved in inferring another's mental state, whether that be their belief or their visual perspective, and how this information is used in lying and deception. VPT-2 and belief reasoning are methods of inferring another's belief or visual perspective and a relationship between these processes has been postulated for some time (e.g., Hamilton et al., 2009). To examine the differences between VPT-2 and belief reasoning, a novel Seeing-Believing Task was developed to directly compare true belief (TB) reasoning and VPT-2. The possibility that differences in the relationship between VPT-2 and belief reasoning could distinguish between autistic and non-autistic adults was explored, as well as whether there are variations in VPT-2 performance in autistic adults. To deceive another, one must consider their mental state, but it is unclear whether one must take into account another's mental state to lie them. A novel Lying-Deception Task, based on the Seeing-Believing Task, was used to compare lying and deception to assess whether belief reasoning is involved in lying.

In this general discussion, the wider theoretical and methodological implications of the findings presented in this thesis will be discussed. Limitations and future directions will be highlighted before ending with a Conclusion. First, however, the rationale and core findings of each Chapter will be summarised briefly.

5.1 Chapter summaries

Chapter 2. VPT-2 and belief reasoning are conceptually similar processes; calculating another's visual perspective or belief, involves inhibiting your own mental state in favour of representing another's. The Seeing-Believing Task was developed to measure VPT-2 and belief reasoning without the complication of between-task differences. Chapter 2 consisted of a series of three behavioural experiments, which aimed to compare VPT-2 and belief reasoning. In contrast to many belief reasoning studies, the key comparison in this investigation was between VPT-2 and TB reasoning, rather than false-belief (FB) reasoning, like most studies. TB reasoning reflects reality, like VPT-2, and therefore represents a fairer comparison between VPT-2 and belief reasoning. Experiment 1 revealed a difference between TB reasoning and VPT-2, whereby TB reasoning judgements were associated with greater RTs than VPT-2 judgements and this was replicated in Experiments 2 and 3. Experiment 2 provided further insight into the nature of the additional processing requirements for TB compared to VPT-2 judgements by including two self-related judgements, Self-current and Self-past. Self-current judgements were associated with greater RTs than Self-past judgments ruling out the notion that an additional memory check was responsible for the greater RTs associated with TB reasoning compared to VPT-2 judgements. Experiment 3 also replicated the additional cost of TB reasoning compared to VPT-2 despite changing the method of belief (i.e., true of false) manipulation. Together, these findings highlight a distinction between VPT-2 and TB reasoning, as well as suggesting that TB reasoning involves more complex social representations than VPT-2.

Chapter 3. Variations in social cognition have been reported in autistic adults; however, few ToM studies have reported differences between autistic adults and non-autistic adults. The possibility that variations in the relationship between belief reasoning and VPT-2 could detect subtle differences between autistic adults and non-autistic adults was considered. The second iteration of the Seeing-Believing Task, also used in Chapter 2 Experiment 2, was administered to groups of autistic adults and non-autistic adults. As in Chapter 2, TB reasoning judgements were associated with greater RTs than VPT-2 judgments in non-autistic adults, but not autistic adults. In addition, Self-current judgements were associated with greater RTs than Self-past judgements, supporting the suggestion that TB reasoning is more demanding because it involves more complex social representations than VPT-2, rather than because it involves an extra memory check. Autistic adults, on the other hand, were more affected by a difference in visual perspective between themselves and the character than non-autistic adults. The possibility that the additional cost of calculating the character's visual perspective may have masked differences in the relationship between VPT-2 and belief reasoning was considered. The data did not clearly support any of our pre-defined hypotheses; instead, they mostly supported the notion that the variations in social cognition reported in ASC are a result of variations in executive functioning.

