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Theory of mind (ToM) is defined as the ability to imagine and reason about states of mind that others hold. This skill is essential for functioning in the social world and core deficits in ToM are seen in the autism spectrum disorder (ASD) population. Recent studies have shown ToM to be functionally lateralized on the right side of the brain, specifically located in the right temporoparietal junction (RTPJ; Saxe & Wexler, 2005). This study examined to what extent ToM is right lateralized, and sought to test the right lateralization account with a behavioural study. A series of 3 experiments were performed, which compared participants' reaction times to ToM information presented to the left and right visual fields and motor responses with left and right hands. Based on well-established findings of the motor advantages of one's dominant hand (Annett, 1970), a right hand advantage on the present task was predicted if ToM is bilaterally distributed across the two sides of the brain. However, if ToM is right lateralized, the left hand should receive its own advantage because the right hemisphere controls it, which predicts that the left hand should be as fast as, if not faster, than the right hand. No significant differences between the two presentation sides or responding hands were found, thus providing moderate support for the right lateralization of ToM. The implications of this in terms of the ASD population are discussed, as well as suggestions for future research that will build upon this finding.

Social interaction is one of the most integral aspects of the human experience. Critical to successful social interaction is the ability to infer the mental states of others. Premack and Woodruff (1978) coined this faculty, theory of mind (ToM). More specifically, it is defined as the capacity to imagine or represent states of mind that we, or others may hold (Baron-Cohen, 1997). Baron-Cohen (1997) illustrates this concept effectively. Imagine seeing an individual walk into a room, look around, and subsequently walk out. Upon seeing this, we immediately begin to formulate hypotheses about this person's intent and purpose. Perhaps they were looking for something and could not find it, or maybe they just remembered they were late to pick someone up and had to leave. Whatever the case, we understand that there was a logical reason for this due to our inferences of this individual's mental state. This demonstrates our ability to imagine and rationalize about others' mental states; in other words, ToM. This ability seems natural, and presupposes that every human being possesses it; however, many individuals show varying degrees of deficits in ToM, including individuals with autism spectrum disorder (ASD). Many characteristic features of ASD are in the social-cognitive domain. These include impairments in social interaction, treating objects and people alike, and diminished pretend play (Wing, Gould, Yeates, & Brierley, 1977). Baron-Cohen et al. (1985) proposed that these deficits could all be traced back to these individuals' impairments in ToM. Without the understanding that others hold states of mind that are unique and distinct, social impairments emerge. Research in the domain of ToM is a critical piece of the ASD puzzle. The present study will examine to what extent ToM is lateralized in the brain. Furthermore, this

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exploration into the neural underpinnings of ToM will contribute to the body of literature working towards the understanding and treatment of ASD.

Testing for ToM

Baron-Cohen et al. (1985) developed a simple behavioural paradigm to test individuals' abilities to attribute false beliefs about object location to others. This task, called the "Sally-Anne Task", and many variations of it, have been used to test for ToM abilities. In this task, participants watch, hear or read a scenario involving two characters, Sally and Anne. Sally places a marble in her basket then leaves the room. While Sally is gone, naughty Anne moves the marble from Sally's basket to a box beside the basket. When Sally returns, the critical question is then asked: where will Sally look for her marble? Those who possess ToM will understand that Sally would look for her marble in the basket, where she last put it, because she is not aware that it has been moved. Those who lack ToM cannot understand that Sally possess beliefs that are different from his or her own, and will hypothesize that Sally will look for her marble in the box. The present study makes use of a variation of this task in order to test for ToM abilities.

Lateralization Studies

There is a large amount of evidence that the human brain is lateralized in function, as shown by Sperry and Gazzaniga's (1967) seminal split-brain research. This research began when patients had their corpus callosums severed in order to treat severe epilepsy. These patients became ideal natural experiments for studying the unique and diverging abilities of each hemisphere of the brain. This research contributed to the widespread notion that certain functions and processes are specialized to one hemisphere of the brain, an idea that had been acknowledged for many years. For instance, in 1861, Paul Broca determined that the left frontal lobe brain area, now referred to as "Broca's area", is important for speech production (Eling, 1984). In a similar vein, in 1871, Carl Wernicke found that the left posterior, superior temporal gyrus, now called "Wernicke's area" is responsible for language comprehension (Geschwind, 1974).

Many other functions have been found to show functional laterality in the brain, one of which is ToM. Neuroimaging research has uncovered ToM to be a right-lateralized function in the brain (Saxe & Wexler, 2005; Young, Camprodon, Hauser, Pascual-Leone, & Saxe, 2010). Saxe and Wexler (2005) sought to determine which brain regions are involved in ToM processing. Regions being explored in this study were the right temporoparietal junction (RTPJ), left temporoparietal junction (LTPJ), posterior cingulate, and the medial prefrontal cortex. It was hypothesized that brain regions that are truly selectively involved in ToM processing will respond minimally to background information about the protagonist in a story, and will respond at greater levels when mental state information is provided. Saxe and Wexler (2005) found that subjects undergoing an fMRI demonstrated the highest activation in the RTPJ when hearing mental state information. These results indicate that the RTPJ is highly involved in ToM processing, supporting the view that ToM is right lateralized in the brain (Saxe & Wexler, 2005).

