

©[2015]

Michelle Cheng

ALL RIGHTS RESERVED

SMALL GROUP THEORY OF MIND: PRESCHOOLERS' ABILITY TO
SIMULTANEOUSLY MAINTAIN MULTIPLE AGENTS AND THEIR FALSE
BELIEFS

By

MICHELLE CHENG

A thesis submitted to the

Graduate School – New Brunswick

Rutgers, The State University of New Jersey

in partial fulfillment of the requirements

for the degree of

Master of Science

Graduate Program in Psychology

written under the direction of

Dr. Alan M. Leslie

and approved by

New Brunswick, New Jersey

May, 2015

ABSTRACT OF THE THESIS

Small group theory of mind: preschoolers' ability to simultaneously maintain multiple agents and their false beliefs

by MICHELLE CHENG

Thesis Director:

Dr. Alan M. Leslie

The Sally-Ann task has become the litmus test to determine if preschoolers possess a theory of mind (ToM). However, despite living in a social world where interacting with multiple agents with distinct mental states is the norm, children are only examined for their ability to track a single agent. Furthermore, researchers have adduced that three-year-olds' fail to attribute a mental state to a single agent, but because of limited empirical evidence, the types of error that three-year-olds produced in such tasks remain unknown. In the current studies, a multiple agent false belief task was introduced to examine the underlying nature of children's errors in a false belief task, children's working memory capacity in tracking multiple agents, and its developmental trajectory. Three- and four-year-olds were successful in tracking three agents with distinct false beliefs (Study 1). But when the number of agents was increased to four, four-year-olds continued to succeed, while three-year-olds' performance suffered greatly (Study 2). The only consistent error pattern, found across studies and ages, was their attribution of a true belief to all agents, which suggest that errors children make tend to be biased by the true belief.

Acknowledgements

I would like to thank Dr. Alan Leslie, my committee members, Dr. Pernille Hemmer and Dr. Kristen Syrett, and all the members of the Cognitive Development Lab, for their help in my thesis. Additionally, I would like to thank Dr. Lu Wang who inspired this project and Brian Cheng for creating the stimuli. I thank the preschool directors and their staff for collaborating with our lab as well as the families for their participation.

Table of Contents

Abstract	ii
Acknowledgements	iii
List of Tables	v
List of Figures	vi
1. Introduction	1
1.1 Why three-year-olds fail: The working memory account	2
1.2 An alternative account: The “decoupler” model	5
1.3 Tracking multiple agents with distinct mental states	8
1.4 The current studies	10
2. Study 1: Triple Agent False Belief	11
2.1 Method	11
2.2 Results	14
2.3 Discussion	18
3. Study 2: Quadruple Agent False Belief	20
3.1 Method	21
3.2 Results	24
3.3 Discussion	29
4. General Discussion	31
5. Conclusions	32
Appendix	34
References	39

List of Tables

1. 3- and 4-year olds' Responses to Belief Questions in Study 1	16
2. Memory Errors in Study 1	17
3. 3- and 4-year olds' Responses to Belief Questions in Study 2	25
4. Memory Errors in Study 2	27

List of Figures

1. Stimuli layout for Study 1.	12
2. Proportion of response types three- and four-year-olds made in Study 1	15
3. Stimuli layout for Study 2.	23
4. Proportion of response types three- and four-year-olds made in Study 2	26
5. Proportion of three-year-olds' response types made for Study 1 and Study 2.	28
6. Proportion of four-year-olds' response types made for Study 1 and Study 2.	29

Introduction

Theory of mind is a term coined by Premack and Woodruff (1978) to describe one's ability to attribute a mental state to another. The development of this ability has historically been studied in preschool children using change location tasks, for example, the Sally-Ann task (Baron-Cohen, Leslie, & Frith, 1985; Wimmer & Perner, 1983). In such a task, Sally puts the marble in the basket and leaves the room. Unbeknownst to Sally, Ann changes the location of the marble from the basket to the box. Children are then asked to predict Sally's action by taking into account her false belief as to where the marble is (Baron-Cohen, et al., 1985). Researchers have found a stark contrast between three and four-year-olds' ability to attribute a false belief to Sally, where three-year-olds systematically fail by pointing to where the marble is currently located while four-year-olds succeed by pointing to where Sally believed the marble to be (see, Wellman, Cross, & Watson, 2001 for meta-analysis).

Notice that in Baron-Cohen, et al.'s (1985) study among many others (Wellman, et al., 2001), it requires children to predict the action of a single agent. However, tracking a single agent's mental state is not representative of our daily social interactions because we typically engage in interactions involving a multitude of individuals with distinct mental states. Moreover, in the Sally-Ann task, there are two beliefs to maintain in working memory: Sally's belief that the marble is in the basket and Ann's belief that the marble is in the box, but researchers have yet to examine children's capacity to track Sally's belief in addition to Ann's belief. Rather since its inception (i.e., Premack, & Woodruff, 1978), theory of mind has been exclusively only been studied by researchers as an emergence issue.

While many researchers have taken three-year-olds' failures to suggest that theory-of-mind is an ability that emerges at the age of four (Perner, 1991; Perner, 1995; Perner & Ruffman, 2005), others argue that processing demands such as working memory (Davis & Pratt, 1995; Keenan, 1998; Keenan, et al., 1998; Olson, 1989), understanding of complements (Villiers, & Pyers, 2002; Hale, & Tager-Flusberg, 2003), or inhibitory control that are inherently embedded in the verbal false belief tasks are responsible for three-year-olds' poor performance (Carlson, Moses, & Hix, 1998; Leslie & Polizzi, 1998; Rakoczy, 2010). More recent studies using various nonverbal measures such as looking time and neuroimaging have found support for earlier theory of mind competence in infants as young as 6 months old (Baillargeon, Scott, & He, 2010; Onishi & Baillargeon, 2005; Southgate, Senju, & Csibra, 2007; Southgate & Vernetti, 2014) as predicted by Leslie (1994). If theory-of-mind competence is present early in the first years of life, what can account for the discrepancy in three-year-olds' performance in verbal false belief tasks?

Why three-year-olds fail: The working memory account

Olson (1989) and others (Davis & Pratt, 1995; Keenan, 1998; Keenan, Olson, & Marini, 1998) have argue that although three-year-olds may have the capability to impute mental states to others, three-year-olds struggle to simultaneously represent multiple states because they have a shortage of working memory space. One of the main components of working memory includes a phonological loop, where verbal information is encoded and can be retrieved for a short amount of time (Baddeley & Hitch, 1974; Baddeley, 1981; Baddeley, 1998). The phonological loop among other functions of working memory (i.e., the visuospatial sketchpad), as Baddeley (1986) posits, has a

limited capacity, which some have argued increases over time (Pasual-Leone, 1970).

Thus, in order to pass the Sally-Ann task, children must maintain both Sally's belief that "the marble is in the basket" and the perceptual representation that "the marble is in the box." Thus, four-year-olds' success is due to an increased working memory capacity (i.e., false belief + reality), while three-year-olds' capacity limits them to only recall the perceptual representation, which results in their failures (Davis & Pratt, 1995; Keenan, 1998; Keenan, et al., 1998; Olson, 1989).

Olson's (1989) limited working memory capacity account goes beyond the theory of mind realm. In a task called the false photographs task, researchers examined whether or not children were able to maintain a previous representation of the world as well as the current representation. Zaitchik (1990) tested this by presenting three- and four-year-olds with a prearranged model room where the target, a duck toy, was placed on a bed. The experimenter took a photograph of the room while the child watched and then moved the duck from the bed to the chair. Three- and four-year-olds were then asked to recall where the duck's location was in the photograph. Like the verbal false belief tasks, Zaitchik (1990) found an asymmetry in performance: three-year-olds failed by responding where the duck was located in the current model when prompted to recall (i.e., the chair) while four-year-olds passed by responding where the duck was located in the picture (i.e., the bed). This supports the claim that three-year-olds may have a limited capacity in tracking more than one representation: the photograph, where the duck was sitting on the bed, and the reality model, where the duck was sitting on the chair.

