Abstract

The ability to reason about other’s beliefs, and in particular their false beliefs, is a fundamental part of having a theory of mind (ToM) – an understanding of the role that mental states (i.e., beliefs, desires, and intentions) play in causing behavior. Reasoning about others’ minds is difficult, particularly when others’ perspectives are different from one’s own, as is the case with false beliefs. One explanation for this phenomenon may be the anchoring-and-adjustment theory, which stipulates that our first guess about other’s mental states is “anchored” to our own perspective (that is, we think that they think what we do) and then adjusted, based on what we know about the other person and their contextual circumstances. If this theory is correct, then neurocognitive processes associated with flexible thinking should be implicated when reasoning about others’ false beliefs. To investigate this possibility, the relationship between beta electroencephalographic (EEG) oscillatory activity and belief-reasoning was examined in adults. The suppression of beta EEG activity has been associated with processes such as cognitive flexibility, learning, and dopaminergic functioning; therefore, it may also be involved in the adjustment process. In this study, 39 adult participants were recruited, and EEG recordings were obtained in response to a series of false-belief and true-belief tasks. It was hypothesized that: 1) beta EEG activity will be suppressed more when reasoning about others’ false beliefs relative to their true beliefs, and that 2) beta suppression will be evident at scalp sites that are typically associated with neural regions that are important for ToM reasoning, including the dorsomedial prefrontal cortex (dmPFC) and the right temporo-parietal junction (rTPJ). Results showed significant trial effects for beta suppression at the dmPFC, but not the rTPJ. These results demonstrate that beta EEG activity may be used as an index for belief-reasoning and, in turn, may reflect aspects of the neurocognitive factors underlying the anchoring-and-adjustment process.
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Chapter 1

Introduction

1.1 Theory of Mind

Theory of Mind (ToM) refers to the conceptual framework we use to make inferences about others’ mental states, such as their intentions, desires, or beliefs. It allows us to understand others’ motives from their actions and make predictions about their thoughts and behaviours. It is considered to be a central component of our social cognition, aiding in our social problem solving, moral evaluation of others’ actions, and social competence (Sabbagh & Bowman, 2018). As such, reasoning about ToM is a critical skill for making our way through the social world.

While our understanding of the specific contents of others’ minds may vary from person to person, our general ToM leads us to assume that our knowledge of the world may differ from that of others. Early in development, children become better able to judge that two people who have different experiences might believe different things about the world. This refers to our ability to understand others’ false beliefs (Wellman et al., 2001). While the idea that we each hold unique beliefs may seem intuitive to adults, this understanding does not emerge until around 5 years of age.

The emergence of false-belief understanding was initially observed using one of the first tests to assess children's ToM, the location-change false belief task (Baron-Cohen et al., 1985). In the original version of this task, the researchers stage a puppet show for children in which one doll, Sally, places a toy in a box and then leaves the scene. While Sally is gone, the other doll, Anne, takes the toy out of the box and transfers it to a different location. Children are then asked where, Sally, after returning to the scene would look for her toy. Correct performance requires
recognizing that Sally has a false belief – that even though the toy really is in the new location, she will (mistakenly) think that it is in the old location, because she was gone when it was moved. Results with this task, and many others like it (Wellman et al., 2001), typically show that correct performance emerges at around 5-years old. Around this age, children start to correctly respond that Sally will look for the object in the location she last left it in. In comparison, 3-year-old children typically respond incorrectly by saying that Sally will look for the toy in the location they know it is really in.

A critical theoretical question concerns why children make this canonical error. There have been several complementary approaches to this issue. One approach emphasizes the nature of the conceptual developments that might take place over the preschool years that are relevant to theory of mind understanding (Gopnik & Wellman, 2012). Along these lines, it could be the case that young 3-year-olds simply have a qualitatively different understanding of the beliefs, perhaps not yet understanding that beliefs can be fallible representations of the world (see e.g., Perner, 1991). Another approach, one that I have been guided by here, is a more process-oriented approach that seeks to delineate the cognitive processes that one might go through in order to accurately reason about others’ minds when those contents are different from one’s own.

1.2 Anchoring and Adjustment

ToM reasoning presents a sort of intriguing paradox from a cognitive science perspective. On the one hand, reasoning about others’ minds is difficult because mental states are abstract, invisible concepts that we have no direct experience of. All we can do is make guesses about what someone might think at any given time. On the other hand, reasoning about others’ thoughts is something that we do naturally with apparent ease and accuracy. One way of resolving this paradox comes from theories suggesting that perhaps we have some fast,
“heuristic,” ways of reasoning about others’ mental states that makes the problem easier for us in many cases. One such heuristic that has been proposed for ToM reasoning is the “anchoring-and-adjustment” heuristic.

The theory for the anchoring-and-adjustment heuristic was first introduced by psychologists Tversky and Kahneman (1974) to explain how people estimate numbers. In one of their first studies, they asked participants to compute the products of the numbers one through eight, either as $1 \times 2 \times 3 \times 4 \times 5 \times 6 \times 7 \times 8$ or reversed as $8 \times 7 \times 6 \times 5 \times 4 \times 3 \times 2 \times 1$. The experimenters gave limited time to respond so that participants had to give an estimate before they could complete their calculations. They found that when they asked participants to solve the sequence that started with the smaller numbers, their median estimate was 512; when the sequence started with the larger numbers, their median estimate was 2250. Even though the product of both sequences should be the same (i.e., 40,320), the participants’ estimates varied depending on the order of the given sequence. This led Tversky and Kahneman (1974) to suggest that participants were demonstrating a cognitive bias. They theorized that when people are implicitly given a reference point, it becomes the “anchor” that their judgments are based on, and in order to make inferences, they make adjustments away from that anchor to reach an estimate. In this case, participants’ estimates were anchored to the first values in the sequence from which adjustments were made. With limited time to respond, participants employ this anchoring-and-adjustment heuristic, resulting in their biased guesses.

Influenced by Tversky and Kahneman’s (1974) theory, Epley et al. (2004) proposed that a similar anchoring-and-adjustment heuristic may be used when we make judgments about others’ behaviour. They suggest that, due to its high accessibility, people initially anchor to their own egocentric perspective, and then adjust it to account for differences between themselves and
others. They theorize that these adjustments are formed serially, such that after receiving new social information, people engage in hypothesis testing and “jump” from their egocentric anchor, evaluate their assessment, and make any required adjustments until they come to a plausible conclusion.

In Epley et al.’s (2004) initial exploration of this theory, they found that people’s judgments about others’ perceptions correlated with their own perceptions. In their first study, they found that after listening to an ambiguous message that could be interpreted as either sarcastic or sincere, participants used their own interpretation of the message as an anchor, so that the extent to which the intention of the message was clear to the participants influenced their perception that the same message would be clear to uninformed listeners (Epley et al., 2004). This finding demonstrates that people's judgments about others’ perceptions tend to be anchored to their own perceptions, producing a bias towards their egocentric perspective.

In further support of Tversky and Kahneman’s (1974) proposal, Epley et al. (2004) also observed that the adjustment process requires time and cognitive effort. Using the same sarcastic message task but with limited time to respond, Epley et al. (2004) found that hurried participants made fewer adjustments and, consequently, held more egocentric judgments than those who responded at their leisure. The degree of egocentricity of participants’ judgments also depended on the amount of cognitive effort participants expended. For instance, participants who were offered a financial incentive for accuracy exerted more effortful thought and were subsequently less egocentric in their perspective-taking. This suggests that, when response times are reduced and cognitive capacity is depleted, people make fewer adjustments away from their egocentric anchor.
To demonstrate that these adjustments are performed serially, Epley et al. (2004) manipulated the likelihood that a participant would cease hypothesis testing at a certain stage in the adjustment process. While participants were trying to take another person’s perspective, the researchers asked them to either nod or shake their head. Actions such as nodding induces acceptance, whereas shaking the head induces rejection (Forster & Strack, 1996; Wells & Petty, 1980). They found that actions that encourage acceptance, more so than ones that encourage rejection, influence whether participants accept a hypothesis early in the adjustment process. This suggests that adjustments are made on a serial, trial-by-trial basis, which can be interrupted or maintained, ultimately influencing how far adjustments are made from the egocentric anchor.