Chapter 4. The previous two chapters investigated how we understand each other's mental states, whereas this final empirical chapter aimed to go further and explore how we use this information in two specific types of social interaction, lying and deception. It is unclear whether lying involves belief reasoning because an understanding of the receiver's beliefs is not strictly necessary to lie to someone. To explore whether lying involves belief reasoning, the Seeing-Believing Task used in the previous chapters was adapted to compare lying and deception and is referred to as the Lying-Deception task. A difference between lying and deception was reported in one instance, but not another suggesting a complex relationship between lying and deception. In addition to lying and deception, this experiment also probed the difference between belief confirming (requires explicit belief reasoning) and truth telling (unclear whether belief reasoning is involved). Comparisons of belief confirming and truth telling reported consistent differences, where belief confirming was associated with greater RTs than truth telling. This suggests that truth telling does not require explicit belief reasoning like belief confirming. It was acknowledged that this experiment probed very specific scenarios and more research into lying and deception, as well as belief confirming needs to before definitive conclusions can be drawn.

5.2 Implications, limitations and future directions

ToM is an umbrella term for the social cognitive functions and mechanisms that allow us to benefit from being in a social group, including both VPT-2 and belief reasoning. Both VPT-2 and belief reasoning are involved in understanding another's mental state; they both involve inhibiting our own mental state in favour of representing another's. It is this conceptual overlap that led to the suggestion that VPT-2 and belief reasoning could be part of the same process, even though the mental content differs (i.e., visual perspective or belief). Several previous investigations related performance on VPT-2 and belief reasoning tasks, which highlighted their similarity but not their differences. To this end, we directly compared VPT-2 and belief reasoning using the Seeing-Believing Task to highlight differences between VPT-2 and belief reasoning. Typically, belief reasoning paradigms tend to focus on FB reasoning, whereas to make a purer comparison between VPT-2 and belief reasoning, we compared VPT-2 and TB reasoning because they both reflect reality. FB reasoning, other the other hand, reflects a misrepresentation of reality. In Chapter 2, a distinction between VPT-2 and TB reasoning was reported where TB reasoning was associated with greater RTs than VPT-2 in Experiments 1, 2 and 3. This suggests that although VPT-2 and belief reasoning are related processes, they are at least partially distinct.

Chapter 2 Experiment 2, as well as Chapter 3, explored what could be responsible for the reported performance difference between VPT-2 and TB reasoning in the general population and non-autistic adults. It was considered that the observed distinction could be an artifact of Seeing-Believing Task. The key stimulus in TB reasoning trials was the first stimulus, whereas in VPT-2 trials, the key stimulus was the second. It is possible that the additional processing associated with TB reasoning could reflect a memory check that is not necessary in VPT-2 trials. To test this, Self-past judgements (to mirror the memory check involved in TB reasoning trials) were compared with Self-current judgments (do not require a memory check, like VPT-2). Surprisingly, Self-current judgments were associated with greater RTs and errors than Self-past judgements, which suggests that greater processing costs associated with TB reasoning judgements are unlikely to reflect a memory check. It is possible that due to the fundamental characteristics of beliefs and perspectives, they cannot be mentally represented in the same way. Full-blown ToM is conceived as a full representation in propositional format, allowing inferences about other's mental states and future actions (Butterfill & Apperly, 2013). One the other hand, to understand another's visual perspective one may use self-rotation to mentally move their body schema into the orientation/viewpoint of the other one wants to understand. Beliefs can be considered more abstract than visual perspectives. Visual perspectives are based on directly observable phenomena, even if they are not being directly observed at the time, whereas beliefs cannot be directly observed in this way. This is in support of the work of Howlin et al. (1999) who proposed five levels of increasing complexity in representing other's minds. They proposed that VPT-2 is level two, whereas TB reasoning is the more complex level four.