A series of experiments by Davis and Pratt (1995) and Gordon and Olson (1998) also supports the limited working memory capacity for children's failure in false belief

tasks by examining the predictive power of working memory capacity on subsequent verbal false belief tasks. In Davis and Pratt's (1995) study, children were asked to recall a series of digits backwards. Their ability to recall the list was found to predict to their performance in the false belief and false photographs task. In another relevant task called the counting and labeling task, children were required to first count a set of objects, then label the same objects, and finally, simultaneously count and label each object (Gordon & Olson, 1998). For example, if the set of objects was a shoe, a cup, and a spoon, children were required to respond, "One is a shoe. Two is a cup. Three is a spoon." Like Davis and Pratt (1995), Gordon and Olson (1998) also found that children's performance in this working memory task correlated with their performance on false belief tasks, suggesting that the limited working memory capacity could be an explanatory account for three-year-olds' failures.

In a similar vein, research has demonstrated that there is a limited working memory capacity when recalling objects (Fukuda, Awh, & Vogel, 2010; Miller, 1956). When tracking multiple objects, there are two streams in which we recognize objects, and thereby used as cues to recall from: the dorsal stream, the "where" or the spatiotemporal location of the object, and the ventral stream, the "what" or the properties/features of the object (Ungerleider & Mishkin, 1982). Researchers have found that adults are limited in capacity where they can track up to four "featureless" objects (Pylyshyn & Storm, 1988; Scholl & Pylyshyn, 1999). Leslie, Xu, Tremoulet, and Scholl (1998) suggest that an "object" should be quantified as an "object index" instead of "objects" because "objects" vary in complexity and is often difficult to compare. An object index is firstly an abstract representation of an object in the real world and secondly is devoid of features (Leslie, et

al., 1998). Once the index “points” to direct one’s attention to an object, the objects’ featural properties can then be bound to the index. Therefore, an object index, itself, is featureless. Analogous to object working memory, when we track multiple minds, there are several features of a mind that we have to index, such as belief and desire. Therefore, to quantify an individual’s “mind” like an object that could be bounded with features, I will use the term, “mind index,” to refer to an agent’s “featureless” mind.

The capacity of mind indices may help explain the performance shift in false belief tasks where three-year-olds’ capacity is limited to one mind index while four-year-olds possess at least two mind indices in their capacity. The increased capacity to handle more two mind indices allows four-year-olds to represent Sally’s false belief bound to her mind and the perceptual representation, thus allowing them to pass the verbal false belief tasks.

An alternative account: The “decoupler” model

Others have found that children’s performance on a battery of working memory tasks was not a significant predictor of theory-of-mind performance when age and IQ were controlled for (Carlson, Moses, and Breton, 2002). Indeed, Leslie (1987) suggests that the ability to manipulate two simultaneous representations is present prior to children’s ability to pass the verbal Sally-Ann task as evident from the early emergence of pretend play (~15 months old, see Bosco, Friedman, & Leslie, 2006; Onishi, Baillargeon, & Leslie, 2007). In order to engage in pretend play, a child must decouple the primary/perceptual representation from the metarepresentation. For example, when mom is pretending a banana is a phone, the primary/perceptual representation, **Mom is talking to a banana**, must be divorced from the metarepresentation, **Mom is**

pretending, “The banana is a phone.” Metarepresentation is defined here as a representation of a representation (Pylyshyn, 1978): for example, the child’s representation of mom’s representation of the primary representation. Otherwise, without Leslie’s (1987) “decoupling” mechanism, children will confuse the function of bananas as devices that allow them to contact their grandmother, which children rarely fall victim to. Moreover, Leslie (1987) argues that the decoupling that occurs when engaging in pretense shares similar properties to false-belief reasoning. When children are required to reason about Sally’s false belief in the Sally-Ann task, for example, children must decouple the primary representation, **the marble is in the box**, within metarepresentation, **Sally believes, “the marble is in the basket**.

In addition, Leslie and Thaiss (1992) argue that three-year-olds fail the false photographs task, as well as false beliefs tasks, for a reason other than limited working memory capacity. Rather, Leslie and Polizzi (1998) argue that three-year-olds fail the false belief tasks and the false photographs tasks because three-year-olds’ performance is hindered by the true belief bias/default and inhibitory control (see also, Friedman, & Leslie 2004a; Friedman, & Leslie, 2004b). According to Leslie and Polizzi (1998), the true belief – one’s own belief – is the default when calculating others’ beliefs. The true belief here is defined as attributing your own belief as to where the marble is (typically where the marble actually is located in the standard Sally-Ann task). Once the true belief is determined, the false belief can then be calculated by applying inhibition to the true belief.

Indeed, there is some evidence that suggest that three-year-olds may be failing because of inhibition of the true belief bias/default. By removing the target object from

the scene, researchers have found that this helps elicit successful false belief attributions from three-year-olds (see Bartsch, 1996; Carpenter, Call, & Tomasello, 2002; Koos, Gergeley, Csibra, & Biro, 1997). For example, Bartsch (1996) told three-year-olds which cupboard the protagonist believes the object to be, but then showed the children that both locations are actually empty. Similarly, Koos, et al. (1997) had the target food eaten before the protagonist returned to search for the item, thereby, having no visible location for the desired target. In this type of task, three-year-olds find it easier to attribute a false belief than in the standard task where the object's location is known. Carpenter, et al. (2007) suggest that this is an artifact of children's sensitivity to the target's "saliency," which requires inhibitory control to reduce the child's knowledge of where the target object is (Carlson, et al., 1998). Therefore, by removing the desired object from the traditional task, child's confidence of where the object's real location is undermined, which decreases the cognitive processing demands. This allows three-year-olds to succeed in attributing a false belief to a single agent.

Leslie's (1987) pretense account like Olson's (1989) can explain the performance difference between three and four-year-olds, but is contrary to Olson's (1989) limited working memory capacity account because Olson (1989) suggested that children could not maintain two representations, namely the metarepresentation and the perceptual reality while Leslie's (1987) claimed that children in their second year of life can maintain and even manipulation two representations. Further evidence against to Olson's (1989) account is found in object tracking studies in which researchers have found that infants in their first year of life can track up to at least three object indices (Feigenson & Carey, 2003; Kibbe & Leslie, 2011; Kibbe & Leslie, 2013). If we take this capacity as a

parallel to mind indexing, children may have three mind indices available to them, but to present, researchers have yet to study children's capacity for tracking multiple mind indices.

Tracking multiple agents with distinct mental states

Decades of research in the development of theory of mind have been focused on the emergence of single agent belief attribution, which, according to researchers, three year olds are unable to do (Wellman, et al. 2001). But as humans, we live in a world where it is often necessary to track multiple agents with distinct beliefs. Even for three-year-olds, when they have to navigate the world, they encounter mom and her mental states, dad and his mental states, and maybe a sibling and her mental states. To date, there have only been a handful of several demonstrations of multiple agent tracking specifically in tracking conflicting desires and conflicting pretense identities.

In Rakoczy, Warneken, and Tomasello's (2007) conflicting desires study, three-year-olds were told a story that agent 1 had a desire for the boat to go to the tree and agent 2 had a desire for the boat to go to the house, found that three-year-olds were able to recall both agents' distinct desires. The same participants in Rakoczy, et al.'s (2007) study, who were told the conflicting desires story, were also tested for false belief reasoning. They found that while three-year-olds successfully attributed the correct desire to each of the agents, the three-year-olds still failed to attribute a single false belief to Sally (Rakoczy, et al., 2007).

Moreover, other studies have shown that three-year-olds could identify multiple pretense identities, and therefore, maintain multiple metarepresentations for a single object (Bruell, & Woolley, 1998; Wyman, Rakoczy, & Tomasello, 2009). Despite

showing three-year-olds' capacity of two mind indices, researchers still found that three-year-olds perform better when maintaining multiple desire and pretense metarepresentations than a single metarepresentation containing a false belief (Bruehl, & Woolley, 1998 Rakoczy, et al., 2007; Wyman, et al., 2009; see also Hickling, Wellman, & Gottfried, 1997).