Further support for the right lateralization of ToM is derived from another study done by Young et al. (2010). This study investigated the role of the RTPJ in mental state reasoning by disrupting its function using Transcranial Magnetic Stimulation (TMS). While undergoing TMS to the RTPJ or to a control region of the right hemisphere, participants were given moral judgment scenarios where the protagonist acted on either a negative or neutral belief, and then caused either a negative or neutral outcome.

Participants' moral judgments were then compared. Results demonstrated that when the RTPJ was disrupted, participants based their moral judgments on the outcome of the scenario, regardless of the protagonist's beliefs and intentions. The scenario was deemed moral as long as the outcome was positive, even if the protagonist had negative intentions. In control condition, participants based moral judgments on the protagonist's beliefs and intentions. The scenario was only deemed moral if the protagonist had good intentions, and did not believe their action would cause any harm, which is generally how moral judgments are made in real life situations. This study demonstrated that the RTPJ is necessary for formulating moral judgments. Making moral judgments, at its core, requires the use of ToM to determine whether others' true intentions are moral or not. This study further strengthens the findings that the RTPJ is in fact involved in making inferences about others' mental states, beliefs, and intentions; or more broadly, ToM (Young et al., 2010).

The Corpus Callosum

As previously discussed, many functions are lateralized in the brain, and some tasks require the use of more than one of these functions. The brain's vehicle for communicating between the two hemispheres is the corpus callosum. The corpus callosum is a bundle of nerve fibers that connects and sends information between the left and right hemispheres (Weber, 2005). Since ToM develops over time, it is important to examine how the corpus callosum develops alongside it.

The function of the corpus callosum is of utmost importance for the present study, as through the use of different presentation and output sides, the interhemispheric transfer rate will have large implications on the results. Poffenberger (1912), a pioneer in interhemispheric transfer studies, developed a simple paradigm in which visual stimuli is presented to either the left or right visual field, and responses are made with either the left or right hand. Poffenberger (1912) demonstrated that when responses are crossed, meaning left visual field and right hand or vice versa, reaction times are significantly slower than when uncrossed. When information is presented to the left visual field, it travels directly to the right hemisphere of the brain. Making a response using the right hand would require this information to be sent to the left hemisphere across the corpus callosum before a signal can be sent out to the right hand, resulting in a cost in reaction time for the task. The present study will use a similar paradigm, in order to target the right and left hemispheres individually, to explore the extent to which ToM is right-lateralized. If ToM is in fact highly right-lateralized, then ToM tasks that require right hand responses are predicted to have a slight delay compared to left hand responses because of the need for interhemispheric transfer. This is just one example of several applications of Poffenberger's (1912) paradigm that will be utilized in the present study.

Dominant Hand Advantage

It is well documented that human beings by and large have a preferred (i.e., dominant) hand for motor tasks (Annett, 1970; Annett, Hudson, & Turner, 1974; Annett, Annett, Hudson, & Truner, 1979). Annett (1970) has shown that performance of motor tasks is both quicker and more accurate with this dominant hand. Furthermore, it is estimated that between 70 and 95 percent of individuals are right-handed (Coren & Porac, 1977). While there is a small minority of participants in the present study who are left-handed, for the remainder of the paper, participants will be discussed in terms of the right-handed majority. This is due to the fact that left-handed participants had no significant impact on the results of the present study, due to the small number of such participants. As such, in the present study, the large majority of individuals are predicted to have a right hand motor advantage on the tasks. However, the *motor* disadvantage in using the non-dominant left hand should be offset by the *cognitive* advantage in using this left hand, due to its direct route to the right hemisphere of the brain, the proposed location of ToM. If responses made with the left hand were just as quick as responses made with the right hand, this would provide mild support for the right lateralization of ToM, as the expected right hand advantage would have disappeared.

Gaps in the Literature

Though the literature on lateralization of ToM is thorough, it is not entirely exhaustive. The present study seeks to illuminate the extent to which ToM is right-lateralized. The research of Saxe and Wexler (2005) and Young et al. (2010) provides evidence that the RTPJ is involved in mental state reasoning. Previous research failed to uncover whether ToM information is solely processed in the right hemisphere, or if it requires contribution from various centers in the left hemisphere. Furthermore, previous studies used neuroimaging technology to study this lateralization, but the present study made use of a behavioural method, which is novel in the study of the lateralization of ToM. Using a unique paradigm, the present study provided insight into the extent to which ToM is right lateralized, if at all, without participants undergoing any scans at all.

The Present Research

The present study aimed to investigate ToM using a novel approach, emphasizing the extent to which it is right lateralized, and how presentation and output mode affect reaction time and accuracy in tasks. A divided field paradigm was used, where an animation of a modified Sally-Anne task played on either visual field. Participants were required to watch the animation and then respond with a button press whether the protagonist acted according to their expectations or not. The within subjects variables were as follows: truth-value (true and false); expectedness (expected and unexpected); presentation side/responding hand (left and right). The dependent variables were reaction time and accuracy. Three variations of this general paradigm were tested. In Experiment 1, ToM information was presented to alternating visual fields and responses were made with matched alternating hands. In Experiment 2, participants responded with their dominant hands only, in order to diminish the dominant hand advantage. Finally, in Experiment 3, ToM information was presented to the middle of the screen, in order to isolate the dominant hand advantage.

