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The Role of Inhibition in Theory of Mind Performance: Evidence for a Non-Modular View of Theory of Mind

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Abstract

As the modularity of Theory of Mind continues to be debated, the present study sought to investigate the relationship between inhibitory control and performance on a linguistic Theory of Mind (ToM) task. Performance on ToM tasks that relied on inhibitory control was contrasted with performance on ToM tasks that did not rely on inhibitory control. In addition, a range of executive function tasks were administered to all participants. It was hypothesized that if Theory of Mind shares resources with the executive process of inhibition, performance on the ToM task would diminish when inhibition demands were high. Results indicated that performance on the ToM task was significantly lower when participants were required to inhibit superficial discrepancies in the Theory of Mind stories. Moreover, performance on the ToM task correlated with the ability to resist non-linguistic interference. These findings challenge the modular views of Theory of Mind, and suggest that Theory of Mind and executive functions may rely on common cognitive resources.

Keywords: Theory of Mind; inhibition; executive function; modularity.

Introduction

Human beings, as the most social of primates, rely heavily on complex social knowledge or social cognition (Adolphs, 1999). Social cognition has been described by Adolphs (1999) as “the processes that subservise behavior in response to other individuals of the same species...especially those higher cognitive processes subserving the extremely diverse and flexible social behaviors that are seen in primates.” Social cognition, as a high-order cognitive process, relies on several cognitive functions for appropriate interaction including goal-directed planning, emotional control and recognition, arousal, vigilance, and memory integration, (Adolphs, 2009). One aspect of social cognition, Theory of Mind (ToM), allows humans to understand that others have mental states and to use reason about these mental states in order to predict the behavior of others (Fletcher, et al., 1995; Frith & Frith, 1999). While the importance of the Theory of Mind for successful social functioning is not debated, there is controversy surrounding the degree to which the development and use of Theory of Mind relies on domain-general cognitive processes. A modular approach views Theory of Mind as a specific and independent cognitive module (Frith & Frith, 1999). A domain-general approach

views Theory of Mind as a skill that relies on executive function (EF) – a collection of complex cognitive processes that includes inhibitory control (or the ability to resist interference), updating (or working memory), and task switching (e.g., Miyake et al., 2000; Smith & Jonides, 1999; Zelazo, Craik, & Booth, 2004).

The modular view is supported by clinical data, with certain clinical impairments, such as autism or schizophrenia, characterized by marked difficulty with Theory of Mind tasks in the face of relatively spared intellect (e.g., Frith & Frith, 1999; Happé, 1994). The modularity of Theory of Mind has also been evaluated in individuals with traumatic brain injury (TBI), a population commonly found to demonstrate impairments in Theory of Mind (Bibby & McDonald, 2005; Channon, Pellijeff, & Rule, 2005; Turkstra, Dixon, & Baker, 2004). For instance, Bibby and McDonald (2005) found that individuals with TBI exhibited impairments in Theory of Mind tasks and that these difficulties could not be accounted for by inference abilities or language skills. As further support for the modular view, functional neuroimaging techniques have identified specific brain regions that are selectively active during Theory of Mind tasks (e.g., Adolphs, 2009; Amodio & Frith, 2006; Fletcher et al., 1995).

In contrast to domain-specific views of Theory of Mind, it appears that other cognitive domains, most notably the executive functions (Leslie, German, & Polizzi, 2005; McKinnon & Moscovitch, 2007), may influence Theory of Mind performance. For example, McKinnon and Moscovitch (2007) used a dual-task experiment to examine whether Theory of Mind and working memory relied on the same resources. Dual-task experiments assume that when two cognitive processes compete for shared resources, performance will be diminished for one or both tasks. McKinnon and Moscovitch (2007) found that adults' performance on a Theory of Mind task was significantly worse when participants were required to simultaneously perform a working memory task. This finding suggested that both the working memory and Theory of Mind tasks rely on common cognitive resources. In another dual-task study, Theory of Mind performance was shown to decrease in both older and younger adults when the executive function demand of the task was increased by requiring participants to also reason about approach or avoidance

beliefs (German & Hehman, 2006). Similarly, Carlson, Moses, & Claxton (2004) found that children's performance on inhibitory tasks was significantly related to their performance on Theory of Mind tasks.