The current state of theory of mind research is limited to examining children's ability to attribute a false belief to a single agent despite our social structure involving multiple agents, and manipulations that show three-year-olds' ability to succeed if cognitive demands are reduced. By examining a single agent's false belief, we further limit ourselves to binary responses in the traditional verbal tasks. For example, in the Sally-Ann task, children either pass by correctly predicting that Sally will look in the basket based on her false belief or they fail by incorrectly predicting that Sally will look in the box. Notice that when children predict that Sally will search the box, it is uncertain what caused their response. Thus, it is not possible to extrapolate what kinds of errors are the three-year-olds committing. For example, three-year-olds could be making working memory errors because of a limited capacity for tracking multiple false beliefs as expected by Olson (1989) or three-year-olds could also be making true belief errors because of a lack of inhibition control as expected by Leslie and Thaiss (1992). We have yet to determine 1) the nature of three-year-olds' poor performance, 2) their the capacity to simultaneously represent and maintain multiple agents and their respective mental states and 3) the development of this ability for working memory in a social environment. In the following studies, I try to investigate these three questions in a novel false belief task as described in the next section.

The current studies

The present study seeks to fill a gap in the theory of mind literature by using a multiple agent false belief task to determine the errors committed by children in the traditional verbal task as well as the capacity and the development of the capacity of tracking multiple agents. The multiple agent task is modeled after the Sally-Ann change location task, but with two modifications: 1) I reduced the saliency of the object as performed by Carpenter, et al. (2002) and 2) I increased the number of agents from two to three characters (for Study 1) and four characters (for Study 2), each with distinct false beliefs. With only a single agent to predict, children can only attribute one of two responses, a false belief or a true belief (where the child thinks the object to be). No further analysis occurred when preschoolers responded incorrectly. However, when the number of agents with false belief increases to two, there are 9 possible responses that a child can make, where only one response is correct. For example, in a task where Sally has a false belief and Ann has a false belief, a preschooler can give the correct response by attributing Sally a false belief and Anne a false belief, but there are also 8 other attribution patterns available that are incorrect attributions such as responding that Sally has Ann's false belief and Ann has Ann's false belief. The novelty of having 8 incorrect attribution patterns allows us for the first time to examine error patterns in children who fail the Sally-Ann task.

By examining the results of the error, I can uncover whether or not limited memory capacity hinders children's performance or if there is an alternative factor that guides three-year-olds' underperformance in the verbal false belief tasks. If a limited working memory capacity suppresses three-year-olds' false belief reasoning competence,

three-year-olds should make various binding errors (attributing the wrong belief to the wrong agent). If, on the other hand, working memory is not a factor in three-year-olds' performance on false belief tasks, I should find that three-year-olds can correctly attribute multiple false beliefs correctly to the correct agents.

Study 1: Triple Agent False Belief

Method

Ninety-six 3 and 4-year-olds participated in the current study: 48 three-year-olds (26 girls, $M=42;3$, $SD=3;18$) and 48 4-year-olds (6 girls, $M=53;9$, $SD=3;21$). They were recruited from local preschools in the central New Jersey area. An additional 40 were tested, but were excluded for the following reasons: 2 were non-native English speakers (1 three-year-old, 1 four-year-old), 25 for experimenter error (12 three-year-olds, 13 four-year-olds), 10 for failing the “see” questions (9 three-year-olds, 1 four-year-old), 2 for failing the reality question (2 three-year-olds), 2 for being unresponsive (1 three-year-old, 1 four-year-old), 2 for being distracted (2 three-year-olds) and 1 for revealing that she was under some form of medication (1 three-year-old). Experimenter errors included repeating the story three times (1 three-year-old, 2 4-year-old), not completing the study because the experimenter stopped the experiment early (10 3-year-olds, 4 4-year-olds), and asking, “Where will [agent’s name] look first for the frog?” instead of “Where will [agent’s name] look for the frog?” (1 three-year-old, 7 four-year-olds) For each age group, children were randomly assigned to one of six counterbalanced conditions (see below).

The story was presented through 13 color pictures in landscape orientation in a binder. There were three locations, where the desired object could be placed: a basket, a

box, and a chest. The locations were always in the same positions for each story: the basket was located at the lower right-hand corner, the box on top of a table at the lower left-hand corner, the chest at the top middle of the page and the characters were also always in the same starting positions for each story: Sammy, in the red shirt, in the middle of the three boys, Aaron, in the blue shirt, to the left of Sammy, and Jake, in the white shirt, to the right of Sammy (See Figure 1). Each subject was first introduced to the three characters in the story, Sammy, Aaron, and Jake; all paper cutouts. Participants were tested on one of three versions of the frog's order of hiding locations: Basket-Box-Chest, Box-Chest-Basket, or Chest-Basket-Box.

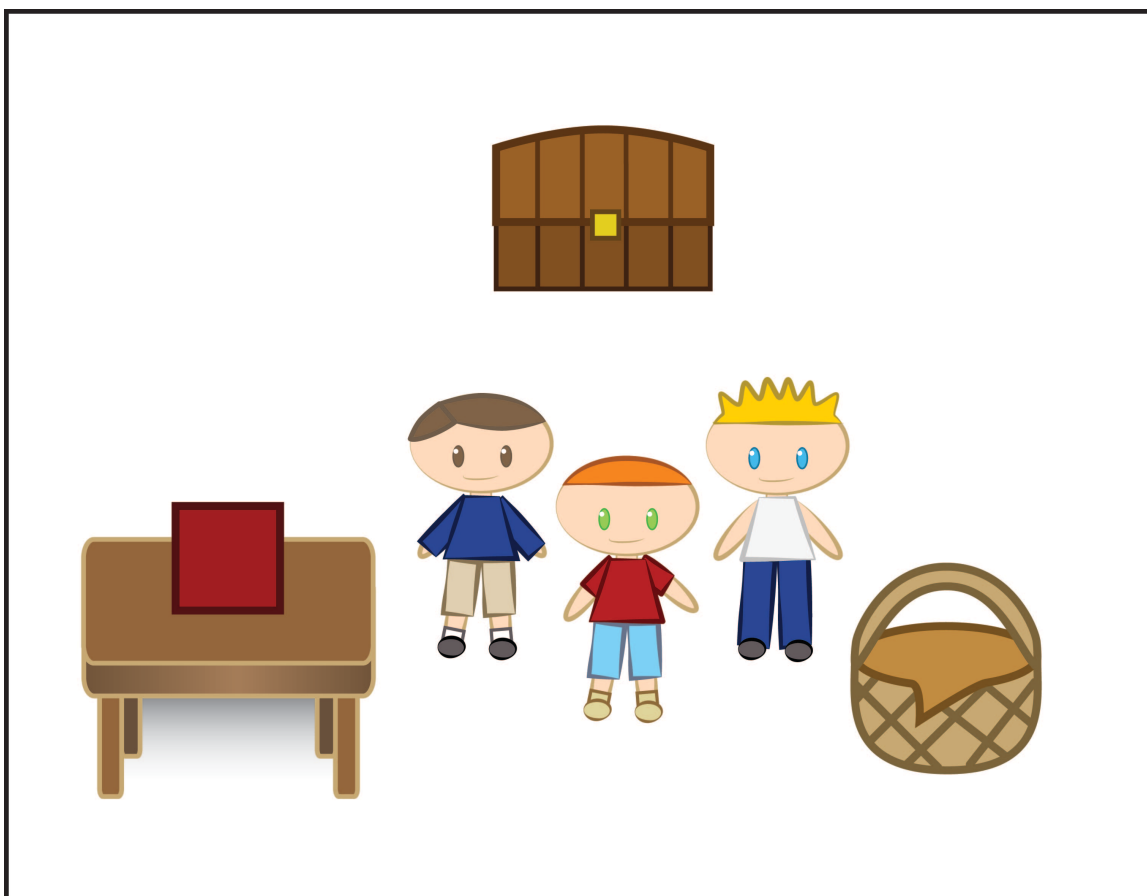


Figure 1. The locations were always in the same positions for each story and the characters were always in the same starting positions for each story.