Due to this egocentric bias, our inferences about others’ mental states may often be insufficient. Since our own perspectives are presumably highly accessible, they serve as the anchor and, thus, the basis for our judgments. As such, we think that others think the way we do. It is not until we receive new evidence that others may perceive the world differently that we make the proper adjustments. Further, the magnitude and frequency of adjustments may depend on whether our own perspectives are already well-known, such as to family or close friends. Fewer adjustments may be made when making predictions regarding out-groups whose perspectives are unknown or heavily influenced by stereotypes. Thus, the anchoring-and-adjustment heuristic has important implications for how we perceive other people in social situations, and for how we interpret their behaviour, as well as our own self-concepts.

1.3 Neural Basis of Anchoring-and-Adjustment

In contrast to false-belief tasks, true-belief tasks assess participants’ reasoning when they share the character's same belief about the event. If a true-belief condition were applied to the scenario of the location-change task, participants would see Sally come back in time to notice
Anne transferring the toy to the new location, therefore Sally would have a true belief about where it actually is. Since the participant holds the same representation of the event as Sally, there is theoretically no need to take Sally’s perspective to answer correctly. The maintenance of one’s egocentric perspective in a true-belief condition has led some researchers to believe that the mechanisms for false-belief and true-belief reasoning are distinct (Back & Apperly, 2010). Although these mechanisms are not fully understood, comparing brain responses between true-belief and false-belief tasks have helped scientists gain a better understanding of how we come to differentiate ourselves from others.

In recent years, false-belief understanding has been linked to activity in specific regions of the brain. Using functional magnetic resonance imaging (fMRI) to measure cortical blood-oxygenation levels, researchers have discovered a group of brain regions, which they refer to as the ToM brain network, as being implicated in the false-belief task (Saxe, 2009). This ToM brain network includes regions like the dorsomedial prefrontal cortex (dmPFC) and the right temporoparietal junction (rTPJ). While these two regions are both recruited for ToM reasoning, the fMRI literature in general makes distinctions between their functions. The dmPFC is associated more broadly with social cognition, integrating social information and understanding norms and enduring dispositions of other and self (Van Overwalle, 2009). On the other hand, the rTPJ is implicated specifically in the attribution of mental states like false beliefs (Saxe & Kanwisher, 2003).

While the neurocognitive basis of ToM is still unclear, the anchoring-and-adjustment framework gives us an idea of how ToM reasoning might be reflected in the brain. As mentioned, during true-belief reasoning, our egocentric perspective would theoretically be maintained so that no adjustment would be needed to our self-anchor. If the theory for our
egocentric bias is correct, then true-belief tasks should not elicit neurocognitive responses any different from our baseline activity. The responses for true-belief tasks could then serve as the control condition to which false-belief responses are compared. Significant differences in activity during false-belief reasoning relative to true-belief reasoning would indicate that an adjustment has been made. This idea has been supported in fMRI research, with the ToM brain network (especially the rTPJ) showing higher responses on false-belief trials than on true-belief trials (Sommer et al., 2007). This led the authors to conclude that the ToM brain regions are recruited specifically for false beliefs. To our knowledge, no study to date has conducted a true-belief vs. false-belief comparison with the location-change task under the anchoring-and-adjustment framework. However, several studies have found evidence of differences in brain responses when making shifts between self- and other-perspectives that would support the existence of the anchoring-and-adjustment process.

There is evidence to suggest that the dmPFC is specifically associated with the adjustment process. In one study, Tamir and Mitchell (2010) demonstrated that larger discrepancies between judgments of the self and the other were correlated with greater activity in the mPFC. In their study, they asked participants a set of questions about their personal preferences and to then judge how another person would respond to the same questions. These questions were brief statements such as “fear speaking in public” or “enjoy winter sports like skiing or snowboarding”. After being cued to either make self-oriented judgments or other-oriented judgments towards a fabricated target individual, the participants rated how well each statement describes themselves or the other person on a Likert scale. Under the anchoring-and-adjustment framework, they reasoned that people’s judgments will be based on their own preferences, will undergo linear adjustments as they reason about others’ preferences, and that
these processes can be quantified with neuroimaging data. The researchers found that the magnitude of activity in the mPFC predicted the difference in ratings between self-oriented and other-oriented judgments. This finding falls in line with previous research, providing further evidence that activity in this brain region may play a role in false-belief understanding by way of making adjustments to the self-anchor to fit with their concept of the other.

Along with the neuroimaging data, the neural basis for the anchoring-and-adjustment mechanism has gone through further elaboration with evidence from event-related potential (ERP) research. In a recent study following the anchoring-and-adjustment model, Bradford et al. (2019) found that making shifts from self-perspectives to other-perspectives expends much more cognitive effort that can be observed behaviourally and neurophysiologically. They found that participants exhibited faster and more efficient behavioral responses in self-oriented belief attributions compared to other-oriented ones, providing further evidence of our egocentric biases. These behavioural responses were further supported by their ERP evidence, in which they found differences in ERP amplitude in the ToM brain network when individuals engaged in perspective-shifting, as well as differences between self-oriented attributions and other-oriented attribution. These results suggest that self-perspectives may already be cognitively pre-processed and that orienting to other-perspectives requires extra computation, which can be indexed by specific electrophysiological activity.

Together, these studies provide some evidence of anchoring-and-adjustment in the ToM brain network. However, the question still remains as to what sort of neural computations occur in these regions that would support this theoretical framework. One theory proposes that dopaminergic activity may be an index of anchoring-and-adjustment (Sabbagh, 2017). Dopamine is generally involved in error-learning, signalling the errors in our model of the world that would
lead to its updating (Schultz, 2015). Since anchoring-and-adjustment is considered to be a
dynamic, error-directed way of reasoning about ToM, dopamine has been theorized to play the
central role. When we make adjustments to our egocentric anchor, it is because we have realized
that our model of the world does not comport with another person’s model. This error is
signalled by mesocortical dopaminergic neurons which catalyze the adjustment process in order
to integrate new information into our model. These errors are generated internally, in real-time,
just as we negotiate the conflicts between our own and others’ beliefs. ERP evidence indicates
that dopamine is sensitive to these internally-generated signals. For instance, early, negative
deflections of the ERP, such as error-related negativity and feedback-related negativity, are
argued to originate from the paracingulate regions, which is involved in the error-processing
modulated by dopamine systems (Holroyd & Coles, 2002). Due to dopamine’s involvement in
prediction error signaling and updating cognitive models, it may also be a factor influencing
online ToM reasoning.

Basic evidence for dopamine’s role in ToM lies in our neuroanatomy: dopamine
receptors are prevalent in the dmPFC. This particular ToM brain region receives neural
projections from the mesocortical dopaminergic neural pathways, suggesting that dopamine may
play a role in the maturation and functioning of the ToM brain network (Sabbagh et al., 2016).
Generally, it seems that deficits in dopaminergic activity leads to lower performance in ToM
tasks. For instance, variations in genes which code for dopaminergic receptors have been shown
to impact ToM reasoning abilities (Lackner et al., 2012). Individuals with longer alleles in the
dopamine receptor D4 (DRD4) gene exhibit reduced DRD4 receptors, a specific type of
dopamine receptor most commonly expressed in the prefrontal cortex, which in turn negatively
affects their ToM performance. In testing non-invasive measures of dopaminergic functioning,
Lackner, Bowman, and Sabbagh (2010) investigated children’s eye blink rates, which originate from activity in brain regions closely linked to/or overlapping with dopamine pathways. With increased eye blink rates being associated with greater dopamine levels, these researchers found that individual differences in eye blink rate predicted children’s ToM performance. Taken together, these studies provide some evidence that dopamine plays a role in ToM. Due to dopamine’s involvement in error signaling and adjusting our cognitive models, it may also be recruited for ToM reasoning. However, further research using more accurate measures of ToM reasoning in real-time are required to support this hypothesis.

1.4 Beta EEG Activity and Theory of Mind

One method that could index the neurocognitive operations behind the adjustment process may be the analysis of EEG oscillatory activity, the rhythmic patterns of neural activity recorded by electroencephalography (EEG). EEG signals contain rhythmic activity that are believed to reflect neural oscillations. These neural oscillations are generated from the fluctuations in the excitability of a population of neurons (Salinas & Sejnowski, 2001). This excitability is produced by changes in post-synaptic potentials as neurons are activated by the binding of neurotransmitters.