The current study sought to evaluate the relationship between adults' performance on a linguistic Theory of Mind Task and inhibitory control – a component of the executive function. Previous work on the relationship between ToM and executive function either focused on very young children (e.g., Leslie et al., 2004), used dual-task methodology (e.g., McKinnon & Moscovitch, 2007), or used a purely correlational approach (e.g., Carlson & Moses, 2001). In the current study, the relationship between inhibitory control and ToM was examined in two ways. First, we manipulated the executive function demands of the ToM task itself. Second, we administered a battery of Executive Function tasks to all the participants, being particularly careful to index inhibitory control in both the linguistic and the non-linguistic domain.

The ToM task designed for the current study presented participants with pairs of short stories that either matched or mismatched in the ToM Structure (see Table 1 for examples of stories). Stories described human behavior that required understanding of people's intentions and beliefs (including engaging in white lie, using sarcasm, etc.). Stories that matched in ToM structure described situations that shared the underlying intent (e.g., both were stories about white lies). Stories that mismatched in ToM Structure described situations that diverged in the underlying intent (e.g., one story was about a white lie and another story was about sarcasm). Participants were asked to make same/different judgments on pairs of stories that either matched or mismatched in ToM structure based on the underlying intentions of the story characters. The key manipulation involved the Surface Structure of the stories. Half of the stories matched in superficial contextual elements (characters had the same names, actions took place in the same location, etc.), while half of the stories mismatched in superficial contextual elements (characters had different names, the actions took place in different locations, etc.). This design yielded four conditions: Stories that matched in both the ToM Structure and Surface Structure; stories that matched in ToM Structure but differed in Surface Structure; stories that matched in Surface Structure but differed in ToM Structure; and stories that mismatched in both the ToM and the Surface Structures. The logic was that making a "same" decision on stories that matched in ToM but that mismatched in Surface Structure would require inhibition of attention to superficial discrepancies. Similarly, making a "different" decision on stories that mismatched in ToM but that matched in Surface Structure would require inhibition of attention to superficial similarities. Conversely, performance on stories that either both matched or both mismatched in ToM and Surface Structure would not require inhibitory control. We hypothesized that if performance on ToM tasks relies on executive function, then participants should be less accurate and slower making

judgments of similarity on the conflicting stories than on the non-conflicting stories, since performance on conflicting stories would require inhibitory control. If, on the other hand, performance on ToM tasks relies on domain-specific mechanisms that are separable from executive function mechanisms, then participants should show similar performance on conflicting and non-conflicting stories.

In addition to embedding inhibitory-control manipulation within the ToM task itself, we also examined the relationship between executive function and Theory of Mind by administering a range of executive function tasks to the participants. We hypothesized that if ToM relies on executive function, then adults' performance on the ToM task would correlate with performance on executive function measures. Since executive function is a complex construct that subsumes a number of dimensions, finding that performance on the ToM task correlates with some executive function measures, but not others would be informative with regards to the specific executive function mechanisms that may underlie performance on Theory of Mind Tasks in adulthood. Because the ToM task designed for the current study was linguistic in nature, we were especially interested in examining the relationship between ToM performance and performance on linguistic vs. non-linguistic executive function tasks.

In summary, the goal of the present study was to examine the modularity of Theory of Mind in adults by testing the relationship between ToM and inhibitory control. We theorized that if performance on ToM tasks requires inhibitory control, then participants should perform less well on ToM tasks that place increased demands on the inhibitory control mechanism. We also theorized that if performance on the ToM tasks is related to executive function, then measures of executive function should correlate with ToM performance.