There are multiple hypotheses for the current study. Firstly, true belief trials will produce quicker and more accurate responses than false belief trials. This is due to the fact that false belief inferences require more cognitive processing than true belief inferences, as they command the use of ToM. The second hypothesis predicts that expected trials will produce quicker and more accurate responses than unexpected trials. The reason for this is that trials where the outcome of the animation is unexpected require more cognitive and higher order ToM processing than trials with expected outcomes. Third, it is hypothesized that there will be an Expectedness X Presentation side/responding hand interaction such that trials with the unexpected condition will demonstrate a greater degree of left presentation side/responding hand advantage than trials with the expected condition. This is based on Saxe and Wexler's (2005) finding that more ToM processing occurs when people behave in unexpected ways. Therefore, the difference in reaction time and accuracy between left and right presentation side/responding hand is predicted to be greater in unexpected trials compared to expected trials.

The final and most critical hypothesis has both a strong and weak prediction. The strong prediction is that trials with the left responding hand/presentation side will produce more quick and accurate responses than trials with the right responding hand/presentation side. Presenting information to the left visual field sends it directly to the right hemisphere for ToM processing, and in order to use the left hand to make a response, activation of the right hemisphere is necessary. Therefore, the combination of left visual field and left hand responses require the use of only the right hemisphere, eliminating the need for crossing over through the corpus callosum. When stimuli is presented to the right visual field, it travels directly to the left hemisphere, has to cross over the corpus callosum before ToM information can be computed in the right hemisphere, and then cross back over in order for a response to be made with the right hand. This crossover is predicted to result in a cost in reaction time. The weak prediction is that left and right presentation side/responding hand trials will have no difference in reaction time and accuracy. Even though hand dominance studies (Annett, 1970; Annett, Hudson, & Turner, 1974) predict that the right presentation side/responding hand will have a motor advantage, it is hypothesized that this will be offset by the cognitive advantage of the left presentation side/responding hand, due to its direct route to the right hemisphere. Therefore, no significant difference in reaction time and accuracy between the left and right presentation side/responding hand would provide moderate support for the right lateralization of ToM.

Experiment 1

Method

Participants. Eighty-six undergraduates from Western University were tested. Students were recruited through the psychology department participant pool and completed the study in partial fulfillment of course credit. Out of the 86 participants, eight participants were not analyzed for failing to meet accuracy criteria of 62.5% correct, which is the point at which performance is statistically better than chance. Thus, the final sample included 78 participants (33 male and 45 female, 71 right-handed and 7 left-handed, ages 17 to 21, M= 18.61 years, SD= 0.73 years).

Materials. ***Computers*****.** Computers used throughout the study were *Dell XPS15s* with a screen resolution of 1920 x 1080. Stimuli were presented and responses recorded using *PsychoPy version 1.81.01*. The animation subtended a visual angle of 10.5° and had an eccentricity of 7.25° degrees to the left or right of midline, depending on the block.

False belief animation. This animation begins with an agent placing their rabbit into one of two boxes in a room. The agent then exits the room through a door (false belief condition) or remains in the room (true belief condition). The rabbit then hops from the original box to the other one. A fixation cross then appears on the screen and an image flashes for 200 milliseconds on either the right or left visual field, or the center of the screen, depending on the experiment and condition. The image that is flashed consists of the agent in front of one of the two boxes as if to look in it. The condition is expected when the agent is in front of the box where they would reasonably believe the rabbit to be based on his or her knowledge. That is, in the true belief condition the agent was present while the rabbit moved, thus expecting it to be in the second box. Alternatively, in the false belief condition, the agent was absent while the rabbit moved, thus expecting it to be in the first box. The condition is unexpected when the agent is *not* in front of the box where he or she would reasonable expect the rabbit to be based on his or her knowledge.

Edinburgh Handedness Inventory. The Edinburgh Handedness Inventory was used to determine the participants' dominant hand (EHI; Oldfield, 1971). The EHI consists of ten questions where participants are instructed to indicate which hand they prefer to use for each of the listed activities. Examples of items on this inventory include: writing, throwing, using scissors, and striking a match. The EHI has been found to be a reliable quantitative measurement tool (Ransil & Schachter, 1994). Results of this inventory indicate whether the participant is predominantly right-handed or left-handed.

Instructions survey. A survey was used in order to determine whether the participants understood the instructions or not. This survey consisted of five questions regarding the task they had just completed. Examples of questions include: "Briefly describe the instructions you were given" and "Did you use any strategies in completing the task".

Procedure. Participants were assessed in a quiet room on a university campus. First, participants were given a letter of information and were asked to provide consent on the consent form given. Next, participants were told to follow the instructions on the computer in front of them. Participants sat 57cm from the screen in order to ensure lateralized presentation sides. After reading instructions, participants were prompted to rest their fingers on the "H" key throughout the course of the task (which is in between the "Y" and "N" keys). Participants were told to watch the animation and that following the animation a fixation cross would appear on the screen, on which they should direct their gaze. An image was then flashed for 200 milliseconds on either the left or right visual field, depending on the block. Participants then made a response indicating whether the final image was expected or unexpected by hitting the "Y" key if what the final image portrayed was expected, and "N" if it was unexpected. Participants were instructed to use their left hands during left visual field trials, and their right hands during right visual field trials. The present study contained three within-subject factors. The three within-subject factors were as follows: truth value (true belief and false belief); expectedness (expected and unexpected); and visual field (left and right), for a total of eight conditions. Participants each experienced a total of 40 trials of this task (five trials for each of the eight conditions). Once the task was complete, participants were asked to fill out the EHI as well as the instructions survey. After completing the surveys, the participants were debriefed on the study and then given permission to leave. This study took approximately 30 minutes to complete.