In order to extract information from EEG signals, data points from its rhythmic activity can be decomposed using time-frequency analyses. The decomposed data is referred to as an event-related spectral perturbation (ERSP), which can be described by measures such as frequency, the speed of their oscillations in hertz (Hz), and power, the amount of energy in the selected frequency band (μV^2) (Cohen, 2014). As brain rhythms contain multiple frequencies, these ERSPs can be separated into distinct frequency bands: delta (2-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), beta-1 (13-20 Hz), beta-2 (20-30 Hz), lower gamma (30-80 Hz), and upper gamma
(80-150 Hz). The patterns of this activity, its frequency and power, are thought to reflect neurophysiological aspects of cognitive functions.

Recent studies provide evidence that beta EEG oscillatory activity, brain waves that oscillate between 13-30 Hz, may be sensitive to online error signals, updates in cognitive models, and fluctuations in dopamine levels, which are all argued to be essential for ToM reasoning. Examining beta EEG activity may thus provide insight into the neurocognitive mechanisms involved in anchoring-and-adjustment.

**Beta EEG and Top-down/Bottom-up Processing.** Our conceptual framework for ToM can be organized into cortical hierarchical structures, such that higher cortical levels create probabilistic models to explain neural activity at lower levels (i.e., sensory input) (Friston, 2002, 2005). This cortical hierarchy distinguishes between feedforward, bottom-up processing and feedback, top-down processing, which can both be applied in our ToM model. For instance, our guesses for people’s mental states are formed by means of top-down processing, in which higher-level systems provide the set of prior beliefs to guide lower-level systems (Friston, 2002). When encountering a novel event that puts our guesses into question, new information is processed bottom-up and transfers feedforward input to more higher-level systems, with the objective of updating the internal model of predictions (Friston, 2002). These processes work together to ensure that more accurate predictions are formed and that new information can be integrated into our cognitive models about human behaviour, proving to be critical in the conceptual development of ToM understanding.

Beta activity is shown to be modulated depending on whether tasks elicit top-down or bottom-up mechanisms. Tasks involving strong, endogenous top-down components have been shown to elicit greater beta enhancement (Engel & Fries, 2010). In contrast, novel or unexpected
events that suppress the flow of top-down information has been shown to disrupt beta activity (Bressler & Richter, 2015). This has been supported with neuroanatomical evidence as enhancement in beta EEG has been associated with top-down processing from higher-level cortical areas, such as the prefrontal cortex, to lower-level cortical areas, such as the extrastriate cortex and primary visual cortex (Bressler & Richter, 2015). Thus, in the context of ToM reasoning, it would be expected that our correct predictions about others’ mental states would enhance beta activity, whereas our incorrect predictions would suppress top-down information flow and suppress its activity. Whether we are accurate in ToM reasoning or not may then be reflected in the modulation of beta EEG.

Indeed, researchers have found that the precision of participants’ predictions is positively correlated with beta enhancement; the more accurate the predictions are relative to the actual outcome, the easier the top-down feedback is transferred, and the more enhanced beta EEG activity is (Van Pelt et al., 2016). Interestingly, this modulation in beta EEG has been observed in regions implicated in ToM reasoning. Park et al. (2018) found that beta activity in the right temporoparietal regions is related to one’s accuracy in estimating others’ preferences, suggesting that this region may be responsible in distinguishing differences between predictions and actual observations of human behaviour.

**Beta EEG and Cognitive Flexibility.** Aside from bottom-up processing, beta suppression may also reflect the flexibility in our cognitive models. When making ToM-like inferences, our internal models must be stable enough to support our prior beliefs, but it must also be flexible enough to integrate updates. Beta suppression is thought to promote this cognitive flexibility (Engel & Fries, 2010). Support for this hypothesis primarily comes from research on Parkinson’s disease, a neurodegenerative disorder caused by the degeneration of
dopaminergic neurons. As the deterioration of dopaminergic neurons expands into the frontal lobes, it increases the likelihood of cognitive dysfunction, including errors in ToM reasoning and decreased cognitive flexibility. Research shows that those with Parkinson’s exhibit elevated beta activity, suggesting that it may be involved in the patients’ cognitive inflexibility and persistence of cognitive models (Engel & Fries, 2010). Treatments such as dopamine agonists and transcranial magnetic current stimulation, which relieve said symptoms, have been shown to disrupt beta activity as well. Researchers theorize that enhanced beta activity may lead to the inability to adjust cognitive models to fit novel information, resulting in such cognitive rigidity. Hence, in addition to its association with bottom-up information flow, beta suppression may be able to explain our cognitive flexibility in making and changing predictions about others’ mental states.

**Beta EEG and Dopamine.** In further establishing the relationship between dopamine and beta activity, research gives indication that they are both involved in similar cognitive processes. For instance, dopaminergic transmission, similar to beta activity, may be able to control the inflow of externally or internally generated information, such that disruptions to the dopamine systems may lead to the generation of erroneous predictions about the mental states of others (Abu-Akel & Shamay-Tsoory, 2011). Moreover, cognitive flexibility and stability are thought to be mediated by tonic and phasic modes of dopamine release (Abu-Akel & Shamay-Tsoory, 2011). Based on the parallels in the nature of their activities, some researchers theorize that beta activity can itself directly reflect dopaminergic activity.

Through further research on Parkinson’s disease and rat models, Jenkinson and Brown (2011) hypothesized that beta activity can distinguish between more specific levels of dopaminergic functioning, such as tonic and phasic release. Differentiating between tonic and...
phasic dopamine levels is important because, from a developmental perspective, different hypotheses exist about the specific roles that different release modes play in supporting ToM development. Tonic dopamine is believed to play a role in supporting long-term functional development of neuroanatomical regions that are important for ToM reasoning (i.e., dmPFC). In contrast, phasic dopamine is thought to be important for the cognitive flexibility required for updating mental representations from moment to moment, enabling us to make adjustments in our predictions about others’ mental states (Popolo et al., 2004). Jenkinson and Brown (2011) purport that lower beta power indexes phasic dopamine and that higher beta power activity indexes tonic dopamine. Dopaminergic neurons typically exhibit tonic firing at a relatively low frequency. However, in response to a salient cue, such as unexpected stimuli, these neurons phasically discharge a burst of high-frequency action potentials, releasing dopamine into the synapses to activate other neurons (Gonon, 1988). This phasic dopamine activity has been associated with suppression in beta activity. Due to this relation, investigating beta activity will not only provide insight into the anchoring-and-adjustment mechanisms of ToM reasoning, but also the neurochemical factors that may be involved in its online function.

1.5 Summary and Objectives

The objective of the current study was to examine adults’ ERSP response to a location-change ToM task. All participants were assessed with the same task, consisting of true-belief (control) and false-belief conditions. Due to its association with bottom-up processing, cognitive flexibility, and dopaminergic functioning, beta EEG activity was investigated as an index for belief-reasoning in real time. Time-frequency analyses were conducted on the EEG data in electrode sites of over the dmPFC and the rTPJ.
Our primary question was whether beta EEG activity (13-30 Hz) can be associated with false-belief reasoning. This will be tested using the false-belief condition, eliciting adjustment from anchor. The true-belief condition will serve as control. We hypothesize that adjustments from anchor, which signal prediction errors and prompt updates in cognitive models, will suppress beta activity. Beta EEG measures of power are expected to be lower in the false-belief trials than in the true-belief ones, providing evidence that adjustments in cognitive models to these unexpected events may be reflected in disrupted beta activity. Since beta EEG can be categorized into distinct beta-1 (13-20 Hz) and beta-2 (20-30 Hz) bands, this study will also explore potential statistical differences between the true- and false-belief conditions to further examine their specific functions.
Chapter 2

Methodology

2.1 Study Participants
This study, approved by the General Research Ethics Board at Queen’s University (Appendix A), recruited 39 volunteers (18-72 years old) from the local community via word of mouth, social media, and the undergraduate participant pool. Since testing occurred during the COVID-19 Pandemic, a university-approved Public Health and Safety protocol was incorporated into the experimental procedure (Appendix B). Participants were required to be over 18 years of age and to follow our laboratory’s health and safety measures. Participants were compensated with $15 or 1.0 course credit.