Preschoolers listened to the story where Sammy puts the frog in the basket while Aaron and Jake are watching. Sammy then leaves. While Jake is watching, Aaron takes the frog from the basket and puts it in the box. Aaron also leaves. Jake, the third character, takes the frog from the box and puts it in the chest. After Jake puts the frog in the chest, he leaves. Then, the frog hops away and the frog's location remains unknown for the remainder of the story. The preschoolers were then asked several comprehension questions for each agent (refer to Appendix):

SEE: "Did Sammy see the frog jump into the chest? ..."

MEMORY: "Do you remember where Sammy put the frog? ..."

REALITY: "Where is the frog right now?"

Because there was no location response for the reality question, if the child answered the following, "I don't know," "Gone," or "The frog hopped away," the child was counted as passing the reality question. If the preschooler failed any of the comprehension questions, the experimenter corrected the child and retold the story. Their second responses, correct or incorrect, were recorded. Finally, the experimenter asked the child to predict the character's action:

ACTION-PREDICTION: "When Sammy comes back, where will he look for the frog?"

For the Memory and Action-Prediction questions, the experimenter showed the child the character's paper cutout. For example, when the experimenter started asking the Action-Prediction question, "When Sammy comes back, where will he look for the frog?" she would also pull out Sammy's cutout to ensure the child did not confuse the characters. Questions were either asked in the story's temporal order (Sammy, Aaron,

then Jake) or asked in the reverse order (Jake, Aaron, then Sammy), which was counterbalanced across subjects within each age group.

Each response to the action-prediction question was coded as one of four different belief attributions: agent 1's false belief (A1), agent 2's false belief (A2), agent 3's false belief (A3), or true belief (TB). A1 is the location where agent 1 falsely believes the frog to be, and likewise for A2 and A3. A true belief attribution entails preschoolers incorrectly imputing to the agent where they themselves believe the frog to be. This is an incorrect attribution because for the child to predict an agent's behavior, they must take into account the agent's belief, which happens to be false, as to where the frog is. In this task, since the frog's location is unknown, children responses included, "I don't know," "nowhere," "everywhere," and pointing to the location where the frog was last seen, i.e., which depended on the permutation the preschooler was told. For example, if the story order was Basket-Box-Chest, the preschooler attributing a true belief to an agent would point to the space above the chest, which was the last place the frog was seen in the story prior to asking the action-prediction questions. Any preschooler's response had three belief attributions. For example, a completely correct response would be responding A1, A2, and then A3 to the belief questions and is represented as A1A2A3 in the results.

Results

In previous false belief tasks, children's responses were always compared to a baseline probability of 0.5 because there was only a single agent's false belief to account for, Sally, and two possible belief attributions, her false belief or a true belief. Thus, to calculate the baseline probability for the task, we used the equation: $\text{beliefs}^{[\text{agents}]}$ or $b^a = 2^1 = 2$ to calculate for the number of possible responses. For the current task, children

must take into account three agents and four possible belief attributions, agent 1's false belief, agent 2's false belief, agent 3's false belief, and a true belief. Using the previous equation, $b^a=4^3$, we calculated that there were 64 possible responses that a preschooler could give in the present task. This task has considerable statistical power because a completely correct response is expected only 1 in 64 times by chance ($P = 0.016$).

Because there were 63 other possibilities where children could be incorrect, we categorized these errors into three different categories: false belief binding (FB) errors, true belief (TB) errors, and mixed errors. To be classified as a "false belief binding error," preschoolers had to mismatch at least one of the character's beliefs with another false belief. For example, a child could attribute agent 1 with agent 2's false belief and then attribute the other two correctly. For a "true belief error," preschoolers had to attribute to at least one agent a true belief. Finally, for a "mixed error" response, a preschooler's response included one false belief binding error and one true belief error. See Figure 1 for the percentages of preschoolers' responses for each response type.

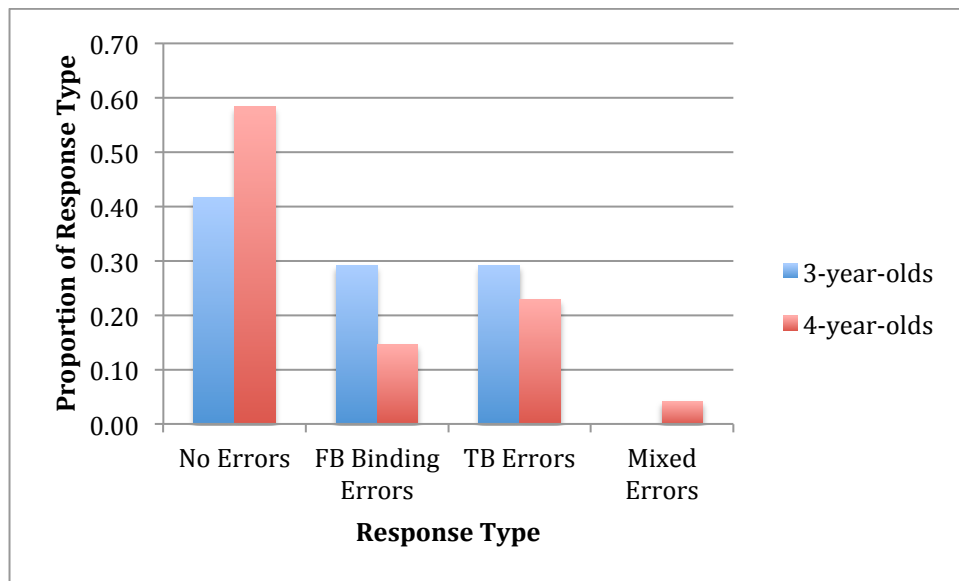


Figure 2. Proportion of response types three- and four-year-olds made in Study 1. No errors, FB binding errors, TB errors, and Mixed errors decreased with age (i.e., increase in no errors, decrease in binding errors).

Responses observed in the current study are reported in Table 1. Those not listed in the table were not observed. Using a binomial with a baseline of 1/64, we found that three- and for four-year-olds can simultaneously track three different minds with three distinct false beliefs (for three-year-olds: (N=20), completely correct= 42%, $p < .0001$, two-tailed, and four-year-olds: (N=28), completely correct = 58%, $p < .0001$, two-tailed).

Table 1. 3- and 4-year olds' Responses to Belief Questions in Study 1

Response	3-year-olds	4-year-olds
A1A2A3	20**	28**
A2A2A3	1	0
A3A2A3	0	1
A1A2A2	0	0
A1A3A2	2	1
A3A2A1	5*	1
A2A1A3	5*	2
A3A3A3	1	1
A2A3A1	0	1
TBA2TB	0	1
TBTBTB	14**	10**
A1A1TB	0	1
TBA3A3	0	1

Orange indicates a completely correct answer, blue a false belief binding error, yellow a true belief error, and green a mixed error. ** indicates $p < .0001$, * $p < .002$.

Even after a second telling of the story, eleven out of 96 preschoolers supplied an incorrect answer for at least one of the agents' memory question (six 3-year-olds and five 4-year-olds). Table 2 reflects their second response to the characters' memory questions and their respective answers for the belief questions. No distinct patterns emerged.