Methods and Procedures

Participants

Twenty-two participants were recruited for this study. Participants ranged in age from 18.9 to 22.8 years, and all were native speakers of English. Each participant scored within the normal range on English receptive vocabulary as measured by the Peabody Picture Vocabulary Test-III (Dunn & Dunn, 1997) ($Mean = 108.57$; $SD = 7.00$), and on reading ability as measured by the Reading Fluency subtest of the WJ III Tests of Achievement, (Woodcock, McGrew, & Mather, 2001a) ($Mean = 110.41$ $SD = 8.28$). Participants also scored in the normal range on the non-verbal intelligence measure (Visual Matrixes subtest of the Kaufman Brief Intelligence Test, Second Edition, K-BIT2; Kaufman & Kaufman, 2004) ($Mean = 101.76$, $SD = 11.87$).

Materials and Procedure

Each participant was tested in one two-hour session. Theory of Mind tasks, executive function tasks, language ability tasks, and a non-verbal IQ test were administered in random order.

Table 1: Examples of Stimuli in Four ToM Conditions

	ToM Match		ToM Mismatch	
	Story A	Story B	Story A	Story B
Surface Match	Ann and her husband left their home for work on a gloomy, rainy day. Ann said, “What a bright cheery day.”	Ann and her husband left their home for work on a gloomy, rainy day. Ann said, “It’s a good thing I packed my sunglasses today.”	Dan attempted to cook dinner for his sister’s birthday, but burnt everything to a crisp. His sister’s friend Kristy said, “You’re quite the chef, Dan.”	Dan attempted to cook dinner for his sister’s birthday. His sister’s friend Kristy said, “Your dinner was great, I just wasn’t very hungry tonight.”
Surface Mismatch	Jacob’s history professor assigned six chapters of reading for the following day’s class. On the way out of class, Jacob said to his friends, “We’ll have plenty of free time tonight, huh?”	Joan had to stay late at work for the next week while her boss was out of town. Her coworker John said, “Aren’t you the lucky one this week?”	Ben and Ryan were walking to class when Ben said, “Did you see John’s shoes at track practice today? They were awful.” Just then Ryan turned around and said, “Oh hi John, I didn’t see that you were behind us.”	Karen really wanted to try out a new café in town but didn’t want to go alone. Karen said to her best friend, Joanne, “I’ll probably try out that new café, but I suppose I’ll have to go alone since no one will go with me.”

Theory of Mind Task The ToM task in this study evaluated participants’ ability to identify Theory of Mind inferences in the face of varying inhibitory control demands. The ToM task presented participants with 40 pairs of short stories to be read silently from a computer screen (see Table 1). Stories ranged from two to four sentences in length and were constructed using vocabulary and syntax at the sixth grade level. Five story types, each requiring Theory of Mind for accurate interpretation were included in the task. Story types included white lie, deception, faux pas, sarcasm, and persuasion. Participants were not informed of the story types. Executive function demands were manipulated through variation in the Surface Structure or context of each story. In the low executive function conditions, the story context and the ToM inference were both similar or both different across stories. In the high executive function conditions, the stories either shared the ToM inference, but differed with regards to story structure or shared story structure, but differed with regards to the ToM inference. Participants first completed two practice trials, each of which was followed by an explanation of the correct response. The order of presentation of story pairs was randomized. Participants first saw a screen with only a black vertical line bisecting the screen at the midline, and then were presented with one story (Story A) on the left side of the screen. After reading the story, participants pressed the space bar and Story A disappeared and Story B was presented on the right side of the screen. After reading story B, the participant again pressed the space bar and both stories appeared on the screen, separated by the vertical black line. This procedure was implemented in order to minimize the effect of reading times and of working

memory demands on ToM performance. While both stories were available on the screen for review, the participant chose whether the stories required the same inference, (e.g., both stories included a faux pas situation) or if they required different inferences, (e.g., one story included faux pas and one demonstrated sarcasm). Participants indicated their decision by pressing the forward slash key if the inferences were the same across stories, or the “z” key if the inferences were different across stories. Both accuracy and reaction times were recorded. Reaction time measurements began as both stories were presented simultaneously and ended as soon as a decision key was pressed. Participants were instructed to respond to each stimulus as quickly as possible while maintaining response accuracy.