Results

Exclusion criteria. All trials with incorrect responses were removed before the analyses. This was done because it is difficult to interpret what processes are involved in incorrect trials. At the individual participant level, if reaction time for a trial was ± 3 S.D. from the participant's own mean, the data point was removed to avoid contamination of the data.

Analysis of Variance. Means and standard deviations for reaction times in each condition are shown in Table 1. A 2x2x2 repeated measures analysis of variance (ANOVA) was conducted using truth value (2 levels: true and false), expectedness (2 levels: expected and unexpected), and presentation side/responding hand (2 levels: left and right) as the within subject variables. A significant main effect of expectedness was found, $F(1,67) = 5.87$, $p = .018$, $\eta_p^2 = .081$. Reaction times were significantly quicker on expected trials ($M = .98$, $SD = .32$) compared to unexpected trials ($M = 1.06$, $SD = .34$) (see Figure 1). Furthermore, an Expectedness X Truth value interaction was found, $F(1,67) = 5.22$, $p = .025$, $\eta_p^2 = .072$. Post

Table 1

Means and Standard Deviations of Reaction Times to ToM Information as a Function of Presentation Side/Responding Hand, Expectedness, and Truth Value for Experiment 1

	Right			Left	
	M	*SD*		*M*	*SD*
			Expected		
True Belief	0.94	0.47		0.91	0.24
False Belief	1.01	0.27		1.05	0.28
			Unexpected		
True Belief	1.10	0.64		1.10	0.24
False Belief	0.99	0.25		1.05	0.22

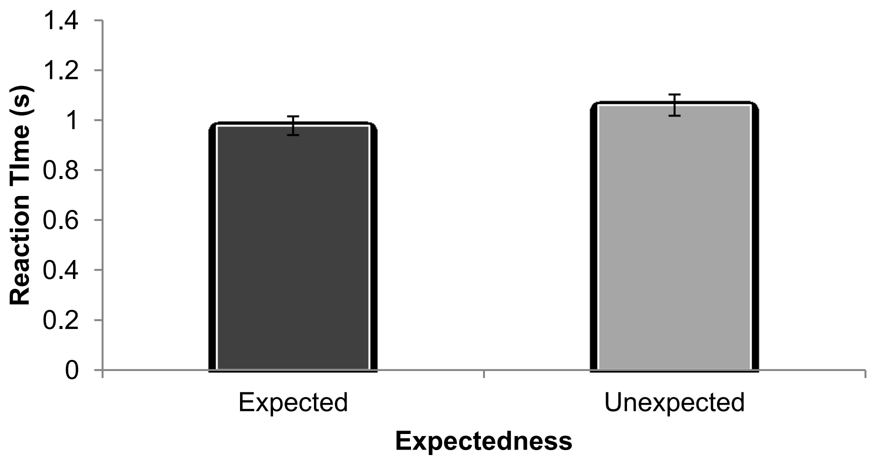

Figure 1. Mean (± S.E.M.) reaction time (s) for expected vs. unexpected conditions. Reaction times on expected trials were significantly quicker than reaction times on unexpected trials, *p*= .018.

hoc t-tests were then conducted to determine the driving force of the interaction. A significant difference was found such that reaction times to conditions that were true belief and expected were significantly quicker than conditions that were false belief and expected, *t*(67) = 2.67, *p*= .01, *d*= .324. A significant difference was also found such that reaction times to conditions that were true belief and expected were significantly quicker than conditions that were true belief and unexpected, *t*(67)= -2.55, *p*= .013, *d*= .309. This enforces prior notions that less cognitive processing is involved in true belief inferences, as well as in situations where the outcome is expected. As such, the combination of true belief and expected produced the fastest responses. Additionally, no significant main effect of truth value was found. Therefore, participants' reaction times on true belief trials were not significantly quicker than reaction times on false belief trials. No significant main effect of presentation side/responding hand was found. Thus, participants' reaction times on left trials were not significantly quicker than reaction times on right trials. Finally, no significant Presentation side/responding hand X

Expectedness interaction was found. Therefore, participants' reaction times on left trials did not become significantly quicker with unexpected trials.

Bayesian Analysis. Given that the ANOVA did not provide evidence for a difference between left and right presentation side/responding hand, Bayesian analyses were applied to examine whether there was evidence for no significant difference between left and right presentation side/responding hand. The Bayes factor gave the odds of 6.62:1, which are in favor of the weak hypothesis and provide substantial support that there is no significant difference in RT for left (*M*= 1.03, *SD*= .25) and right (*M*= 1.01, *SD*= .41) presentation side/responding hand (see Figure 2).