Table 2. 3- and 4-year-olds' Errors on the Memory Questions and Their Respective Belief Response in Study 1

	Memory Response	Belief Response
3-year-olds (n=6)	A3A2A1	A3A2A1
	A1A3A1	TBTBTB
	A2A1A3	TBTBTB
	A2A1A3	TBTBTB
	A2A1A3	TBTBTB
	A1A1A1	A1A2A3
4-year-olds (n=5)	A2A1A3	A2A1A3
	A3A1A2	TBTBTB
	A2A1A3	A2A1A3
	A3A1A2	A1A2A3
	A2A1A3	A1A2A3

Of the possible false belief binding errors, only two patterns occurred more often than chance and were observed only in 3-year-olds: swapping the first and second agents'

beliefs and swapping the first and third agents' beliefs ($N=48$, 10.42%, binomial (1/64), $p=.002$, two-tailed, and 10.42%, binomial (1/64), $p=.002$, two-tailed, respectively). See Table 1. In further analysis of these two errors, it was found that preschoolers who swapped the first and third agents' beliefs were the preschoolers in the forward questioning condition (4 out of the 5 A3A2A1 binding errors, binomial (1/64), $p=.001$, two-tailed) while preschoolers who swapped the second and first agents' beliefs were the preschoolers in the reverse questioning condition (3 out of the 5 A2A1A3, binomial (1/64), $p=.01$, two-tailed). No significant false belief binding error patterns emerged for the four-year-olds. Notice, however, when three- and four-year-olds incorrectly attribute the wrong false belief, they are still demonstrating their false belief reasoning. By collapsing the responses to four different categories: no TB attribution, one TB attribution, two TB attribution, and three TB attribution, we calculate a binomial with a baseline of 1/ 4 to demonstrate that three- and four-year-olds succeed in passing the false belief task (three-year-olds: 34 out of 44, binomial (1/4), $p<<.0001$, two-tailed, four-year-olds: 35 out of 44, binomial (1/4), $p<<.0001$, two-tailed).

The other pattern that was observed to occur significantly above chance and across both age groups is a true belief error. With the exception of two four-year-olds, when a child attributed her own belief to one agent, they attributed a true belief to all three characters (three-year-olds: ($N=14$), $p<<.0001$, two-tailed and four-year-olds: ($N=10$), $p<<.0001$, two-tailed).

Discussion

I found that both three- and four-year-olds were able to track up to three agents with distinct false beliefs. This evidence conflicts with the explanatory account of a

limited working memory capacity as posited by Olson (1989) and others because in the Study 1, I found that three-year-olds were able to succeed in tracking three agents and their respective false beliefs, i.e., three bounded mind indices. Further evidence against the limited working memory capacity account was found in the error analysis.

Traditional verbal false belief tasks such as Sally-Ann were limited to a binary response pattern: children either attributed Sally her correct false belief or attributed Sally an incorrect response, the true belief, and thus, researchers were never able to perform an error analysis. But with 63 possible incorrect responses, we can now examine what underlies the nature of children's mistaken attributions. The errors in the current study fell into one of three different categories: false belief binding errors (possible responses=26, e.g., A1A2A1, A1A1A2, etc.), true belief errors (possible responses=7, e.g., A1A2TB, A1TBTB, etc.), and mixed errors (possible responses=30, e.g., A1TBA2, A2TBTB, etc.).

Out of all the possible false belief binding errors (26), only two patterns observed occurred above chance in the three-year-olds: swapping the first agent with the last agent in the forward questioning and the first and second agent in the reverse questioning. In the forwards questioning, three-year-olds responded in the order A3A2A1 while in the reverse questioning, three-year-olds responded in the order A3A1A2. These findings suggest that we tapped into a recency effect in the domain of working memory (Deese & Kaufman, 1957; Murdock, 1962). The recency effect is a tendency to recall the last item or in the current study the third agent's false belief first. Interestingly, four-year-olds did not succumb to these bindings errors, which may suggest that we tapped in working

memory processing which develops from three to four, but it does not limit three-year-olds in maintaining multiple metarepresentations simultaneously.

If working memory capacity is responsible for three-year-olds' failures, the findings should have yielded a more diverse set of errors, but aside from the temporal switches, we found that the only other error that was committed a substantial number of times was the attribution of true belief to all characters (three-year-olds: 29.17%, four-year-olds: 22.92%). This could provide some support for the true belief bias (Leslie & Polizzi, 1998; Leslie & Thaiss 1992) because despite using a false belief task that has been shown to reduce inhibitory control demands in the past by undermining the child's own belief of where the frog is (see, Bartsch, 1996; Carpenter, Call, & Tomasello, 2002; Koos, Gergeley, Csibra, & Biro, 1997), we still observed true belief attribution to not only one character, but all characters. Therefore, this error could have emerged because children are unable to overcome the true belief bias.

Study 2: Quadruple False Belief

In the previous study, I found that preschoolers were able to track up to three agents and their respective false beliefs. I have still yet to address if there are any capacity limits in tracking multiple agent indices like there is in object working memory: 3 object indices for infants (see Feigenson & Carey, 2003; Kibbe & Leslie, 2011; Kibbe & Leslie, 2013) and four object indices for adults (see Pylyshyn & Storm, 1988; Scholl & Pylyshyn, 1999). For the following study, I increased the number of agents to four, each again with a distinct false belief, and I made three other modifications that were possible limitations to the previous study.

1) Because some subjects in Experiment 1 insisted that the frog was a helicopter/airplane, we changed the target object from a frog to a chick. If a preschooler genuinely thought that the frog was a helicopter, preschoolers may have possibly thought that agents were operating the object after they “left” in the story, and thus leading to preschoolers’ failures of the “see” question (10 in Study 1). 2) Because there was little difference in binding errors between the forward and the reverse questioning aside from the recency effect, the current study only asked questions in the story’s temporal order. 3) Unlike Study1, where only three orders of the frog’s hiding locations were tested, the following study tested all possible order versions. In the previous study, the frog’s hiding locations happened to be circular. So, to avoid children using a circular heuristic, preschoolers were randomly told one of twenty-four story versions.

Method

Thirty 3- and 4-year-old preschoolers were recruited for the experiments. There were 13 three-year olds (8 girls; $M = 42;24$ months, $SD = 3;0$ months) and 17 four-year-olds (9 girls; $M = 56;27$, $SD = 2;0$) tested on four circular versions (i.e., Basket-Jar-Box-Chest, Jar-Box-Chest-Basket, Box-Chest-Basket-Jar, and Chest-Basket-Jar-Box). To avoid the possibility of preschoolers using a simple clockwise heuristic to remember all the character’s beliefs, an additional 20 three-year-olds (12 girls; $M = 43;08$ months, $SD = 3;0$ months) and 20 four-year-olds (12 girls; $M = 54;27$, $SD = 2;0$) were tested on the other twenty possible location permutations. All participants were recruited from local preschools in the central New Jersey area. An additional 21 preschoolers were tested, but were excluded for the following reasons: 11 for failing the “see” question (10 three-year-olds, 1 four-year-old), 2 for failing the reality question (2 three-year-olds), 1 for being

distracted (1 three-year-old), 2 for being unresponsive to the experimenter's questions (2 three-year-olds), 1 for refusing to listen to the story a second time (1 three-year-old), and 4 for experimenter error (4 four-year-olds). Experimenter error here is defined by the experimenter misnaming/mixing the characters' names. For each age group, children were randomly assigned to one of twenty-four counterbalanced conditions of the story (see below).

Study 2 followed the same procedure as Study 1 except with the addition of a fourth character, Mary, and a fourth location, a jar. The four characters were also designed to look perceptually different from one another (different skin tones and different colored clothing), and the experimenters contrasted genders as well: two boys and two girls. The locations were designed to be a diamond shape and were always in the same locations on the page: the basket was located on the center right, the jar centered on the bottom of the page, the box on top of a table on the center left, and the chest centered on the top of the page and all characters were always in the same starting locations: Sammy, in the red shirt, bottom vertical middle, Aaron, in the blue shirt, left horizontal middle, Jane, in the green dress, right horizontal middle, and Mary in the pink dress, top vertical middle (See Figure 3.) Each subject was introduced to the four characters in the story, Sammy, Aaron, Jane, and Mary; all paper cutouts.



Figure 3. The locations were always in the same positions for each story and the characters were always in the same starting positions for each story.

Preschoolers then listened to the story where Sammy puts the chick in the basket while the other three characters are watching and leaves. Next, while Jane and Mary are watching, Aaron takes the chick from the basket and puts it in the jar. Then, Aaron leaves. Then, while Mary is watching, Jane takes the chick from the jar and puts it in the box. Jane leaves. Finally, the last character, Mary, takes the chick from the box and puts it in the chest. She also leaves. While all four characters were gone, the chick flew away, and the preschoolers were told that the chick's location remains unknown for the rest of the story. Participants were asked the same questions as Study 1 except with an

additional question to account for Mary with the See, Memory, and Action-Prediction questions.