TB reasoning might be more representationally complex than VPT-2 because TB are associated with more "processing uncertainty". What this means is we know much less about another's beliefs and desires than their visual perspective. There is uncertainty about what exactly might inform another's beliefs, but as participants in the Seeing-Believing Task (and many other belief reasoning tasks), we must assume that what the character has seen is their primary source of information and will therefore inform their beliefs. Conversely, when making perspective judgements, only visual information is relevant and there is therefore less processing uncertainty associated with perspective judgements compared with belief judgements. Another source of uncertainty in the Seeing-Believing Task (and the Lying-Deception Task) could be the character's perceived uncertainty which is referred to a "representational uncertainty". In other words, participants may think that the character is uncertain about her belief. Participants might also be uncertain about their own processing of the trial events and therefore their ability to select a correct answer. The current experiments cannot provide any more insight on the types of certainty affecting participant's judgements, but future investigations could go further and probe the participant's certainty and their perception of the character's uncertainty at different points in the task.

A more mechanistic explanation for the processing differences between TB reasoning and VPT-2 comes from the dual system model of ToM (Apperly & Butterfill, 2009; Butterfill & Apperly, 2013). The model details two ToM systems, minimal and full-blown ToM. Minimal ToM handles relational content, whereby objects and their relative locations are registered with another agent (i.e., what the other can or cannot see at a given time and whether the last registration of an object is correct or false with respect to the object's current location). Minimal ToM is fast and efficient in enabling goal-directed actions that allow for completion of ToM tasks (Butterfill & Apperly, 2013). Full blown ToM, on the other hand, is conceived as a full representation in propositional format, allowing inferences about other's mental states and future actions (Butterfill & Apperly, 2013). Although VPT-2 engages an embodied transformation which requires substantial processing, this might not generate a propositional representation of the other's visual experience (Kessler, 1999) and therefore could possibly be performed using minimal ToM, rather than full-blown ToM. The outcome of minimal ToM could simply register the correct perceptual orientation of the object from the mentally embodied viewpoint (also McNeill, 2012)

As explained in the Introduction, there are arguments that VPT-2 develops prior to belief reasoning and arguments that belief reasoning develops prior to VPT-2. Chapters 2 and 3 present evidence for a distinction between VPT-2 and belief reasoning in the general population and non-autistic adults, where belief reasoning is associated with greater RTs than VPT-2. This could support accounts that VPT-2 develops prior to belief reasoning. However, several objections will have to be considered. In the Seeing-Believing Task, TB judgements had to be made based on the other's viewpoint. Thus, a viewpoint transformation was required at 90º in any case and while longer processing times for TBs may indicate additional/different processing compared to VPT-2, it does not necessarily indicate that TB processing depends on fully developed perspective taking abilities. In other words, TBs that do not rely in their content on a VPT-2 transformation, e.g., TBs about the correct location of an object (rather than its viewpoint-dependent orientation), could actually develop before VPT-2. Furthermore, there are indications that children may pass simple forms of TB (around the age of 3+) before FB (e.g., Fabricius et al., 2010) and VPT-2 (around the age of 4-5; e.g., Hamilton et al., 2009). This is at odds with Howlin and colleagues' (1999) proposed levels of complexity, which proposed that VPT-2 (level 2) is less complex than TB reasoning (level 4) and FB reasoning (level 5). One possibility to consider is that TB reasoning might be performed differently depending on age and therefore stage of development. TB reasoning at an early age (i.e., around 3 years) could be different to TB reasoning at the age where FB tasks begin to be passed (i.e., 4-5 years; Fabricius et al., 2010; Huemer et al., 2023). At the younger age of three years, children may perform true belief reasoning using minimal ToM, whereas at the later age of four to five years, children may use full-blown ToM to perform TB reasoning. The use of full-blown ToM at later ages may be more similar to FB reasoning and counterfactual thinking. This suggest that VPT-2 could be a developmental stepping stone for FB reasoning, which could in turn affect how a child performs TB and FB operations. This implies that children at around three years of age might be able to perform VPT-2 and TB tasks, but not FB tasks. It follows that these children would not show a difference between VPT-2 and TB on the Seeing-Believing Task. They might process VPT-2 and TB judgements in the same relational fashion, using minimal ToM.