Experiment 2

Method

Participants. Forty-four undergraduates from Western University were tested. Students were recruited through the psychology department subject pool and completed the study in partial fulfillment of course credit. Out of the 44 participants, four participants were not analyzed for failing to meet accuracy criteria. Thus, the final sample included 40 participants (18 male and 22 female, 35 right-handed and 5 left-handed, ages 17 to 21, *M*= 19.02 years, *SD*= 0.57 years).

Materials and Procedure. The materials and procedure of Experiment 2 were identical to those in Experiment 1, except that participants were instructed to use their dominant hand throughout the course of the experiment. As in Experiment 1, the presentation side of the final still alternated depending on the block.

Results

Exclusion criteria. Exclusion criteria for Experiment 2 were identical to that of Experiment 1.

Analysis of Variance. Means and standard deviations for each condition are shown in Table 2. A 2x2x2 repeated measures analysis of variance (ANOVA) was conducted using truth value (2 levels: true and false), expectedness (2 levels: expected and unexpected), and presentation side/responding hand (2 levels: left and right) as the within subject variables. No significant main effect of expectedness was found. Reaction times were not significantly quicker on expected trials compared to unexpected trials. A marginal effect of truth value was found, $F(1,39)= 3.21$, $p= .081$, $\eta_p^2=$ .076. Therefore, participants' reaction times on true belief trials (*M*= .92, *SD*= .30) were marginally quicker than reaction times on false belief trials (*M*= .97, *SD*=.26). No significant main effect of presentation side/responding hand was found. Therefore, participants' reaction times on left trials were not significantly quicker than reaction times on right trials. Finally, no significant Presentation side/responding hand X Expectedness interaction was found. Thus, participants' reaction times on left trials did not become significantly quicker with unexpected trials.

Bayesian Analysis. Since the ANOVA did not provide evidence for a difference between left and right presentation side/responding hand, Bayesian analyses were applied to examine whether there was evidence for no significant difference between left and right presentation side/responding hand. The Bayes factor gave the odds of 3.44:1, which are in favor of the weak hypothesis and provide weak support that there is no significant difference in RT for left (*M*= 92, *SD*= .33) and right (*M*= .97, *SD*= .19) presentation side/responding hand (see Figure 3).

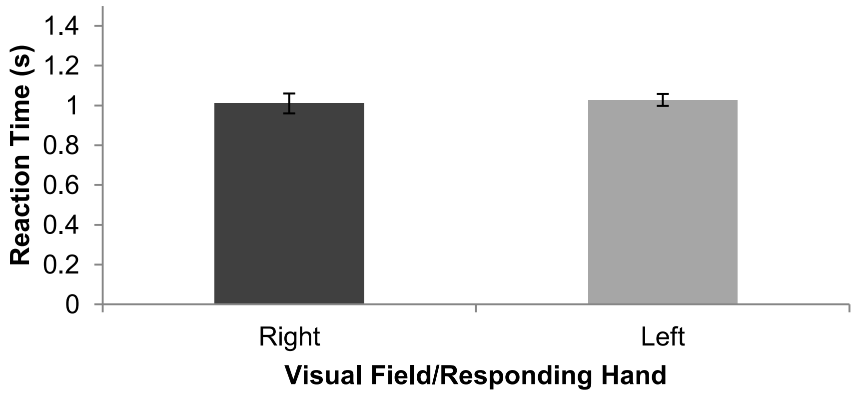

Figure 2. Mean (± S.E.M.) reaction time (s) for right vs. left visual field/responding hand. No significant difference was found for mean reaction time, *p*= .638, *BF*= 6.62.

Table 2

Means and Standard Deviations of Reaction Times to ToM Information as a Function of Presentation Side/Responding Hand, Expectedness, and Truth Value for Experiment 2

	Right		Left	
	M	*SD*	*M*	*SD*
		Expected		
True Belief	0.87	0.25	0.87	0.21
False Belief	1.00	0.34	0.94	0.24
		Unexpected		
True Belief	1.02	0.35	0.91	0.16
False Belief	0.98	0.23	0.96	0.21

Experiment 3

Method

Participants. Thirty-six undergraduates from Western University were tested. Students were recruited through the psychology department subject pool and completed the study in partial fulfillment of course credit. Out of the 36 participants, five participants were not analyzed for failing to meet accuracy criteria. Thus, the final sample included 31 participants (15 male and 16 female, 30 right-handed and 1 left-handed, ages 17 to 21, *M*= 19.13 years, *SD*= 1.17 years).

Materials and Procedure. The materials and procedure of Experiment 3 were identical to those in Experiments 1 and 2, except that the final still image was always projected to the center of the screen, and the responding hand alternated depending on the block.

Results

Exclusion criteria. Exclusion criteria for Experiment 3 were identical to that of Experiments 1 and 2.