Executive Function Tasks Tasks measuring distinct EF components were administered to each participant. *Linguistic inhibitory control* was measured via the Color-Word Interference Task (a version of the Stroop task, Stroop, 1935), where participants were asked to name ink colors and inhibit the more automatic processing of print (Delis, et al., 2001). *Non-linguistic inhibitory control* was measured via the Simon task (Simon & Rudell, 1967), where participants were presented with either red or green circles in the center, or on either the left or the right side of the computer screen and were required to press a left key when they saw a green circle and a right key when they saw the red circle. On incongruent trials, the location of the colored circle conflicted with the response key, and participants had to inhibit the automatic spatially-based response. *Complex problem solving and planning* were measured via The Towers Task (Delis, et al., 2001), where participants were presented with disks of different sizes and

three rods, and were required to achieve the target arrangement of disks on rods in as few moves as possible. *Working Memory* was measured using the Numbers Reversed subtest of the Woodcock Johnson III Tests of Cognitive Abilities, (Woodcock, McGrew, & Mather, 2001b), where participants heard increasingly-long sequences of digits, and were required to repeat each sequence in the reverse order.

Results

Accuracy and Reaction Time data were analyzed using 2 x 2 Repeated-Measures ANOVAs, with ToM Structure (matching vs. mismatching) and Surface Structure (matching vs. mismatching) as within-subjects independent variables. A-priori follow-up paired-samples comparisons were conducted to examine (1) whether surface mismatch impaired participants' ability to identify similar ToM structure in the stories, and (2) whether surface match impaired participants' ability to differentiate distinct ToM structures in the stories. Finally, correlation analyses were conducted to examine the relationship between ToM performance and Executive Function measures. Here, we were especially interested in comparing the relationships between ToM performance and language-based EF tasks and the relationship between ToM performance and non-linguistic EF tasks.

For accuracy, a 2 x 2 ANOVA with ToM Structure and Surface Structure as within-subjects Independent Variables yielded a marginally-significant interaction between the two independent variables, $F(1, 20) = 3.23, p = 0.09, \eta_p^2 = 0.14$. The interaction of ToM and Surface Structure variables indicates that performance on the ToM task was influenced by superficial contextual information, and suggests that the inhibitory-control demands mediated ToM performance. For RTs, a similar analysis yielded a main effect of ToM structure, $F(1, 19) = 8.10, p = 0.01, \eta_p^2 = 0.30$, indicating that conditions in which ToM matched required shorter response time than those in which ToM differed.

A-priori pair-wise t-tests were conducted to determine whether accuracies and reaction times differed across high and low inhibitory control conditions. For accuracy, a significant difference was observed between performance on stories where both ToM and Surface Structure matched and stories where ToM matched but Surface Structure mismatched, $t(20) = 2.03, p = 0.06$. However, there were no differences in performance on stories where ToM and Surface Structure both matched and stories where ToM mismatched but Surface Structure matched, $t(20) = 0.83, p = 0.42$. Figure 1 displays average accuracy for each condition.

For RTs, a significant difference was observed between performance on the condition in which both ToM and Surface Structure matched, and the condition in which ToM Structure differed but Surface Structure Matched, $t(19) = -2.21, p = .04$. Figure 2 displays average RTs for each condition.