Deception has been used as an index of ToM ability because belief reasoning is heavily implicated in deception (e.g., Ding et al., 2015). Deception can be conceptualised as the act of purposefully creating a FB reasoning in the mind of another and therefore it generally agreed that belief reasoning (full-blown ToM) is essential to deceive someone. This is supported by evidence that children tend to begin to purposefully deceive at a similar age to when they begin to pass FB tasks (e.g., Evans & Lee, 2013; Hogrefe et al., 1986). Lying is closely related to deception, but to lie to someone belief reasoning is not strictly necessary. Chapter 4 sought to understand if belief reasoning is involved in lying by comparing lying and deception using the Lying-Deception Task, which is based on the Seeing-Believing Task used in Chapter 2 and 3. The findings from this investigation are mixed. In some instances, it appears that participants recruit belief reasoning (full-blown ToM) when belief reasoning is implicit, whereas in others they do not. For example, the comparison of deceiving a TB and telling a lie (Hypothesis 1) did not reveal differences in RTs or errors. This suggests that participants might be recruiting additional belief reasoning (i.e., full-blown ToM) processes to lie, even though it is not strictly necessary. It is also possible that participants are using less belief reasoning processes when deceiving (i.e., minimal ToM), however given that participants appear to have used full-blown ToM to infer TBs in Chapter 2 and 3, this seems less likely. One factor that may have affected the Lying-Deception Task's ability to detect a difference between implicit and explicit belief reasoning is the way TBs and FBs were manipulated. In TB trials, participants only viewed one of the two objects (i.e., hare or locomotive), but when telling the character a strategic lie, they had to select the other object that they had not seen in the current trial. Thinking about the object that had not seen in that trial may have incurred an additional time cost. Creating another iteration of the Lying-Deception Task where the object is always swapped and whether the character witnesses the object swap is manipulated, like in Chapter 2 Experiment 3. This would allow us to ascertain if only seeing one of the two objects affect the Lying-Deception Task's ability to detect a difference between lying and deception. Together, the results of Chapter 4 suggest that lying is unlikely to be an accurate index for ToM ability, so future research should differentiate between lying and deception. This is of critical importance in developmental studies seeking to establish when children begin to demonstrate ToM abilities.

All experiments in this thesis can be conceptualised as a comparison between reasoning about beliefs and reasoning about reality. Belief reasoning, by definition, involves reasoning about beliefs and evidence suggests that deception involves belief reasoning (e.g., Ding et al., 2015). Alternatively, VPT-2 is based on directly observable visual information, which is based on reality. Likewise, lying involves making a statement, which is untrue in relation to reality and is therefore grounded in reality. Together, the results of Chapters 2 and 3 suggest that reasoning about beliefs is more difficult than reasoning about reality (as evidenced by RTs and/or errors), especially when a perspective change in required. This is particularly evident in Hypothesis 1 in Experiment 3 Chapter 2, which presents a difference between VPT-2 and TB reasoning regardless of whether perspective change is required. Along with Hypothesis 3 in Chapter 4, which presents a difference between confirming a TB and telling the truth, again, regardless of whether a perspective change was required. In both of these instances reasoning about another's beliefs (i.e., judging the character's TB, confirming a true belief) was associated with greater RTs than reasoning about reality (i.e., judging the character's visual perspective, telling the truth). Together, these suggest that it is more costly to reason about another's beliefs than reality, which may reflect the greater representational demands of beliefs compared to representations of reality.

Variations in social cognition have been reported in individuals with ASC, but due to the subtlety of these difference in adults in particular, many studies do not report variations on ToM tasks. Although, the relationship between VPT-2 and belief reasoning did not differ between those autistic adults and non-autistic adults per se, VPT-2 was associated with a greater processing cost (evidenced by RTs) in autistic adults compared to non-autistic adults This is an important finding because genuine VPT-2 has not been studied in a sample of autistic adults before. There are a number of theories to explain the variations in social cognition reported for ASC. Two theories considered in this thesis were the ToM hypothesis and the executive functioning hypothesis. The ToM hypothesis dictates alterations in behaviour and cognition in ASC are variations in ToM ability (Rajendran & Mitchell, 2007), whereas the executive functioning hypothesis suggests variations in behaviour and cognition in ASC are due to differences in executive functioning (e.g., meta-cognition). The results reported in Chapter 3 are not easily explained by the ToM or executive functioning hypotheses. Autistic adults did not exhibit a specific difficulty with belief reasoning, which is regarded as more socially complex than VPT-2 and therefore these findings do not clearly support the ToM hypothesis. In addition, both TB reasoning and VPT-2 were not associated with greater processing in autistic participants compared to non-autistic participants, so these results do not clearly support the executive functioning hypothesis either. There was, however, an interaction between group and angular disparity where autistic participants' responses were slowed more by a perspective change than non-autistic participants, which hints to an executive functioning explanation, as there are greater executive demands at greater angles.