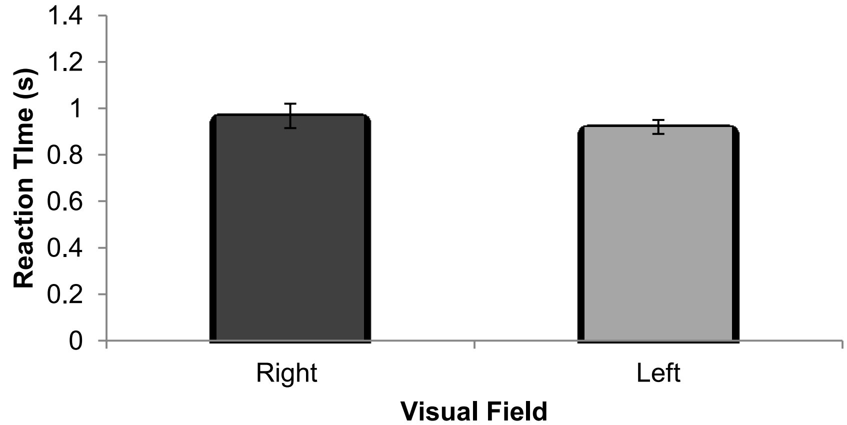

Figure 3. Mean (± S.E.M.) reaction time (s) for right vs. left visual field. No significant difference was found for mean reaction time, $p= .307$, $BF= 3.44$.

Analysis of Variance. Means and standard deviations for each condition are shown in Table 3. A 2x2x2 repeated measures analysis of variance (ANOVA) was conducted using truth value (2 levels: true and false), expectedness (2 levels: expected and unexpected), and presentation side/responding hand (2 levels: left and right) as the within subject variables. A significant main effect of expectedness was found, $F(1,67) = 5.29$, $p < .029$, $\eta_p^2 = .154$. Reaction times were significantly quicker on expected trials ($M= .85$, $SD= .20$) compared to unexpected trials ($M= .90$, $SD= .22$) (see Figure 4). No significant main effect of truth value was found. Therefore, participants' reaction times on true belief trials were not significantly quicker than reaction times on false belief trials. No significant main effect of presentation side/responding hand was found. Participants' reaction times on left trials were not significantly quicker than reaction times on right trials. Finally, no significant Presentation side/responding hand X Expectedness interaction was found. Thus, participants' reaction times on left trials did not become significantly quicker with unexpected trials.

Bayesian Analysis. Given that the ANOVA did not provide evidence for a difference between left and right presentation side/responding hand, Bayesian analyses were applied to examine whether there was evidence for no significant difference between left and right presentation side/responding hand. The Bayes factor gave the odds of 6.85:1, which are in favor of the weak hypothesis and provide substantial support that there is no significant difference in RT for left ($M= .88$, $SD= .21$) and right ($M= .87$, $SD= .23$) presentation side/responding hand (see Figure 5).

Discussion

The present study sought to investigate the degree to which ToM is right lateralized in the brain. Past neuroimaging studies have shown that ToM is a right lateralized function; specifically located in the RTPJ. Saxe and Wexler (2005) found that the RTPJ had no clear BOLD response pattern when background information about a character was mentioned, and only showed a spike in activity when mental state information about the character was mentioned. While the laterality of ToM account was originally motivated by neuroimaging results, the present study obtained converging

Table 3
Means and Standard Deviations of Reaction Times to ToM Information as a Function of Presentation Side/Responding Hand, Expectedness, and Truth Value for Experiment 3

	Right		Left	
	M	*SD*	*M*	*SD*
	Expected			
True Belief	0.86	0.23	0.81	0.17
False Belief	0.85	0.20	0.88	0.21
	Unexpected			
True Belief	0.88	0.28	0.90	0.20
False Belief	0.90	0.20	0.93	0.19

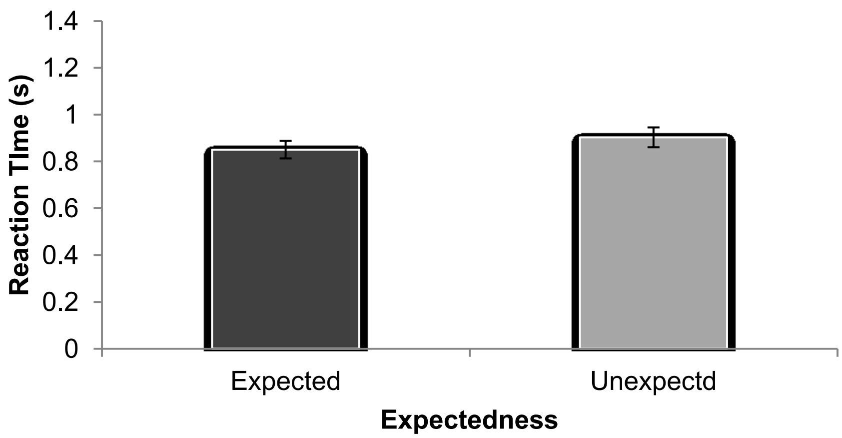

Figure 4. Mean (± S.E.M.) reaction time (s) for expected vs. unexpected conditions. Reaction times on expected trials were significantly quicker than reaction times on unexpected trials, $p = .029$.

evidence for this by using a novel behavioural method and provided moderate support for the right lateralization of ToM. Since the present task involved the use of motor responses, a right hand advantage should have been seen, due to extensive research findings that individuals have an advantage on tasks using their preferred hand, and the preferred hand is the right hand in the majority of cases (Annett, Annett, Hudson, & Truner, 1979; Coren & Porac, 1977). In Experiments 1 through 3, right hand and right visual field advantages were not seen; rather, there were no significant differences in right vs. left presentation side/responding hand. This provides mild support for the right lateralization of ToM. The left-hand disadvantage that should have been seen was offset by the cognitive advantage provided to the left hand due to its direct route to the right hemisphere.