Each of the preschoolers' responses to the belief questions was coded into five different belief attributions: agent 1's false belief (A1), agent 2's false belief (A2), agent 3's false belief (A3), agent 4's false belief (A4), or true belief (TB). A1 is the location where agent 1 falsely believes the frog to be, and likewise for A2, A3, and A4. An attribution of true belief entails preschoolers incorrectly attributing their own belief to the agent. Since the chick's location was unknown, children's responses were coded exactly like Study 1. Any given preschool response had four belief attributions. For example, a completely correct response would be responding A1, A2, A3, then A4 and is represented as A1A2A3A4 in the following tables.

Results

From Study 1, I used the previous equation, $\text{beliefs}^{[\text{agents}]}=5^4$, to compute the number of possibilities, we find that there are 625 possible responses that the preschoolers could give where only one of the 625 responses is completely correct ($P=.0016$). Because there are a tremendous number of possible responses, Table 3 includes only the responses that were observed in the current study. Using a binomial with a baseline of $1/625$, we found that four-year-olds can simultaneously track four different minds with four different false beliefs ($N=18$), 49%, $p<<.000001$). In addition, because of the sensitivity of the test, we found that three-year-olds make this response significantly above chance ($N=5$, 15.15%, $p<.000001$).

Table 3. 3- and 4-year olds' Responses to Belief Questions in Study 2.

Response	3-year-olds	4-year-olds
A1A2A3A4	5**	19**
A2A2A2A2	2	0
A4A4A4A2	1	0
A1A1A3A4	1	0
A1A4A2A3	1	0
A2A4A1A3	1	0
A1A3A2A4	1	0
A1A4A3A2	1	0
A4A2A3A1	1	1
A4A4A4A4	3**	2
TBTBA3A4	1	0
TBTBA3TB	1	0
TBTBTBTB	14**	13**
TBA1A4A3	0	1
TBA1A4A2	0	1

Orange indicates a completely correct answer, blue a false belief binding error, yellow a true belief error, and green a mixed error. ** indicates $p < 0.000001$, * $p < 0.00004$.

We are conservative in the interpretation of three-year-olds' ability to maintain four simultaneous agents and their respective beliefs because in Figure 2, we present the proportion of response types made by three- and four-year-olds, which shows a dramatic difference in performance. This is discussed further in the error section below.

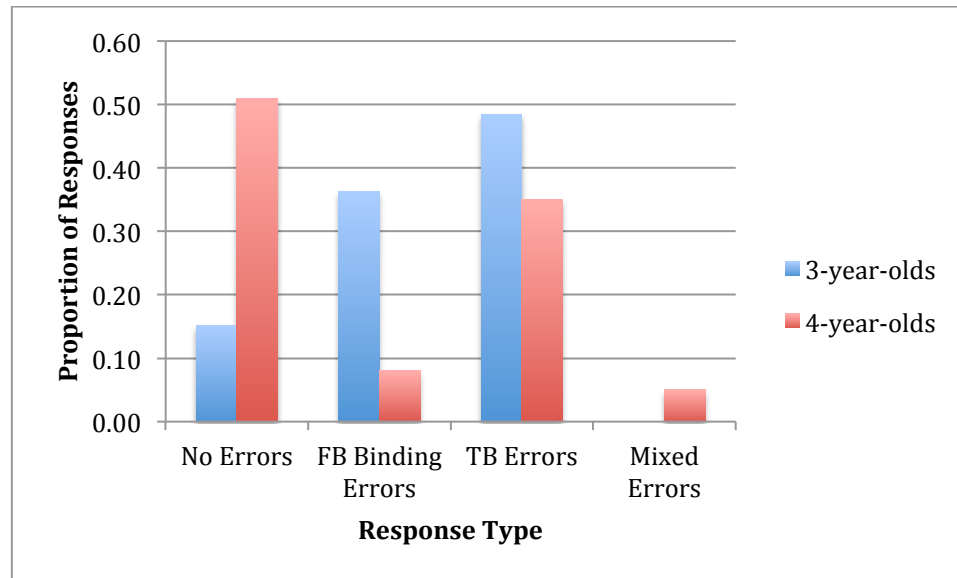


Figure 4. Proportion of errors types three- and four-year-olds made in the Study 2. Errors decreased with age (i.e., sharp increase of no errors and decrease in binding errors).

If preschoolers were using a simple heuristic such as circular ordering to aid working memory for the original four permutations, then we should find worse memory performance in the other 20 permutations than the original 4. We found that out of 70 preschoolers, 14 recalled the wrong location placement for at least one of the characters (i.e., answered incorrectly for one of the memory questions) even after a second telling of the story (10 3-year-olds: 5 in the four clockwise permutations and 5 in the other 20 permutations and 4 4-year-olds: 3 in the four clockwise permutations and 1 in the other 20 permutations). Table 4 reflects their (second) incorrect responses to the memory questions and their subsequent answers for the belief questions. Again, no distinct patterns emerged.

Table 4. 3- and 4-year-olds' Errors on the Memory Questions and Their Respective Belief Response

	Memory Response	Belief Response
3-year-olds (n=10)	A1A2A4A3	A1A2A3A4
	A1A2A4A3	TBTBTBTB
	A1A2A4A3	TBTBTBTB
	A1A2A4A3	A1A2A4A3
	A1A2A3A3	A1A1A3A4
	A1A1A2A3	A1A4A2A3
	A1A4A3A2	A1A3A2A4
	A1A4A3A2	A1A4A3A2
	A2A2A2A2	A2A2A2A2
	A3A2A1A2	A4A2A3A1
4-year-olds (n=4)	A1A2A4A3	A1A2A3A4
	A4A2A3A4	A4A4A4A4
	A3A1A4A3	A1A2A3A4
	A2A1A3A4	TBTBTBTB

Out of the possible false belief binding errors, only one pattern occurred more often than chance (and were observed only in 3-year-olds): attributing all of the agents agent 4's false belief (3 out of 33, 9%, binomial (1/625), $p < .0001$). No significant false belief binding error patterns emerged for the four-year-olds.

Like Study 1, only one error occurred significantly above chance for both three-year-olds (42.42%) and four-year-olds: (37.83%). With the exception of 4 preschoolers (2 three-year-olds and 2 four-year-olds), when a child attributed her own belief to one agent, they attributed a true belief to all four characters (three-year-olds: (N=14), $p < .0001$, two-tailed and four-year-olds: (N=13), $p < .0001$, two-tailed).

If we compare three-year-olds' performance in Study 2 to three-year-olds' performance in Study 1 as depicted in Figure 3, there was a decrease in the proportion of no error responses from Study 1 to Study 2 and an increase in the proportion of true belief responses from Study 1 to Study 2.

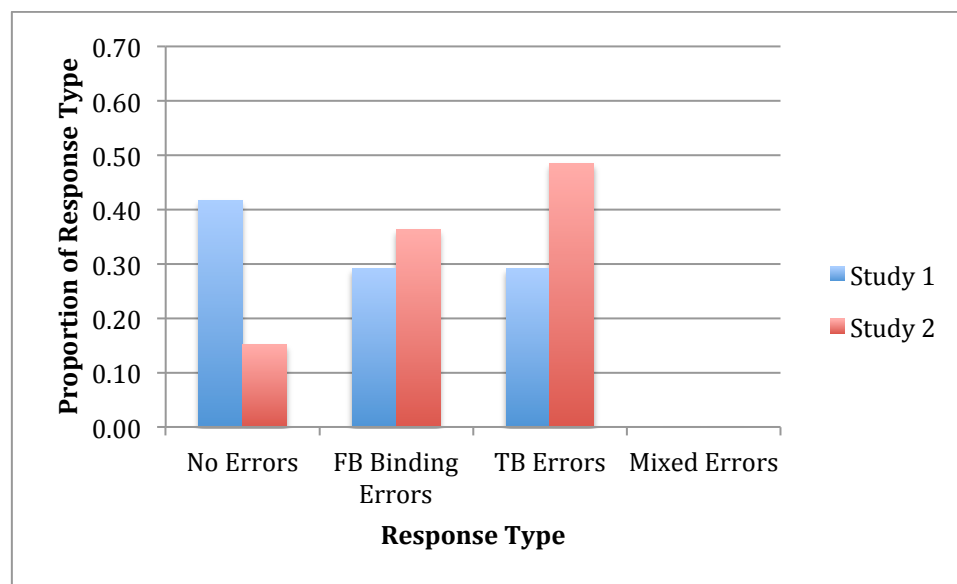


Figure 5. Proportion of three-year-olds' response types made for Study 1 and Study 2.