An alternative explanation is that autistic participants demonstrated less differentiated mentalizing abilities. Findings from the general population and non-autistic participants presented in Chapters 2 and 3 respectively, reported a distinction between VPT-2 and TB reasoning, which might reflect that adults in the general population and non-autistic adults were using at least partially distinct processes to infer visual perspectives and beliefs. On the other hand, a distinction between VPT-2 and TB reasoning was not reported in autistic participants. This could reflect that autistic participants are using the same processes to infer visual perspectives and beliefs, however this difference was not statistically significant at group-level. From the current evidence, it is unclear why autistic participants might not have differentiated between belief reasoning and VPT-2 tasks. It was suggested previously that younger children (around 3 years) might use a different method to infer TB, whereas slightly older children (4-5 years) may begin using full-blown ToM to infer TB once they have gained the ability to infer FBs. Perhaps autistic participants also used a different method perform VPT-2 and TB reasoning, which resulted in the lack of difference between VPT-2 and TB reasoning. At this stage, it is not clear whether this alternative TB reasoning method is minimal ToM. Conversely, the general population and non-autistic participants may have used minimal ToM for VPT-2, but full-blown ToM for TB reasoning. Previous investigations have reported that autistic children pass FB reasoning tasks at a later age than non-autistic children (e.g., Baron-Cohen et al., 2001), which may represent delayed ToM development in ASC. The typical age that autistic children begin to pass FB tasks is less clear than in non-autistic children, which may be due to the large heterogeneity in the ASC population. It is acknowledged, however, that this is the study to investigate genuine VPT-2 and to directly compare TB and VPT-2 in autistic adults, so these results are preliminary in nature and any implications should be approached with caution. Future research should seek to replicate the present findings and the addition of neuroimaging methods could elucidate any differences in processing between autistic and non-autistic participants. For example, fMRI could be used to investigate if different neural substrates that support

VPT-2 and belief reasoning in autistic and non-autistic adults differ. Alternatively, magnetoencephalography could be used to assess the communication between the regions that support VPT-2 and belief reasoning in autistic and non-autistic adults.

There are some limitations that should be considered in the context of these studies. Differences in ToM performance have been reported in a range of clinical populations including attention deficit hyperactivity disorder (Maoz et al., 2019), schizophrenia (Sprong et al., 2007), social anxiety disorder (Washburn et al., 2016) and major depressive disorder (Washburn et al., 2016). One limitation is that because of study constraints previously mentioned, it was not possible to measure their impact on ToM performance in these studies. For example, the global pandemic meant it was not possible to conduct face-to-face testing and therefore all studies presented here were conducted using Prolific (https://www.prolific.co/) to collect participant data online in contrast to the majority of previous studies. Several studies have reported high quality behavioural of data collected online and using Prolific specifically (Peer, Rothschild, Gordon, Evernden, & Damer, 2022).

It should also be acknowledged that the social scenarios studied in this thesis were depicted using a series of images, which lack some of the richness of real life social interactions. Future investigations should consider using more realistic stimuli; for example, naturalistic videos of real people as opposed to computer-generated avatars. Additionally, it could be argued that the social scenarios used in these experiments were overly simplistic. Many real life social interactions may be more complex and nuanced than differing opinions concerning the identity of an object. Furthermore, it could be considered odd that the character in the tasks did not learn that the identity of the object on the table might change despite the fact that the scenario was repeated. Despite the issues described, it can be advantageous to limit the complexity of social interactions in early-stage investigations of complex cognitive phenomena. Future research should increase the complexity the social scenarios we have employed to see if the differences between belief reasoning and VPT-2 presented here are replicated.