During Experiment 1, participants watched an animation where a character placed his or her toy animal into a box and then either watched it hop to the other box (true belief condition) or left the room while it hopped to the other box (false belief condition). The character then searched for the toy in the location where it was

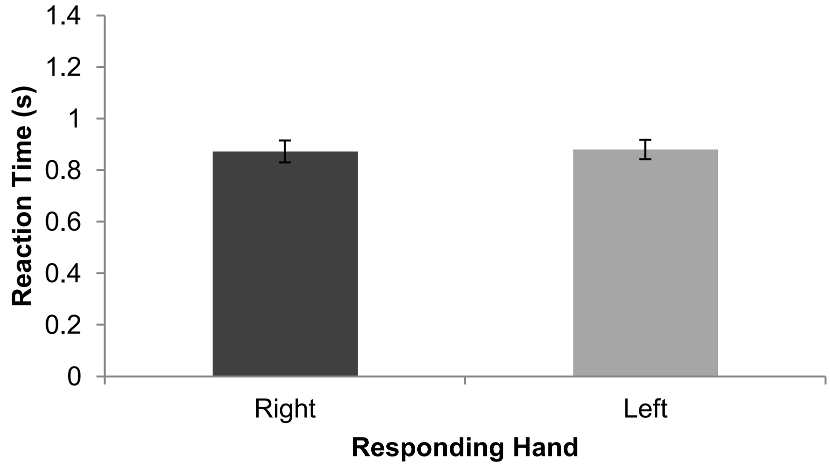

Figure 5. Mean (± S.E.M.) reaction time (s) for right vs. left responding hand. No significant difference was found for mean reaction time (p= .941, BF= 6.85).

expected they would (expected condition) or would not search (unexpected condition). Finally, this search was presented as a still image to either the left visual field, to which participants responded with the left hand (left condition) or the right visual field, to which participants responded with the right hand (right condition). There was no significant difference found in reaction time for the left condition in comparison with the right. Although this does provide moderate support for the right lateralization of ToM due to the aforementioned processes, a second experiment was performed in order to control for hand dominance and possibly strengthen the results. Experiment 2 was identical to Experiment 1, except that participants responded with only their dominant hand throughout the experiment. Since the vast majority of participants were using their right hands, there was reason to believe that this experiment would reveal significantly quicker responses to information presented to the left visual field, because left and right hands were not being compared. The experiment, however, revealed no significant difference between left and right presentation sides, strengthening the hypothesis. This can be explained by the number of times the information had to cross over the corpus callosum in each condition. When the still image was flashed on the right visual field, information had to cross from the left hemisphere to the right hemisphere to be computed for ToM processing. The information then had to be shuttled back to the left hemisphere in order for a right hand response to be made, entailing a total of two crossovers. When the still image was flashed on the left visual field, information had to cross over the corpus callosum once in order for a response to be made with the right hand. Although Bayesian analyses revealed no significant difference between the two reaction times, this Bayes factor was lower than that of the other experiments. While Experiments 1 and 3 provided substantial support for the weak hypothesis, Experiment 2 only provided weak support for it. In Experiment 2, reaction times for the left presentation side were slightly quicker than reaction times for the right presentation side, although this difference was not significant. Since the Bayes factor only provided weak evidence that this lack of difference was significant, this suggests that Experiment 2 was verging on finding support for the strong hypothesis. Experiment 3 was identical to Experiments 1 and 2, except that the final still image was always presented to the center of the visual field and the responding hand alternated. In trials with left hand responses, there was a cost in using the non-dominant hand but an advantage in the absence of need for a crossover to occur. In trials with right hand responses, there was an advantage in using the dominant hand, but a cost due to the crossover necessary for the ToM information in the right hemisphere to reach the left hemisphere so that a right hand motor response could be made. As such, the two responding hands produced no significant difference in reaction times.

Throughout the three experiments of the current study, participants required the use of their corpus callosums to transfer information between the brain's two hemispheres. These participants were all adults and therefore possessed corpus callosums that were fully developed and refined. The refinement process of the corpus callosum allows for effective transfer of information between the two hemispheres (Westerhausen et al., 2011). It is possible that the reason the cost in reaction time for information to cross over the corpus callosum was almost negligible was due to the efficiency of these participants' corpus callosums. Even though information did have to transfer back and forth between the two hemispheres, perhaps the mature corpus callosum's efficiency led to an almost instantaneous transfer. In order to test this, the present study should be extended to children. Westerhausen and colleagues (2011) have shown that as children age, specific regions of their corpus callosums become thinner. At the same time, interhemispheric transfer abilities in these children improve with age. Future studies should look at various cohorts of children and compare their reaction times to ToM information using alternating presentation sides/responding hands. If it is found that as children get older, their differences in reaction times between the two sides get smaller, this would support the claim that the lack of difference in reaction time in adults may be in part due to the efficiency of the fully developed corpus callosum. On the other hand, if the difference gets larger as children age, this may be due to the finding that younger children show less hand dominance (Hill & Khanem, 2009). In this case, a right-hand motor advantage would be less apparent, potentially making it more likely to find a left-hand advantage due to ToM's right laterality. Testing children of various ages would also be valuable, as it is known that ToM substantially develops between the ages of four to six years (Perner, 1991). It is possible that young children will show the greatest degree of right lateralization because being a newly developed skill, ToM would yet to have established strong neural pathways across the corpus callosum. Discordantly, young children may initially develop ToM in both hemispheres of the brain, and lateralization may only occur over time through refinement. Many of the neuroimaging studies done on ToM in the past consisted of language demands due to the complex stories used to activate ToM in the brain and therefore used adult participants (Saxe & Wexler, 2005; Young, Camprodon, Hauser, Pascual-Leone, & Saxe, 2010). The animation used in the present study is fairly simple and applicable to children. Forthcoming studies should utilize the current paradigm to investigate lateralization of ToM in children of various ages.