Data for eight participants were excluded from the analysis due to noisiness determined through visual inspection. The final sample, therefore, consisted of 31 participants (18 female), ages 18-50 years ($M=25.5$, $SD=8.2$). With 31 participants, power is .796, thus the study is slightly underpowered in order to get a medium effect size ($d=.5$). The demographics of our final sample reflected the predominantly white, middle-class university population in eastern Canada from which it was drawn (17 White/European, 8 hispanic/latino, 2 Asian, and 4 other). All participants provided written informed consent.

2.2 Materials and Stimuli
Theory of Mind Task. Participants’ EEG was recorded during a multi-trial theory of mind task. Figure 1 demonstrates a trial from the true-belief and false-belief conditions. The task consisted of 32 short, animated scenarios presented on a computer monitor with accompanying audio narration played through speakers. The task presented false-belief (16 trials) and true-belief (16 trials) trials in a randomized order. For each trial, it depicted a character acting on the
basis of their true or false beliefs, resembling a story according to the “location-change” false belief task (Baron-Cohen et al., 1985). The first 3 images in both conditions were the same and illustrated the following series of events: Picture 1, a character introduces their pet animal (e.g., cat, dog, etc.); Picture 2, the character places their pet animal in one of the two locations set in the scene (e.g., character places cat into the box); Picture 3, the character turns around and leaves their pet animal. The location in which the pet animal is placed is counterbalanced across trials so that they are placed in either the left or right location for an equal number of times. After the character leaves, the subsequent series of events depended on the trial condition. In the false-belief trials, the participant watched a video clip of the animal switching to the other location (e.g., cat moves from the box) before the character returns, consequently having a false belief about where their pet is. Following the logic of a traditional false belief task, the character should thus have a false belief about the location of their pet. In the true-belief condition, the animal switches to the other location after the character returns, and thus, having seen the pet move the story character has a correct belief about their pet’s location. The event of interest within the theory-of-mind trial is the video clip showing the animal switch locations (location-change event) in both true-belief and false-belief trials. As the location-change event occurs prior to when participants make a decision, it can be argued that is when belief-reasoning processes occur.

After the location-change clip, the experimenter asked the participant two questions: an attention question (“where did the animal go?”) and the theory-of-mind reasoning question (“where will the character look for it?”). To answer the true-belief trials correctly, the participant had to reason that their own belief of where the animal is located matches the character’s beliefs, thus the participant would have to predict that the character will look for the animal in the correct
location. To answer the false-belief trials correctly, the participant had to reason that the character’s knowledge of their animal’s location does not match their own, thus the participant would predict that the character will look for their animal in the original, incorrect location. Participants were instructed to point to the location they think is correct on the computer screen and their behavioural responses were recorded. The final image in the trial illustrated the character searching for the animal based on either their true or false belief about its location.

Figure 1. Multi-trial theory of mind task. A) Example trial from false-belief condition B) Example trial from true-belief condition. Location-Change event marks event of interest for data analyses.

2.3 Procedure

Arrival. Upon arrival at the testing building, a research assistant greeted the participant at the entrance. Under Public Health and safety regulations, participants were asked to put on lab-provided surgical masks and gloves. The research assistant confirmed the participant was not experiencing any COVID-19 symptoms using the local hospital’s COVID-19 Screening Questionnaire. The research assistant then led the participant to the laboratory. They were seated
in the waiting area and were asked to read the letter of information (Appendix C) and to sign a consent form outlining the purpose, procedures, risks, and benefits of participation in this study (Appendix D).

**Session Procedure.** Following the signing of the consent form and administration of the demographics questionnaire (Appendix E), participants were brought into the EEG suite and seated in a comfortable seat. Participants completed one practice false-belief and true-belief trial. Participants indicated their response to the questions by pointing at the computer screen. After confirming the participant’s understanding of the instructions, the experimenter prepared for EEG placement.

Prior to placing it on the participant’s head, the EEG net was soaked in a mild electrolyte solution (1.5 teaspoons of potassium chloride and a drop of baby shampoo in 1L of water). While the net was soaking for approximate 5 minutes, the experimenter measured and lightly marked (with a soft, washable crayon) the vertex of the participant’s head; this mark was used to guide net placement. The experimenter ensured that excess water was off of the net. The net was stretched over the participant’s head such that all of the electrodes made contact with the scalp evenly. Once the net was in place, one experimenter worked to ensure that the electrodes were positioned properly. Throughout this procedure, the experimenter monitored the electrode impedances to ensure that all electrodes were making good contact with the scalp. Thereafter, the procedure was conducted in the following fixed order: 1) two 2-min resting state EEG recordings (eyes open and eyes closed) were collected; 2) a 20-min theory-of-mind task was conducted.

2.4 EEG Recording and Data Analysis

**Recordings and Data Processing.** The electroencephalogram (EEG) was recorded using a Hydrocel Geodesic Sensor Net that consists of 128 Ag/AgCl electrodes that are connected in
an elastic geodesic tension structure that distributes the electrodes evenly when the net is fitted onto a head. EEG activity in all channels was recorded in reference to the vertex electrode (Cz), sampled at 250 Hz, and bandpass-filtered between .1 and 100 Hz. EEG was recorded continuously throughout the presentation of all trials. Impedances were maintained below 40Ω.

Raw EEG signals were filtered using a 60 Hz notch filter to remove electrical noise. Bad channels (i.e., noisy, flat, or drifting channels) were detected by inspection and excluded them from analysis. No interpolations of bad channels were conducted. Next, continuous data was segmented into discrete trials corresponding with the false-belief and true-belief trials. The event of interest within the theory-of-mind trial is the video clip showing the animal switch locations (location-change event) in both true-belief and false-belief trials. Participants’ continuous EEG data was segmented to epochs of 4500ms time-locked to the event of interest; this included 1000ms prior to the location-change, 3000ms of the location-change event and 500ms post-location change. Trials that contained large or paroxysmal artifacts were identified by visual inspection and removed from further analysis. The data were then submitted to the extended runica routine of EEGlab software (Delorme & Makeig, 2004), a function for automated infomax independent component analysis decomposition algorithm (ICA; Makeig, Jung, Bell, Ghahremani, & Sejnowsky, 1997). ICA components that were judged to contain ocular artifacts were identified and removed from scalp topographies and the time series of the components. We then re-referenced these single-subject averages to the average reference (Cz).

**ERSP Analysis.** The off-line data analysis was performed using custom MATLAB (Mathworks) scripts. 4500ms epochs time-locked to the event of interest were segmented. For the time-frequency analyses, a Morlet wavelet transform was computed to characterize power in the range of 13-40 Hz for beta in 0.5 Hz frequency steps at 200 timepoints over the 4500 ms
recording epoch relative to a 1000 ms baseline period. Due to the cycling parameters chosen, the recording epoch was truncated by 560 ms at the beginning and end of the epoch, reducing the observable data points to the time range of 560 to 3940ms. Of interest was whether there was evidence for reduced beta power during the location-change event and so, for these analyses we averaged beta power during the section of the epoch that included that event (1000-3940 ms of our original recording epoch).

Time-frequency analyses of EEG beta band power were conducted for the average ERSP of each participant on the electrode sites of interest over theory-of-mind brain regions. For the dmPFC, 8 electrodes were chosen around the frontal midline: E4 (F2), E5, E10, E11 (Fz), E12, E16 (A fz), E18, E19 (F1). For the rTPJ region, 6 electrodes were chosen over the right temporoparietal lobes: E98 (CP6), E102 (TP8), E103 (C6), E109, E110, E116. Data analysis was conducted using Rstudio. The dependent variable, power, was analyzed with repeated-measures analysis of variance (ANOVA) containing a two-level within-subjects condition factor (i.e., false-belief and true-belief).
Chapter 3

Results

All participants completed all 32 trials. One incorrect trial for the memory question and 17 incorrect trials for the belief question were excluded from analysis. After exclusion of bad trials due to noisy data during pre-processing, the final dataset consisted of 422 false-belief trials and 394 true-belief trials in total. Table 1 lists the participant demographic characteristics.

Table 1.