In contrast, four-year-olds' performance from Study 1 to Study 2 is depicted in Figure 4, where the decrease in the proportion of no error responses was not as pronounced as three-year-olds' decrease. But there was a noticeable increase in true belief binding responses for the four-year-olds from Study 1 to Study 2.

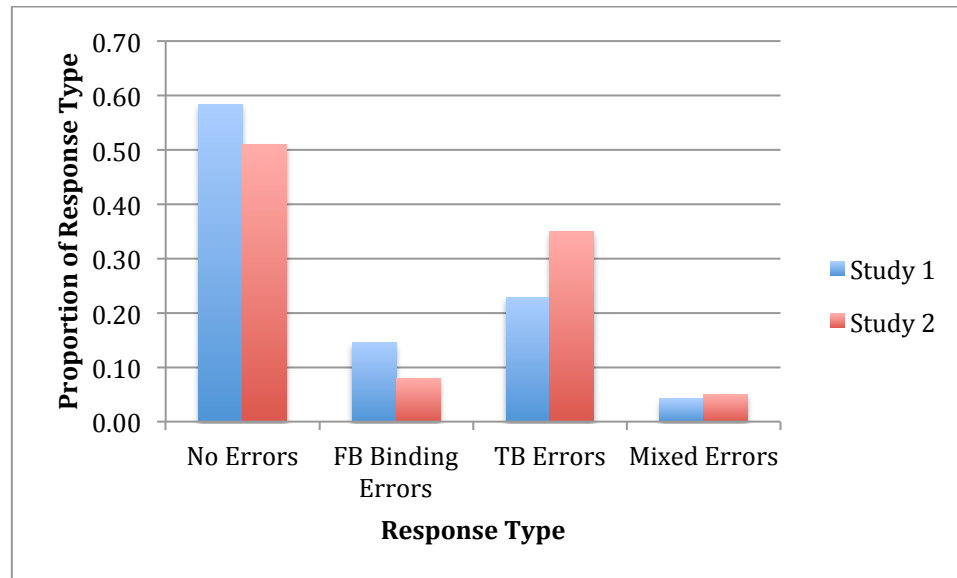


Figure 6. Proportion of four-year-olds' response types made for Study 1 and Study 2.

Notice for FB binding errors that despite making an incorrect belief attribution, three-year-olds are still making false belief attributions when they commit a false belief binding error. Like Study 1, we collapsed all correct and all false belief binding responses together into one category of no true belief attributions, and had four other responses (one TB attributions, two TB attributions, three TB attributions, and four TB attributions), and we found that three- and four-year-olds succeed in demonstrating their false belief reasoning (three-year-olds: 17 out of 33, binomial (1/5), $p < .0001$, two-tailed, four-year-olds: 22 out of 37, binomial (1/5), $p < .0001$, two-tailed).

Discussion

In Study 2, we found that four-year-olds were able to track up to four characters with four distinct false beliefs. In addition, using a binomial test with baseline of 1/625, we found that three-year-olds also made the correct response significantly above chance (only 5 out of the 33 three-year-olds made the correct response). Because of the sensitivity of the test, we should be conservative in interpreting three-year-olds'

performance of being able to track up to four characters and their respective false beliefs simultaneously. When compared to Study 1, three-year-olds' performance in Study 2 shows a dramatic difference in response type whereby three-year-olds' performance in correctly attributing all the correct false beliefs to its respective characters decreased dramatically from Study 1 to Study 2. However, when we collapse response types to categories based on the number of attributed true beliefs, we found that three-year-olds (as well as four-year-olds) still attribute false beliefs to the agents significantly more often than chance. Despite showing poor performance in remembering four metarepresentations, three-year-olds still were able to attribute more false belief responses than true belief responses, which suggest their ability to attribute false beliefs are separate from their working memory capacity limitations.

Of all the false belief binding errors, there was one pattern committed significantly above chance (3 out of 33 responses) and only by the three year olds, where they attributed the last agent's false belief to all the characters. This response may have occurred because the working memory demand in this task was too high, and thereby, causing the three-year-olds to be overwhelmed with the amount of information. Thus, they used the most recent agent's false belief to bind to all the characters' minds.

Like Study 1, the most frequent error found in both age groups was attributing true belief to all characters. Moreover, out of all true belief errors, only three children (2 three-year-olds and 1 four-year-olds) showed a different pattern. For example, one three-year-old attributed a true belief for the first two agents, but correctly attributed the third and fourth agent's their respective false belief.

General Discussion

The question that has plagued the theory of mind research for three decades has been the emergence of theory of mind. Using verbal false belief tasks, researchers preemptively concluded that theory of mind emerged at age 4 because three-year-olds typically fail by attributing the wrong belief to Sally (Perner, 1991; Perner, 1995; Perner & Ruffman, 2005). Some challenged this claim, and instead granted three-year-olds the ability to impute mental states, but suggested that their faulty performance was due to a limited working memory capacity (Olson, 1989; David & Pratt, 1995). However, explanatory accounts have yet to be examined empirically the nature of three-year-olds' errors. This is because previous tasks were limited to a binary response: either the child was correct or the child was incorrect. Therefore, when three-year-olds "fail," it is uncertain what type of error they were committing, whether it is a working memory error, or a true belief error.

By increasing the number of agents and the number of possible false beliefs that could be attributed in a task, children can now make a multitude of errors (in Study 1, 63 different error responses and in Study 2, 624 different error responses). But this is not the case. Across both ages and studies, there were only two common responses out of all possible responses: all correct false belief attributions or all (incorrect) true belief attribution. The "binary" response that I find in Study 1 and 2 aligns with the binary response found in the Sally-Ann task, where the child was either correct by attributing to Sally her false belief, which parallels with an all correct response in the multiple agent false belief, or the child incorrectly points to where the marble actually is, which parallels with an all true belief response, and thus, giving researchers insight as to the type of error

three-year-olds' are committing. Attributing true beliefs to all the agents as one of the most common response may provide some evidence for Leslie and Polizzi's (1998) true belief default, where three-year-olds must initially inhibit the true belief, which is the default belief, in order to then attribute a false belief. However, because three-year-olds have yet to develop the required inhibitory control, the model would then predict that the child would attribute a true belief to not only one character, but to all of the agents. The question of inhibitory control playing a role in theory of mind processing can only be entertained in the current task and cannot be concluded from the current studies' results, but this is a future direction that should be examined directly.

In addition, several questions still remain unanswered. By increasing the agents and distinct false beliefs from three in Study 1 to four in Study 2, I found that four-year-olds' success in attributing the correct false belief to each agent was not hindered with the addition of a fourth agent, but three-year-olds' performance suffered. Thus, four-year-olds' working memory capacity for theory of mind is still unknown. Findings from working object memory suggest that adults' capacity is limited to four featureless objects (Pylyshyn & Storm, 1988; Scholl & Pylyshyn, 1999), and therefore, if the number of agents and false beliefs were increased to five, I might see a decline in four-year-olds' performance as we did with the three-year-olds' on a penta-false belief task.