There are three limitations in the present study. Firstly, although the large majority of participants were right-handed, there still existed a number of left-handed participants. This presents a problem because the notion that the right lateralization of ToM offsets the motor disadvantage of the left hand does not apply to the left-handed minority. Instead, these individuals have double the advantage with their left hands, and double the disadvantage with their right hands. Since there were so few of these individuals, they were not removed from the analyses because they did not contaminate the data. However, it has been shown that the cortical asymmetry for motor control that exists for right-handed individuals differs from that of left-handed individuals (Kawashima, Inoue, Sato, & Fukuda, 1997). Support for this finding comes from a study on lateralization of negative and positive affect (Natale, Raquel, & Ruben, 1983). The “valence hypothesis” maintains that processing of negative affect occurs in the right hemisphere and processing of positive affect occurs in the left hemisphere (Natale et al., 1983). Natale et al. (2013) found that this hypothesis holds true for right-handed but not left-handed individuals. Therefore, it would be beneficial for future studies on lateralization of ToM to examine equal amounts of left-handed and right-handed individuals, as hemispheric lateralization may differ between the two groups. A second limitation concerns the method of lateralized presentation sides. Although the divided field paradigm has shown to be efficacious, Bourne (2006) cites multiple control methods that should be used in order to ensure the paradigm is effective. These include using a chin rest and tracking eye saccades in order to withhold stimulus presentation until fixation point is obtained. The present study did not use these control mechanisms, and as such lateralized presentation sides may not have been at maximum reliability. Future studies should employ the present paradigm with modifications such as the added control measures mentioned by Bourne (2006) or the use of a tachistoscope, which is a device used to display images for certain amounts of time in each visual field. A final limitation in the present study is the absence of a measure taken to identify if any of the participants were on the autistic spectrum, or possessed qualities characteristic of ASD. Research has shown that the RTPJ of individuals with ASD responds atypically to mental state information (Lombardo, Chakrabarti, Bullmore, Consortium, & Baron-Cohen, 2011). It is plausible that in individuals who are on the spectrum, mental state reasoning does not selectively occur in the RTPJ. If participants in the present study were on the spectrum, this may have contaminated the data. In the future, a questionnaire should be administered in order to isolate individuals on the ASD spectrum and analyze their data separately.

The present study provides a solid foundation upon which many follow up studies can be done in order to shed more light on the neural basis of ToM. Just as ToM has been shown to be right lateralized in the brain, many other functions have shown lateralization. A well-known finding is that speech production and language comprehension are left lateralized (Gazzaniga & Sperry, 1967). This is relevant to the present study; as mentioned earlier, many ToM tasks require a developed language system and the use of speech production. The fact that ToM is right lateralized and language is left lateralized has great implications for the study of ToM, as the two systems require constant communication on tasks that involve both. The present study did not involve tasks that required speech production, as responses were solely motor. In the future, verbal responses should be recorded in order to illuminate how ToM and language systems will interact to produce a response. Apperly and Butterfill (2009) postulated that young children fail ToM tasks because they are in the process of acquiring a new system for ToM. This new system lacks the flexibility required to integrate language demands into ToM tasks, which may explain why young children initially have difficulty with ToM tasks. This highlights the importance of studying ToM in collaboration with language. This is also an essential interaction to study due to its high applicability to real world interactions. ToM processing very often occurs during interpersonal interaction and conversation and as such is constantly interacting with language systems in the brain.

The study of ToM has its most important implications in those who lack it, including the ASD population. ASD is a developmental disorder that has widespread effects on those living with it. Baron-Cohen (1995) suggested that the triad of deficits seen in ASD, which include language impairments, impaired social development, and insistence of sameness and repetition, all stem from a central deficit in ToM. Studying ToM has clinical applications for the treatment of ASD. Knowing that many of the impairments that this population shows may stem from a specific cognitive deficit in the RTPJ will help behavioural therapists implement a treatment strategy. Sabbagh (2004) proposed that individuals with ASD might show improved social ability if mental state information is explicitly explained to them. The knowledge that this deficit can be specifically located in one hemisphere of the brain may help therapists to understand its concrete effects. The ability to understand and reason about others' mental states, as well as the knowledge that others can have thoughts, beliefs, and desires that are different from one's own, are critical skills to possess for everyday social interaction. Studying ToM and its neural underpinnings helps the population of individuals who lack this essential ability, and ultimately contributes to the body of research working towards the understanding and treatment of ASD.

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