In addition, there is a range of benefits with online data collection, including quicker overall data collection time (Taşkın, Taşkın, Doğan, & Kulczycki, 2021) and less social demands on participants, which may be more relevant for specific populations (e.g., ASC). Another limitation is that there were some participants across all experiments that had to be excluded because of poor task performance (>3 correct answers out of 12 in each condition). The decision to remove participants with low accuracy was made to increase the reliability of condition averages. In total, across all three experimental chapters, 114 participants were removed due to low accuracy on the experimental task. It is not clear why these participants struggled with the tasks. Possible reasons include low study motivation, online task instructions (as opposed to more interactive face-to-face instructions) or genuine ToM difficulty. Future studies could assess if the number of participants with low accuracy is a result of online testing by replicating one of these studies face-to face in the lab.

5.3 Conclusion

This thesis aimed to explore the differences between two social cognitive process, VPT-2 and belief reasoning in the general population and in autistic individuals, as well as to explore whether belief reasoning is likely to be involved in a specific type of social interaction – lying. The novel Seeing-Believing Task was developed to directly compare VPT-2 and TB reasoning without the complication of between-task differences. Chapter 2 reported a distinction between VPT-2 and TB reasoning where TB reasoning was associated with slower responses than VPT-2 across three experiments indicating that VPT-2 and TB reasoning are at least partially distinct processes. It was deemed unlikely that participants performing an additional memory check could account for this difference. It was considered that there is greater uncertainty associated with belief judgements compared to perspective judgements and the possibility that beliefs are more representationally complex than visual perspectives due to their propositional nature was considered. It was suggested that VPT-2 may be performed using minimal ToM, whereas TB reasoning may be performed using the more complex full-blown ToM. Chapter 3 reported a distinction between VPT-2 and TB reasoning in non-autistic adults, but not autistic adults. Additionally, autistic adults were more slowed by a change in perspective than non-autistic adults. These results lean more towards an executive function explanation for the variations in social cognition reported in ASC because greater angular disparities are associated with greater executive demands. Alternatively, it was suggested that the lack of distinction between VPT-2 and TB reasoning in autistic adults may less reflect a less differentiate mentalizing ability in ASC, which may mean than autistic adults may try to use the same processes for VPT-2 and TB reasoning, whereas non-autistic adults use different processes, minimal and full-blown ToM respectively. In Chapter 4, the novel Lying-Deception Task was used to compare lying and deception to see if lying was likely to involve belief reasoning (full-blown ToM), like deception. A distinction between lying and deception was reported when the character held a FB, but not a TB. In addition, a distinction between belief confirming and truth-telling was reported regardless of whether the character held a TB or a FB. It was suggested that individuals might choose to employ belief reasoning (full-blown ToM) in some circumstances, but not others. This is the first experiment to compare lying and deception and results are regarded as preliminary, so suggestions were made for future research. The results of Chapters 2, 3 and 4 regarded as comparisons of reasoning about another's beliefs and reasoning about reality. Together, the reported findings support a distinction between reasoning about another's belief and reasoning about reality. Reasoning about another's beliefs was associated with slower responses than reasoning about reality, which may reflect greater uncertainty associated with belief reasoning and/or that beliefs are more representationally complex than perspectives.

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Appendices

Appendix A

Ethical approval letter for the studies conducted as part of this thesis

Aston University
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Date: 18 May 2020

Study title:	Understanding how we represent the beliefs and visual perspectives of others
REC REF:	#1564

Confirmation of Ethical Opinion

On behalf of the Committee, I am pleased to confirm a favourable opinion for the amendment to this research as described in the Amendment Request Form dated 30 April 2020 (appendix a)

Documents approved

Document	*Version*	*Date*
Protocol	2.1	1 May 2020
Information sheet	4	30 April 2020
Consent form	4	30 April 2020
Advert	4	15 May 2020
Post experiment questions	2	April 2020
Ethics form	6	April 2020

With the Committee's best wishes for the success of this project.