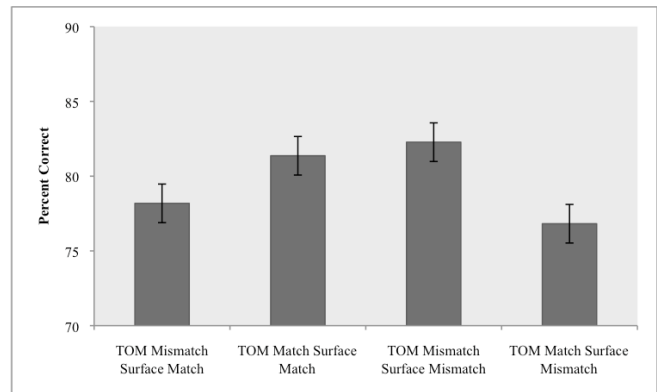


Figure 1: Performance Accuracy on ToM Task

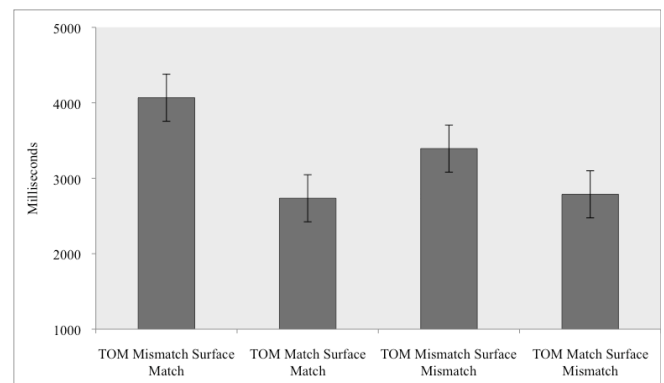


Figure 2: Performance RTs on ToM Task

Pearson Correlation analyses were conducted to examine the relationship between participants' accuracy and RTs on the ToM task and their performance on the executive function tasks.

Performance on the Digits Reversed task did not correlate with any of the performance measures. This indicates that the ToM task in the current study did not tax working memory capacity. Performance on the Stroop task was positively correlated with accuracy on the ToM task where both ToM and Surface Structure differed ($r = 0.45$). The finding that only one condition of the ToM task correlated with Stroop performance was unexpected, especially because this ToM condition did not require inhibition. It may be that the lack of association was due to the fact that the Stroop task demanded inhibition of an irrelevant perceptual dimension (conflicting color word) while the ToM task required inhibition of an irrelevant response dimension (response based on surface structure). It may also be that the lack of association was due to differences in response modality across the two tasks, with the Stroop task requiring vocal responses, and the ToM task requiring button-press responses.

Unlike the Stroop findings, performance on the Simon task was associated with ToM performance. To measure non-linguistic inhibitory control, a difference score was calculated where participants' RTs on the incongruent Simon trials (requiring inhibition) were subtracted from the

neutral Simon trials. Small difference scores indexed successful conflict resolution, and thus, superior inhibitory control. This measure of conflict resolution was correlated with ToM performance in each of the four conditions, and only one analysis yielded a significant correlation. Namely, successful conflict resolution on the Simon task was associated with higher accuracy on the ToM task in a condition where two stories shared the underlying ToM structure but diverged in Surface Structure ($r = -0.51, p = 0.02$). This finding suggests that non-linguistic inhibitory control was associated with ToM performance only in a condition where participants had to select the “match” response and inhibit the “mismatch” response based on non-overlapping superficial structural characteristics.

Interestingly, accuracy scores on the Towers Task were inversely correlated with accuracy on the ToM condition in which both ToM and Surface Structure matched ($r = -0.55$), and the total time taken to complete the Towers Task was inversely correlated with RTs for all conditions in the ToM task (correlation coefficients ranged from -0.51 to -0.58). It is difficult to interpret these correlations since it is unclear what cognitive abilities the Towers Task indexes. In our data, performance on the Tower task did not correlate with any other executive-function measure, indicating that the skill(s) it was indexing may not have been related to executive function. It is possible that these inverse relationships between performance on the Tower task and performance on the ToM task are due to the different modalities tapped by each task: visuospatial in the Towers and linguistic in the TOM task.