Participant Demographics

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<tr>
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<td>Stimulants</td>
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<tr>
<td>Testosterone</td>
<td>3%</td>
</tr>
<tr>
<td>Bronchodilators</td>
<td>3%</td>
</tr>
<tr>
<td>Birth Control</td>
<td>3%</td>
</tr>
<tr>
<td>Antihistamines</td>
<td>3%</td>
</tr>
</tbody>
</table>
3.1 Beta ERSP in rTPJ

Time-frequency plots of overall beta power are shown in Figure 2. There was no significant difference in mean beta power between the two conditions, $F(1,30) = .049, p = 0.826$, suggesting no main effects of task condition on beta activity in the rTPJ region. In distinguishing the beta bands, there were no significant differences in mean beta-1 power, $F(1,30) = 1.742, p = 0.197$ nor any significant difference in beta-2 power, $F(1,30) = 1.149, p = .292$, between the two conditions. These analyses suggest that there were no reliable changes in either the upper or lower beta frequency bands in the rTPJ region between the two experimental conditions. The ERPs for averaged overall beta EEG power across time for the false-belief and true-belief conditions is shown in Figure 3. The averaged overall beta, beta-1, and beta-2 power values for the false-belief and true-belief conditions are shown in Figure 4.

![Figure 2](image-url)
EEG in the true-belief condition averaged across all participants D) Topography of beta EEG over rTPJ channels in the true-belief condition averaged across all participants and location-change event. Vertical lines in time-frequency plots indicate start of location-change event (1000 to 3940ms). Horizontal lines in time-frequency plots indicate separation between beta-1 (13-20 Hz) and beta-2 (20-30 Hz) frequency bands.

**Figure 3.** Average overall beta (13-30 Hz) ERP across time. The averages were calculated by averaging channels 98, 102, 103, 109, 110, 116. Vertical black line indicates start of event of interest (location-change event).

**Figure 4.** Average overall beta (13-30 Hz), beta-1 (13-20 Hz), and beta-2 (20-30 Hz) power values in the false-belief and true-belief conditions. The averages were calculated by averaging channels 98, 102, 103, 109, 110, 116 in the time window of 1000:4000 ms. Error bars represent standard error of the mean.

### 3.2 Beta ERSP in dmPFC

Time-frequency plots of mean overall beta power in the dmPFC are shown in Figure 5.

The mean beta power for the task conditions are shown in Figure 6 and was significantly lower
in the false-belief condition than in the true-belief condition, $F(1,30) = 9.989, p = .00358$, suggesting a main effect of task condition on beta activity in the dmPFC region. Cohen’s effect size value ($d = .7$) suggests a moderate to high practical significance. In distinguishing the beta bands, time-frequency analysis was conducted on beta-1 and beta-2 bands. There were no significant differences in mean beta-1 power between the two conditions, $F(1,30) = 1.283, p = 0.266$, suggesting no main effects of task condition on beta-1 activity in the dmPFC region. However, significantly lower mean beta-2 power was found in the false-belief condition than in the true-belief condition, $F(1,30) = 18.13, p = 0.000187$. Cohen’s effect size value ($d = .9$) suggests a high practical significance. The ERPs for average overall beta EEG across time for the false-belief and true-belief conditions is shown in Figure 5. The mean overall beta, beta-1, and beta-2 power values for the task conditions are shown in Figure 7.

Figure 5. Time-frequency plots and scalp topographies of average dmPFC beta EEG activity. A) Time-frequency patterns of beta EEG in the false-belief condition averaged across all participants B) Topography of beta EEG in the false-belief condition averaged across all participants and location-change event C) Time-frequency patterns of beta EEG in the true-belief
condition averaged across all participants D) Topography of beta EEG in the true-belief condition averaged across all participants and location-change event. Vertical lines in time-frequency plots indicate start of location-change event (1000 to 3940ms). Horizontal lines in time-frequency plots indicate separation between beta-1 (13-20 Hz) and beta-2 (20-30 Hz) frequency bands.

**Figure 6.** Average overall beta (13-30 Hz) ERP across time. The averages were calculated by averaging channels 4, 5, 10, 11, 12, 16, 18, 19. Vertical black line indicates start of event of interest (location-change event).

**Figure 7.** Average overall beta (13-30 Hz), beta-1 (13-20 Hz), and beta-2 (20-30 Hz) power values in the false-belief and true-belief conditions. The averages were calculated by averaging channels 4, 5, 10, 11, 12, 16, 18, 19 in the time window of 1000:4000 ms. Error bars represent standard error of the mean. **p < .01, ***p < .001, based on repeated-measure ANOVA.
Chapter 4

Discussion

3.3 Overview

This study sought to examine whether suppression of EEG activity in the beta frequency band is associated with false-belief reasoning. A within-subjects design was employed in order to compare beta activity between false-belief and true-belief (control) conditions in a theory-of-mind task. Beta activity was hypothesized to be suppressed in the false-belief condition relative to the true-belief condition in both the dmPFC and rTPJ regions. While there were no significant differences in rTPJ beta activity between the two conditions, a main effect of condition was found for beta activity in the dmPFC, with greater beta suppression in the false-belief condition than in the true-belief condition. This dmPFC beta suppression was found in the average overall beta frequency band, and more specifically in the beta-2 frequency band. These findings provide some support for our hypothesis of the role of beta activity in the anchoring-and-adjustment during ToM reasoning. In the following paragraphs, we will discuss: 1) dmPFC beta suppression and its association with ToM, 2) rTPJ beta activity and its association with ToM, and 3) the limitations of the present study and future developments and directions.

3.4 Beta Suppression in the dmPFC

Research on the neural bases of ToM suggests the engagement of mPFC during ToM reasoning. This has been observed in fMRI research, demonstrating the activation of the mPFC when making judgments about others’ mental states (Frith & Frith, 2006). The role of the mPFC in ToM judgements has also been noted in developmental studies, showing that the functional maturation of the mPFC is correlated with greater performance in false belief tasks in children (Sabbagh et al., 2009). Children who could successfully pass a false belief task were shown to
exhibit a left-lateralized frontal late slow wave (Liu et al., 2009; Meinhardt et al., 2011; Bowman et al., 2012). In contrast, those who were not successful did not exhibit this same ERP, suggesting that ToM reasoning may be associated with discrete neural systems in the mPFC. In studies on adults, greater activation was found in the mPFC during false-belief reasoning over true-belief reasoning (Dohnel et al., 2012; Tamir & Mitchel, 2010). This has led to the conclusion that mPFC activity is activated when we think about others as dissimilar to ourselves.

While these studies have established that there is differential processing between false- and true-belief reasoning, the neurocognitive mechanisms that underlie these findings have since remained unclear. The aforementioned studies concluded that the mPFC is involved in ToM reasoning through a self-other decoupling mechanism. This refers to the cognitive process of making a distinction between one’s own and another’s mental states. While this mechanism is argued to be critical for ToM reasoning, the neuroscientific evidence for its existence remains disputed, as the concept of self-other decoupling pertains to ToM reasoning specifically. Theoretically, this makes it difficult to associate with the neuroscience literature that would otherwise allow us to better understand the neurocognitive operations behind ToM.

In the current study, we have detected dmPFC beta suppression during false-belief reasoning compared to the true-belief condition, putting forth a potential role of beta EEG as a neural correlate of ToM. In addition to the suggested role in self-other decoupling, beta activity has also been associated with other, more well-established neuroscientific functions. Research has shown that beta activity is suppressed when new information is processed bottom-up and integrated into our cognitive models (Engel & Fries, 2010). This bottom-up processing is required when encountering new social information, such as when we realize the discrepancy between our beliefs and those of others. Such an adjustment to our models requires some
cognitive flexibility, which has been shown to be influenced by beta activity. While beta enhancement results in the maintenance of cognitive models, its suppression results in flexibility in adjusting our models to new information (Engel & Fries, 2010).

Dopaminergic functioning, which has been proposed as a neurocognitive factor supporting ToM reasoning and its development, has been suggested to underlie beta activity. Clinical studies have shown that deterioration of dopaminergic pathways have been associated with beta enhancement, resulting in cognitive rigidity. On the other hand, dopamine agonists have been shown to suppress beta activity and ameliorate these symptoms (Engel & Fries, 2010). Moreover, studies on animal models suggest that beta suppression may index specific tonic and phasic dopaminergic functions, which are argued to play distinct roles in ToM (Jenkinson & Brown, 2011). Here, beta suppression was observed during false-belief reasoning over the dmPFC, suggesting that these mechanisms may be involved in ToM. Taken together, these findings provide evidence that beta suppression may reflect the neurocognitive mechanisms of the adjustment process required for reasoning about ToM online.