Yours sincerely

Professor James Wolffsohn,
Acting Chair, University Research Ethics Committee

Appendix B

Supplementary Materials for Chapter 2

Supplementary Results

Hypothesis 6

Self- vs Other-Perspective differ, particularly at high angular disparity (Experiment 2 only)

In replication of previous perspective taking results (e.g. Surtees, Samson & Apperly, 2016; Surtees, Butterfill & Apperly, 2012), it was expected that self judgements would be associated with shorter RT and/or lower errors than judgements about another's perspective, especially – or even only - when another's perspective is different to one's own (i.e., ± 90º angular disparity). This hypothesis was examined in Experiment 2 using a 2 x 2 ANOVA with Angular Disparity (0°, 90°) and Judgement Type (Self-Perspective, Other-Perspective) as factors. (Note that Self-Past and Self-Current judgements were collapsed into Self-Perspective and only no-swap trials were included in this analysis). Main effects of Angular Disparity ($F(1,61) = 49.795$, $p < .001$, $n_p^2 = .449$) and Judgement Type ($F(1,61) = 4.908$, $p = .03$, $n_p^2 = .074$), as well as the Angular Disparity-by-Judgement Type interaction ($F(1,61) = 4.587$, $p = .036$, $n_p^2 = .07$) reached significance (Figure S-1). With respect to errors, only the main effect of Angular Disparity ($F(1,61) = 11.438$, $p = .001$, $n_p^2 = .101$) was significant.

Two paired samples *t*-tests were employed to follow up on the ANOVA for RTs, one comparing Other-Perspective and Self-Perspective judgements made at 90º, and another comparing Other-Perspective and Self-Perspective judgements made at 0º. Other-Perspective judgements made at 90º where associated with significantly greater RTs ($t(61) = 2.682$, $p = .009$, $d = .341$) than Self-Perspective judgements, whereas, other-perspective judgements made at 0º were not associated with greater RTs ($p = .162$).

Based on the RT results we conclude that there is little difference in processing speed between Self- and Other-Perspective judgements when there is no angular disparity, i.e., the other's perspective is identical to the egocentric perspective. In contrast, when there is an angular disparity of 90º it is more difficult to adopt the other's perspective (RTs), which replicates extant literature.