Discussion

Questions regarding the degree to which higher-order cognitive tasks rely on domain-general processes permeate every aspect of cognitive science. The goal of the current study was to inform the debate surrounding the modularity of Theory of Mind by examining the relationship between performance on the Theory of Mind task and inhibitory control. The results indicated that performance on the linguistic ToM task was associated with inhibitory control function. This conclusion was supported by three main findings.

First, higher accuracy was observed on the condition with similar ToM and Surface Structure compared to the condition with similar ToM Structure but differing Surface Structure. Because the condition with divergent Surface Structure required more inhibitory control than the matching condition, we interpret this pattern of results to suggest that ToM and inhibitory control draw on common cognitive resources.

Second, participants were significantly quicker to respond to trials in which both ToM and Surface Structure were similar than when the ToM Structure differed, but the Surface Structure was similar. This finding suggests that the inhibitory-control demands imposed by the incongruent ToM and Surface Structure resulted in prolonged response times.

Finally, performance on an executive function measure as assessed by the Simon task correlated with ToM performance, particularly for the condition where participants had to detect matching ToM across two structurally-distinct stories. This finding suggests that performance on the linguistic ToM task (especially one that involved inhibition) was associated with performance on the non-linguistic inhibitory-control task.

While this study included a small sample size and all participants scored very high on measures of receptive English vocabulary, the findings of a link between ToM and executive function support the non-modular view of the Theory of Mind (e.g., Carlson, et al., 2004; McKinnon & Moscovitch, 2007). It appears that Theory of Mind performance in adulthood may in fact draw on the same complex cognitive processes as inhibitory control. However, the findings are also consistent with the view of Theory of Mind proposed by Leslie, Friedman, & German (2004). Leslie et al. (2004) argued that Theory of Mind is comprised of an innate, modular ‘Theory of Mind mechanism’ that generates alternate interpretations of social situations, and an executive selection process that chooses one interpretation from those suggested by the Theory of Mind mechanism. According to this view, the selection process is inhibitory in nature. This theory has been tested previously using a false belief task, in which the participant must correctly identify that a character in the task has a belief that is different from the actual state of reality (Leslie, et al., 2004; Leslie, et al., 2005). In the case of a false-belief task, Leslie (2004) argued that the Theory of Mind mechanism generates several possible beliefs with the reality of the situation being the default selection. In a false-belief task, however, because the character’s belief is false, the selection process must inhibit the default interpretation in favor of a belief that is different than the reality of the situation.

When considering the findings of the present study, it could be argued that in the condition in which the ToM and surface structure are incongruent, the irrelevant surface structure information must be inhibited in favor of the deeper ToM structure. Therefore, the present data may in fact support the view of Theory of Mind that construes performance on ToM tasks as a process that consists of mechanisms specific to the Theory of Mind, and domain-general inhibitory control mechanisms.

Whatever the interpretation of the findings, it is intriguing that only one ToM condition was taxing for the participants – the condition with similar ToM and differing surface structure. The opposite condition, in which the ToM structures differed, but the surface structure matched did not seem to incur higher inhibitory demands. Perhaps suppressing a “no” response requires more inhibitory control than suppressing a “yes” response, although it is unclear why this may be so. The degree to which different ToM tasks require inhibitory control is therefore a crucial area of further research.

This study provides evidence that performance on Theory of Mind tasks may rely on domain-general inhibitory control mechanisms, and more broadly provides insight into the non-modularity of processes associated with high-order cognition. It is possible to increase inhibitory-control demands of the ToM task by pitting similarities in the underlying intentional structure of the stories (ToM) against superficial similarities in the linguistic structure of the stories. Requiring participants to make decisions about ToM similarities while ignoring structural differences imposes inhibition demands on performance. Crucially, performance on the linguistic ToM task correlated most highly with a measure of non-linguistic inhibitory control, pointing to an association between ToM and executive function in particular, and linguistic and non-linguistic performance in general. This pattern is in line with non-modular views of Theory of Mind, that construe performance on social cognition tasks as drawing on the same basic cognitive mechanisms that underlie performance on complex planning tasks, i.e., executive function.

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