As exploratory analyses, this study also compared average power differences between the true-and false-belief conditions for the beta-1 (13-20 Hz) and beta-2 (20-30 Hz) frequency bands. As shown in Figure 7, greater beta-2 suppression was observed in the false-belief condition relative to the true-belief condition. This provides some evidence of differential processing between false- and true-belief reasoning in the specific beta-2 frequency band. While the beta-1 frequency band did exhibit suppression, there were no significant differences in its activity between the false- and true-belief conditions. Due to time constraints, the current study did not compare the differences between beta-1 and beta-2 suppression to draw conclusions about their
distinct roles. Thus, in the following section, beta-1 and beta-2 activity will be discussed separately.

While dopaminergic activity cannot be examined directly with the study’s methods, inferences can be made as the distinct beta-1 and beta-2 frequency bands have been associated with processes that dopamine is involved in. For instance, beta-2 frequency bands have been specifically associated with reward-processing, exhibiting an increase in power after unexpected rewards (HajiHosseini et al., 2012; Cohen et al., 2007). This has led to the conclusion that beta activity may reflect cognitive mechanisms involved in monitoring unexpected positive events (HajiHosseini et al., 2012). The current study shows significantly higher power in the beta-2 frequency band for the true-belief condition, suggesting that belief-reasoning engages systems in reward- and error-processing. Indeed, successful social interactions can be considered as rewarding stimuli, whereas unsuccessful interactions in which errors are made can prompt adjustments in our cognitive models (Krach et al., 2010). The mesocortical dopamine pathway that is argued to play a role in ToM reasoning is also part of the reward system, with phasic dopaminergic activity being associated with reward-processing (Krach et al., 2010; Wightman & Robinson, 2002). Since true-belief conditions are designed to align the beliefs of the participant and the story character, this may perhaps elicit a positive-reward feedback as the participant’s beliefs of the current event do not need to be adjusted. In contrast, false-belief conditions are designed to assess whether the participant recognizes the errors in their beliefs and makes adjustments accordingly. In considering this research on beta-2 and reward-processing, beta-2 suppression in the false-belief condition may be interpreted as reflecting an error feedback system that catalyzes the adjustment process.
While beta-2 bands are associated with feedback processing, beta-1 frequency bands have been shown to increase in power during the omission of rewards relative to receiving them (Yaple et al., 2018). If this is true, then beta-1 power differences may be elicited after the location-change event when the character searches for their pet (character-search event). The current study did not find any significant differences in beta-1 power between the two conditions, nor did it examine EEG activity beyond the location-change event. However, based on the aforementioned study, beta-1 suppression may be expected upon receiving the correct answer during the character-search event. Since most adults can correctly answer the location-change task, beta-1 suppression may be expected during the character-search event regardless of the condition. However, this may be different in a sample of preschoolers who incorrectly respond to the false-belief condition and are, thus, omitted the reward of a correct answer. This may also be different in a location-change task consisting of a violation-in-expectation in which omissions of rewards occur as the character acts inconsistently with their beliefs.

While the ToM literature does not explicitly interpret belief-reasoning in terms of reward-processing, both lines of research point to the role of the dopaminergic system in signaling errors and catalyzing the adjustment process. Both systems are linked to the mesocortical dopaminergic pathways in the PFC. As all these processes are associated with beta activity, this suggests that beta activity in the dmPFC may be reflecting a neurocognitive mechanism not specific to ToM reasoning, but a more domain-general process of error-signaling and adjustment. This opens up further discussion about the functional role the dmPFC plays in ToM reasoning. While past research has associated the dmPFC to self-other decoupling, our results, along with past research on beta activity, instead provides support for its role in an adjustment mechanism according to the anchoring-and-adjustment framework.
3.5 Beta Suppression in the rTPJ

The literature states that the rTPJ is recruited specifically for the attribution of mental states, revealing more activation in false-belief tasks (Saxe & Kanwisher, 2003). In contrast, true-belief trials reveal less activation in the rTPJ, as participants respond based on the true location of the target object and do not need to attribute beliefs (Sommer et al., 2007). Based on this idea, it was hypothesized that the rTPJ should be recruited in response to false belief stimuli. However, no significant differences in beta activity were found in the rTPJ region between the false- and true-belief conditions. This was found in the average overall beta band, as well as the distinct beta-1 and beta-2 frequency bands.

Although beta suppression was not observed, this does not mean that false-belief reasoning is not occurring in the rTPJ. It may be that ToM reasoning in the rTPJ operates at a frequency band other than beta. For instance, coherence in resting alpha EEG as a measure of the functional maturation of the rTPJ has been correlated with children’s performance in theory-of-mind tasks (Sabbagh et al., 2009). While the relation between resting alpha coherence and the function of the rTPJ during task performance is still unclear, this demonstrates that ToM activity can be associated with EEG bands in the rTPJ other than beta activity.

3.6 Limitations and Future Directions

This study brings evidence of beta suppression during false-belief reasoning. There are, however, limitations to this study that can be addressed in future research. The limitations of the study discussed here will include the minimal statistical analyses conducted, the lack of certain experimental design elements according to the anchoring-and-adjustment framework, and the biases in the research.

As can be inferred from visual inspection of Figure 6, the averaged beta power levels show maximal divergence from pre-stimulus baseline at approximately 1000 ms into the
That is, beta suppression appears to reach a trough at approximately 1000 ms into the location-change event for the false-belief condition. At around the same time point, beta activity reaches a peak in its power for the true-belief condition. This divergence in beta activity between the two conditions provides evidence for differential processing between false- and true-belief reasoning. However, most interestingly, the time range of this maximal divergence gives us an idea of when ToM reasoning may be occurring in the brain. However, due to the time constraints of this study, changes in beta activity were not analyzed along the time course of the trials. With the advantage of the high temporal resolution of EEG, a future research direction for the current dataset is to analyze the differences in power levels across the event of interest in order to determine how the processes underlying online ToM reasoning changes across time. Narrowing down the time range of ToM processing may allow us to further clarify its neurocognitive mechanisms. By knowing when to look for a specific process, then the actual neural firings responsible for that process can be measured.

While rTPJ beta suppression in the false-belief condition was not significantly different from the true-belief condition, beta activity in the rTPJ might still be worthy of further investigation. Based on visual inspection, the time-frequency plots for the rTPJ channels do demonstrate more ‘blue’ areas in the false-belief condition, potentially signifying greater suppression (Figure 2). Here, the analysis was conducted based on the assumption that beta activity in the dmPFC and rTPJ are comparable. However, it may be that baseline beta activity is different between these regions; further research is required to establish whether such differences may exist. One solution may be to compare resting-state EEG activity between these two brain regions. This would elucidate the task-independent neurocognitive mechanisms that occur in these regions, providing us with its baseline activity to serve as a control against belief-reasoning
conditions. In turn, this would help us understand whether beta activity during belief-reasoning in these two regions can be compared or whether analyses at different resolutions for each region would be required. Alternatively, as mentioned in the discussion, a different frequency band, such as alpha EEG, may be investigated in the rTPJ as it may not operate specifically within the beta band.

As mentioned, beta-1 and beta-2 bands were examined in this study as an exploratory analysis. An association between beta activity and belief-reasoning was made on the basis of beta-1 and beta-2 bands’ involvement with reward- and error-processing. While reward- and error-processing has been associated with phasic and tonic dopaminergic activity (Wightman & Robinson, 2002), it is difficult to make the claim that reward-processing can distinguish between true- and false-beliefs. This makes the results on the beta-1 and beta-2 bands difficult to interpret and draw firm conclusions from. Moreover, studies on the relationship between beta activity and phasic and tonic dopamine were conducted on rat models and no study to my knowledge has examined this possibility with human participants. Due to time constraints, beta-1 and beta-2 suppression were not compared in this study. Further analysis would be needed to determine whether these two bands are distinct during active-state and resting-state to draw conclusions about their specific functions.