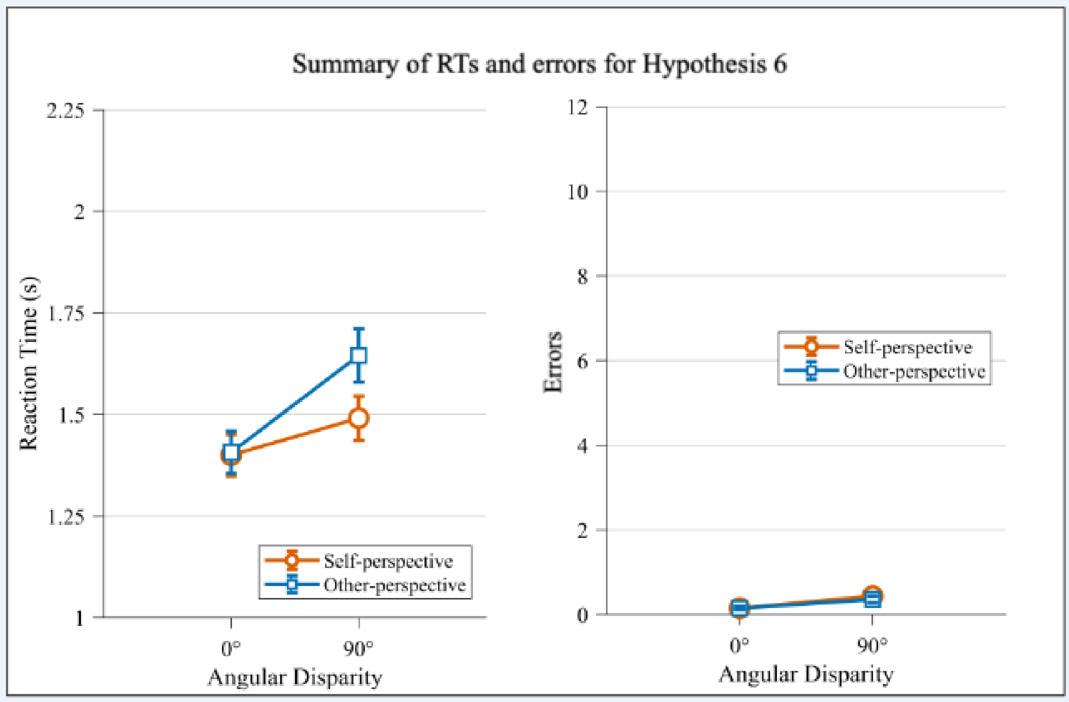

Figure 24. Results for Hypothesis 6. Angular Disparity-by-Judgement Type interaction for RT data (in seconds) on the left and errors on the right. Error bars are standard error of mean.

However, it is important to note that these differences between self and other perspectives in RTs were only observed when Self-Past and Self-Current judgements were averaged together. As shown in Table 5 (main text), only Self-Past but not Self-Current judgements actually appear to differ from Other-Perspective judgements, which is also the case for no-swap trials, where Self-Past and Self-Current judgements required identical responses. As we argue for Hypotheses 4 and 5 in the main text, for the complex paradigm we have employed here, participants appeared to anchor each trial to the scene at the start, resulting in Self-Past judgements being processed the fastest, while Self-Current judgements being significantly slowed down, to the level of Other-Perspective judgements (while Other-Belief judgements being slowest, see Hypothesis 1 in the main text). Further research is therefore required to understand the slow responses for Self-Current judgements. For instance, a blocked design separating Self and Other judgements might reveal diminished differences between Self-Past and Self-Current, when answer options are narrowed down to Self judgements only. In contrast, a block of Other judgements should replicate the findings from Experiment 1, revealing a difference between Other-Perspective (VPT-2) and Other-TrueBelief (TB) judgements (at 90°). With such a design we would also expect to observe differences between Self-Current and Other-Perspective judgements, e.g. at 90° angular disparity.

Hypothesis 7

Are TBs ascribed by default? (Experiment 2 only)

Based on previous research (Back & Apperly, 2010) it was predicted that TB judgements would be associated with greater RTs and/or errors relative to "reality" (Self-Current) judgements, indicating that TB judgements are *not* ascribed by default (e.g., Back & Apperly, 2010). This was tested in Experiment 2 using one-tailed *t*-tests. Contrary to this prediction, judgements about "reality" (Self-Current) were numerically associated with greater RTs than TB judgements (Table 5), but the difference did not reach significance (p = .0975). There was also no difference in errors (p = .500). These results might suggest that TBs are in fact ascribed by default in some circumstances. However, it is important to note that the current comparison was conducted for conditions where the other's perspective and their TB about reality were fully aligned with the participants' own perspective (0º angular disparity) and privileged knowledge of reality. This differs from typical designs in previous research, where the other always occupied a different viewpoint than the self (e.g., Back & Apperly, 2010, on which our hypothesis was based; see pre-registration). Such misalignment of perspectives is likely to trigger additional processing in itself. It could therefore be that processing another's (true) belief and perspective only require additional resources when their representation cannot be simply "assimilated" into the egocentric perspective and knowledge of reality. This latter statement is further corroborated by the analysis in relation to Hypothesis 7 below, which confirms that processing times (RTs) for other-perspectives are not significantly longer than processing times for self-perspectives at 0º angular disparity in Experiment 2.