Based on the literature, the dmPFC beta suppression observed here is interpreted as an index of the adjustment process. This interpretation is based on established conclusions that the dmPFC is involved in making distinctions between the self and the other (Tamir & Mitchell, 2010; Dohnel et al., 2012). Realizing the discrepancy between one’s own and another’s beliefs is critical for ToM reasoning and this is argued to be based on individual differences in egocentrism. That is, an individual’s bias towards their egocentric views may influence the
magnitude of their adjustment from their self-anchor. While past studies investigated this aspect of the anchoring-and-adjustment framework, the current study did not assess participants’ tendency towards egocentrism. Thus, conclusions about the magnitude of one’s adjustment from their self-anchor cannot be drawn. Additionally, due to the limitations of the location-change task, it cannot be confirmed whether individuals are actually adjusting from their self-anchor or a different anchor. In contrast to the anchoring-and-adjustment framework, a recent developmental theory has proposed that we may hold altercentric biases instead of an egocentric one (Kampis & Southgate, 2019). Thus, in order to support the current framework, future research on beta suppression should implement design elements to examine behavioural and cognitive tendencies towards egocentrism and whether this may be correlated with individual differences in the magnitude of beta suppression. Moreover, as anchoring-and-adjustment may be construed as a trial-to-trial process, future research may wish to implement a serial trial-by-trial ToM task in order to more accurately probe the adjustment process.

Lastly, since our final sample reflected the predominantly white, middle-class university population in eastern Canada from which it was drawn, the results here may not be generalized to the greater population. Moreover, due to the simplicity of the location-change task for an adult sample, the results here may not be generalized to different measures or settings. Thus, the current study may be lacking in external validity that would need to be addressed in future directions using a more diverse sample or a more difficult task.

3.7 Conclusion

In this study, beta suppression was found in the dmPFC during false-belief reasoning relative to the true-belief condition. This dmPFC beta suppression was found in the overall average beta frequency band, and more specifically the beta-2 band, supporting the hypothesis of
its association with ToM. This dmPFC beta suppression is interpreted to reflect an adjustment process during false-belief reasoning, further refining the functional role the dmPFC plays in ToM. These findings open up further discussion of the possible neurocognitive mechanisms in the ToM brain network and suggest beta EEG as a neural correlate of ToM worthy of further investigation.
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Appendix A
Certification of Ethics Clearance

October 08, 2019

Mr. Mark Payumo
Master’s Student
Department of Psychology
Queen’s University
Kingston, ON, K7L 3N6

GREB Ref #: GPSYC-947-19; TRAQ # 6027591
Title: "GPSYC-947-19 Theory of Mind Development and Beta EEG Activity"

Dear Mr. Payumo:

The General Research Ethics Board (GREB), by means of a delegated board review, has cleared your proposal entitled "GPSYC-947-19 Theory of Mind Development and Beta EEG Activity" for ethical compliance with the Tri-Council Guidelines (TCPS 2 (2014)) and Queen's ethics policies. In accordance with the Tri-Council Guidelines (Article 6.14) and Standard Operating Procedures (405.001), your project has been cleared for one year. You are reminded of your obligation to submit an annual renewal form prior to the annual renewal due date (access this form at http://www.queensu.ca/traq/signon.html; click on "Events;" under "Create New Event" click on "General Research Ethics Board Annual Renewal/Closure Form for Cleared Studies"). Please note that when your research project is completed, you need to submit an Annual Renewal/Closure Form in Romeo/traq indicating that the project is 'completed' so that the file can be closed. This should be submitted at the time of completion; there is no need to wait until the annual renewal due date.

You are reminded of your obligation to advise the GREB of any adverse event(s) that occur during this one-year period (access this form at http://www.queensu.ca/traq/signon.html; click on "Events;" under "Create New Event" click on "General Research Ethics Board Adverse Event Form"). An adverse event includes, but is not limited to, a complaint, a change or unexpected event that alters the level of risk for the researcher or participants or situation that requires a substantial change in approach to a participant(s). You are also advised that all adverse events must be reported to the GREB within 48 hours.

You are also reminded that all changes that might affect human participants must be cleared by the GREB. For example, you must report changes to the level of risk, applicant characteristics, and implementation of new procedures. To submit an amendment form, access the application by at http://www.queensu.ca/traq/signon.html; click on "Events;" under "Create New Event" click on "General Research Ethics Board Request for the Amendment of Approved Studies." Once submitted, these changes will automatically be sent to the Ethics Coordinator, Ms. Gail Irving, at University Research Services for further review and clearance by the GREB or Chair, GREB.

On behalf of the General Research Ethics Board, I wish you continued success in your research.

Sincerely,

[Signature]

Chair, General Research Ethics Board (GREB)
Professor Dean A. Tripp, PhD
Departments of Psychology, Anesthesiology & Urology Queen’s University

c: Dr. Mark Sabbagh, Supervisor
    Dr. Luis Flores, Chair, Unit REB
Appendix B
Certification of Ethics Clearance (COVID-19)

August 07, 2020

Mr. Mark Ephraim Payumo
Master’s Student
Department of Psychology
Queen’s University
Kingston, ON, K7L 3N6

Dear Mr. Payumo:

RE: Amendment for your study entitled: GPSYC-947-19 Theory of Mind Development and Beta EEG Activity; TRAQ # 6027591

Thank you for submitting your amendment requesting the following changes:

1) To shift the experimental procedure to recruit and test adult participants instead of children;

2) To revise the Letter of Information and Consent Form to accommodate adult participants and new research goals;

3) To add the following statement to the Consent Form: “There is a remote possibility that during your research activities you could come into contact with someone with COVID-19. If this highly unlikely event were to occur, we are required by the Public Health Unit to retain on file your email address or phone number to share with them for contact tracing purposes;”

4) To add a self-report questionnaire to the experiment;

5) To add a COVID-19 screening questionnaire for each participant;

6) To add Safety Protocols to the Experimental Procedure: (1) Contact Tracing and COVID-19 Screening; (2) Experimenter and Participant donning personal protective equipment; (3) Physical Distancing at all times except when close contact is required; (4) Completion of forms and surveys online to reduce in-lab time; (5) Modifications to EEG net application to reduce physical contact; (6) Proper disinfection of all equipment and furniture;

7) Attachments (v. 2020/08/04): (1) COVID-19 Screening Questionnaire; (2) Self – Other Differentiation Scale; (3) Revised Consent Form; (4) Revised Letter of Information.

By this letter, you have ethics approval for these changes.

Good luck with your research.

Sincerely,

Chair, General Research Ethics Board (GREB)  
Professor Dean A. Tripp, PhD  
Departments of Psychology, Anesthesiology & Urology Queen’s University

c.:  Dr. Mark Sabbagh, Supervisor
Appendix C
Letter of Information

Theory of Mind and Beta EEG Activity

You are invited to participate in a research project, funded by the Natural Sciences and Engineering Research Council (NSERC), conducted by Mark Payumo, a Master’s student in Psychology, working with Dr. Mark Sabbagh, Professor, of the Early Experience Lab within the Department of Psychology here at Queen’s University. The goal of this project is to learn more about the neural underpinnings of theory-of-mind reasoning.

What is the study about?

This study will be investigating the neuro-cognitive factors involved in theory of mind. Theory of mind is the understanding that people's behaviours are guided by internal mental states, such as their intentions, desires, and beliefs. There is evidence to suggest that brain regions such as the dorsomedial prefrontal cortex (dmPFC) and the right temporo-parietal junction (rTPJ) are involved in reasoning about others’ beliefs. However, further research is required to examine the neural activity occurring in these brain regions during belief-reasoning in real-time. Using electroencephalography (EEG), we will be examining your brain rhythms as you try to reason about others' beliefs. There is evidence to suggest that brainwaves at frequencies of 13-30 Hz (i.e., beta waves) may reflect neural processes engaged as we reason about the beliefs of others. Investigating resting and online beta EEG activity may then provide us insight into the brain mechanisms that contribute to theory-of-mind reasoning.

What will I be doing?

If you agree to participate, you will take part in resting-state and active-state EEG tasks. In these tasks, you will sit in a comfortable booster seat across a computer. In order to obtain resting EEG data, you will be instructed to sit as still as possible and to fixate on an image until the experimenter indicates the end of the block. In the active EEG task, you will participate in a multi-trial false-belief task. False-belief reasoning is the understanding that others may hold beliefs that are distinct and separate from one’s own. Tasks that test this false-belief understanding are considered to be a robust measure of theory-of-mind performance. In this task, you will be instructed to watch and listen to videos of cartoon characters interacting with their pet animals. After each story plays out, you will then be asked to make judgments about the characters' beliefs. We estimate that you will be in our lab for approximately 30-40 minutes to complete these tasks.

What are the risks and benefits to participating in this study?

During the EEG tasks, we will record your brain electrical activity with a kind of hair net that fits comfortably over your head and positions “sensor electrodes” gently on the surface of your scalp. During the fitting of the net, you may feel some mild physical discomfort. For instance, you may find the wet sponges to be a bit cool at first. When we’re finished with the EEG tasks, we’ll take off the cap. We do this by first loosening it and then gently lifting it off
from the front to the back. There is some risk for some mild physical discomfort here as there may be some gentle tugs at the hair. If, for any reason, you feel uncomfortable or upset during the session, feel free to interrupt the procedure at any time and let the experimenter know what changes you would like to be made. The EEG recording procedure is completely non-invasive and has very little risk involved. The only thing that ever touches your head is the sponge, which is pre-soaked in a mild electrolyte solution (salt water and baby shampoo). All materials that touch you are non-irritating and have been disinfected before each use. Our researchers are trained to minimize this possibility and every effort will be made to ensure your comfort.

The research participants will not incur any direct benefits themselves, although participants tested in our lab with similar protocols typically enjoy themselves and indicate that they would come back again if asked. The benefits to the research community are more substantial. This significant work will provide insight into the development of theory-of-mind.

Due to the in-lab procedure of this experiment, participants are exposed to risks of COVID-19 transmission. Although it is impossible to eliminate these risks completely, we have taken a number of steps to mitigate these risks. These safeguards include: contact tracing, wearing of personal protective equipment by the experimenter and participant, physical distancing, completion of forms and questionnaires online to reduce in-lab time, modifications to EEG net application to reduce physical contact, and thorough disinfection of all equipment.

**Will the information be kept confidential?**

Our sessions will be videotaped so that researchers involved in our project can access it for academic and scholarly purposes. In order to ensure that the information is confidential, and that your anonymity is maintained, we will record a number rather than your names on the videotape, and on any summaries of the data. Paper and digital records will be kept in a locked filing cabinet here at Queen’s and kept indefinitely, so they remain accessible to researchers directly involved with the study. When we present our findings at scientific meetings or in journals, scientific standards requires us to make the data that we use in our analyses available to anyone in the scientific community with an interest in verifying our reports. These records will be anonymized to minimize the possibility that your specific performance can be connected with identifying information. For instance, while our secured records will have your information (i.e. age, gender), only your participant number will be released to the scientific community. However, there is always the possibility that observers or other researchers will be able to identify you from videos shown. If you do not wish to have your video or behavioural data shared with other researchers, we will remove them from all presentations and publications, and restrict access to directly-involved researchers only. The Queen's General Research Ethics Board (GREB) may request access to study data to ensure that the researcher(s) have or are meeting their ethical obligations in conducting this research. **NOTE: GREB is bound by confidentiality and will not disclose any personal information.**

**What are my rights as a participant in this study?**

Participation is voluntary and you can decline to participate in the research or any aspect of the research at any time without penalty/loss of benefits. If you decide to participate, you will be free to withdraw your consent and discontinue participation at any time, by indicating this verbally to the researcher or research assistant. While most participants typically find these
sessions fun, occasionally participants may feel uncomfortable. If you notify us that you do not wish to continue to participate in the study, the administration of tasks will be stopped and you will receive full compensation for participating in the session. All data collected will be destroyed to ensure confidentiality. If you notify us that you wish all of your data to be withdrawn from the study at any time, including during the study or up to three months from the date of participation, by emailing Mark Payumo at 11mep13@queensu.ca, we will destroy the corresponding data right away. Note that it is not possible to withdraw data after we have published the anonymized data in aggregate form. You can keep a copy of this letter of information for your records.

Will I be compensated for my participation?

As a token of our appreciation, $15 cash will be given to you after participation.

Who should I contact if I have questions?

If you have any questions about your participation in this project at any time, please feel free to contact Mark Payumo (11mep13@queensu.ca) and/or Dr. Mark Sabbagh (sabbagh@queensu.ca). If you have any ethics concerns please contact the General Research Ethics Board (GREB) at 1-844-535-2988 (Toll free in North America) or chair.GREB@queensu.ca. Call 1-613-533-2988 if outside North America. Please note that GREB communicates in English only.

Again, thank you. Your interest in participating in this research study is greatly appreciated.

Mark Payumo
Master’s Student in Developmental Psychology
11mep13@queensu.ca

Mark A. Sabbagh, Ph.D.
Director, Early Experience Lab
sabbagh@queensu.ca
Appendix D
Consent Form

Theory-of-Mind and Beta EEG Activity

By signing below, I indicate that I have read the letter of information describing the purpose of Mark Payumo and Dr. Mark A. Sabbagh’s research investigating “Theory of Mind Development and Beta EEGActivity” and have had any questions answered to my satisfaction.

I understand that my involvement in this research consists of having my brain responses (EEG) recorded while resting and while watching a video presented on a computer screen and participating in a task that assesses theory-of-mind performance. I understand that the entire study should last about 30-40 minutes. Information from this research will help investigators understand the brain mechanisms that contribute to theory-of-mind reasoning. I understand that I will receive $15 cash as thanks for participating.

I understand that my participation in this study is voluntary and that I may withdraw my data from the study at any time, including during the study or up to three months from the date of participation, by emailing Mark Payumo at 11mep13@queensu.ca. I understand that every effort will be made to maintain the confidentiality of the data now and in the future. Only the primary researcher, Mark Payumo, the supervisor, Dr. Mark A. Sabbagh, and selected laboratory research assistants in the Early Experience Lab will have access to this data during collection and processing. Paper and digital records will be kept in a locked filing cabinet here at Queen’s and kept indefinitely, so they remain accessible to researchers directly involved with the study. In the event that other researchers inquire about our data, scientific rigor demands that we make available to them any relevant anonymized raw data. The data may also be published in professional journals or presented at scientific conferences, but any such presentations will be of general findings and will never breach individual confidentiality. Finally, I understand that I may directly contact the Chair of the General Research Ethics Board at 1-844-535-2988 (toll free in North America) or chair.GREB@queensu.ca with any questions, concerns, or complaints.

There is a remote possibility that during your research activities you could come into contact with someone with COVID-19. If this highly unlikely event were to occur, we are required by the Public Health Unit to retain on file your email address or phone number to share with them for contact tracing purposes.

You have not waived any legal rights by consenting to participate in this study.

Name: ________________________
Date of Birth (MM/DD/YYYY): _____________________ Gender: M F
Signature: _____________________ Date: _____________________

To send you a summary of the findings, and keep you informed about research in our lab, we ask for your email address: _________________________
### Appendix E
Demographics Overview

<table>
<thead>
<tr>
<th>SEX</th>
<th>1 = male</th>
<th>2 = female</th>
<th>3 = Intersex</th>
<th>4 = prefer to not disclose information concerning my sex</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGE</td>
<td></td>
<td></td>
<td></td>
<td>__ __ yrs</td>
</tr>
<tr>
<td>ETHNICITY</td>
<td>1 = White (European descent)</td>
<td>2 = Black (eg. African-Canadian,)</td>
<td>3 = Asian</td>
<td>4 = First Nations</td>
</tr>
<tr>
<td>YEAR AT QUEEN'S</td>
<td></td>
<td></td>
<td></td>
<td>__ __</td>
</tr>
<tr>
<td>HANDEDNESS</td>
<td>1 = right handed</td>
<td>2 = left handed</td>
<td>3 = don't have a dominant handedness</td>
<td></td>
</tr>
<tr>
<td>IF YOU ANSWERED 3, WHICH HAND DO YOU TYPICALLY WRITE WITH?</td>
<td>1 = right</td>
<td>2 = left</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ARE YOU CURRENTLY SEEKING TREATMENT FOR DEPRESSION OR ANY OTHER PSYCHOLOGICAL DISORDER? (e.g., anxiety, anorexia or bulimia, etc.)</td>
<td>0 = no treatment</td>
<td>1 = medication</td>
<td>2 = therapy/counseling</td>
<td>3 = medication and therapy</td>
</tr>
<tr>
<td>WHAT MEDICATIONS ARE YOU CURRENTLY TAKING?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>