Conclusions

In the current studies, I found that a limited working memory capacity account is unable to explain three-year-olds' traditional failures in verbal false belief tasks because both three- and four-year-olds were able to track up to three agents with their distinct false beliefs. When I increased the load to four agents and four distinct false beliefs, I

found that three-year-olds' performance suffered while four-year-olds continued to succeed in the task. Furthermore, the present studies add to current theory of mind research by examining for the first time in false belief task history errors made in a verbal false belief task. Despite the number of possible error patterns there was only one clear consistent error that prevailed across studies and ages. When a child attributed a true belief to one agent, they tended to attribute a true belief to all the agents, which may provide some evidence for the true belief default, but it has yet to be tested directly.

Appendix 1

Study 1: Triple False Belief Task

Introduction/Warm-up

First, I'm going to introduce you to two people that are going to be in my story today, okay? This boy's name is Sammy. (Experimenter shows the cutout of Sammy.) This boy's name is Aaron. (Experimenter shows the cutout of Aaron). And this boy's name is Jake. (Experimenter shows the cutout of Jake) And all three of these boys are going to be in my story today, okay? So let's look at the story now. (Experimenter opens to first page.) Look! Here's Sammy. (Experimenter points to Sammy.) Here's Aaron. (Experimenter points to Aaron.) And here's Jake. (Experimenter points to Jake) And look! (Experimenter turns the page.) Look at what Sammy has in his hand. (Experimenter points to the frog in Sammy's hand.) Do you know what he has in his hand? (Child responds.) That's right! It's a frog. And do you know what sound frogs make? (Child responds.) That's right, frogs say, "(Experimenter parrots child's response.)"

Story

So, Sammy was playing with the frog, but Sammy has to go away. So Sammy puts the frog (Experimenter turns the page.) into the basket. Then, he goes away. (Experimenter turns the page.) But then Aaron wants to play with the frog, so Aaron goes into the basket (Experimenter turns the page.), and he takes the frog out the basket. But then Aaron has to go away. So Aaron puts the frog (Experimenter turns the page.) into the box. And then, Aaron goes away. (Experimenter turns the page.) But then Jake wants to play with the frog. So Jake goes to the box (Experimenter turns the page), and he takes

the frog out of the box. But then Jake has to go away. So Jake puts the frog
(Experimenter turns the page.) into the chest. But while the all three boys are gone, look
what happens! The frog comes out of the chest (Experimenter turns the page.) and hops
away! (Experimenter turns the page.)

Questions

Now I have a few questions for you.

[See]

Did Sammy see that?

Did Aaron see that?

Did Jake see that?

[Memory]

Do you remember where Sammy put the frog? (Experimenter shows Sammy cutout.)

Do you remember where Aaron put the frog? (Experimenter shows Aaron cutout.)

Do you remember where Jake put the frog? (Experimenter shows Jake cutout.)

[Reality]

And where is the frog right now?

[Action Prediction]

When Sammy comes back, (Experimenter shows Sammy cutout.), where will he look for
the frog?

And how about Aaron? (Experimenter shows Aaron cutout.) When Aaron comes back,
where will he look for the frog?

And how about Jake? (Experimenter shows Jane cutout.) When Jake comes back, where
will she look for the frog?

Study 2: Quadruple False Belief Task

Introduction/Warm-up

First, I'm going to introduce you to four people that are going to be in my story today, okay? This one is Sammy. (Experimenter shows the cutout of Sammy.) This one is Aaron. (Experimenter shows the cutout of Aaron.) This one is Jane. (Experimenter shows the cutout of Jane.) And this one is Mary. (Experimenter shows the cutout of Mary.) And all four of these kids are going to be in my story today, okay? So let's look at the story now. (Experimenter opens to first page.) Look! Here's Sammy. (Experimenter points to Sammy.) Here's Aaron. (Experimenter points to Aaron.) Here's Jane. (Experimenter points to Jane.) And here's Mary. (Experimenter points at Mary.) And look! (Experimenter turns the page.) Look at what Sammy has in his hand. (Experimenter points to the chick in Sammy's hand.) Do you know what he has in his hand? (Child responds.) That's right! It's a chick. And do you know what sound chicks make? (Child responds.) That's right, chick says, "(Experimenter parrots child's response)"

Story

So, Sammy was playing with the chick, but Sammy has to go away. So Sammy puts the chick (Experimenter turns the page) into the basket. Then, he goes away. (Experimenter turns the page.) But then Aaron wants to play with the frog, so Aaron goes into the basket (Experimenter turns the page.), and he takes the frog out the basket. But then Aaron has to go away. So Aaron puts the chick (Experimenter turns the page.) into the box. And then, Aaron goes away. (Experimenter turns the page.) But then Jane wants to play with the chick. So Jane goes to the box (Experimenter turns the page.), and she takes

the frog out of the box. But then Jane has to go away. So Jane puts the chick (Experimenter turns the page.) into the chest. But then Mary wants to play with the chick. So Mary goes to the chest (Experimenter turns the page.), and she takes the chick out of the chest. But then Mary has to go away. So Jane puts the chick (Experimenter turns the page.) into the jar. But while the all the kids are gone, look what happens! The chick comes out of the chest (Experimenter turns the page.) and flies away! Far far away where no one knows where it went. (Experimenter turns the page.)

Questions

Now I have a few questions for you.

[See]

Did Sammy see that?

Did Aaron see that?

Did Jane see that?

Did Mary see that?

[Memory]

Do you remember where Sammy put the chick? (Experimenter shows Sammy cutout.)

Do you remember where Aaron put the chick? (Experimenter shows Aaron cutout.)

Do you remember where Jane put the chick? (Experimenter shows Jane cutout.)

Do you remember where Mary put the chick? (Experimenter shows Mary cutout.)

[Reality]

And where is the chick right now?

[Action Prediction]

When Sammy comes back, (Experimenter shows Sammy cutout.), where will he look for the chick?

And how about Aaron? (Experimenter shows Aaron cutout.) When Aaron comes back, where will he look for the chick?

And how about Jane? (Experimenter shows Jane cutout.) When Jane comes back, where will she look for the chick?

And how about Mary? (Experimenter shows Mary cutout.) When Mary comes back, where will she look for the chick?

References

- Baddeley, A.D. (1998). Recent developments in working memory. *Current Opinion in Neurobiology*, 8, 234-238.
- Baddeley, A.D. (1981). The concept of working memory: A view of its current state and probable future development. *Cognition*, 10, 17-23.
- Baddeley, A.D., & Hitch, G. (1974). Working memory. In G.A. Bower (Ed.), *The Psychology of Learning and Motivation*. (pp.47-89). New York, NY: Academic Press.
- Baddeley, A.D. (1986). *Working Memory*. Oxford: Clarendon Press.
- Baillargeon, R., Scott, R., & He, Z. (2010). False-belief understanding in infants. *Trends of Cognitive Sciences*, 14(3), 110-118.
- Baron-Cohen, S., Leslie, A.M., & Frith, U. (1985). Does an autistic child have a theory of mind? *Cognition*, 21, 37-36.
- Bartsch, K. (1996). Between desires and beliefs: Young children's action predictions. *Child Development*, 67, 1671-1685.
- Bosco, F., Friedman, O., & Leslie, A.M. (2006). Recognition of pretend and real actions in play by one- and two-year-olds: Early success and why they fail. *Cognitive Development*, 21, 3-10.
- Bruell, M. J., & Woolley, J. (1998). Young children's understanding of diversity in pretence. *Cognitive Development*, 13, 257-277.
- Carlson, S.M., Moses, L.J., & Breton, C. (2002). How specific is the relation between executive function and theory of mind? Contribution of inhibitory control and working memory. *Infant & Child Development*, 11, 73-92.
- Carlson, S.M., Moses, L.J., & Hix, H.R. (1998). The role of inhibitory control in young children's difficulties with deception and false belief. *Child Development*, 69, 672-691.
- Carpenter, M., Call, J., & Tomasello, M. (2002). A new false belief test for 36-month-olds. *British Journal of Developmental Psychology*, 20, 393-420.
- Davis, H.L., & Pratt, C. (1995). The development of children's theory of mind: The working memory explanation. *Australian Journal of Psychology*, 47, 25-31.
- Deese, J., & Kaufman, R.A. (1957). Serial effects in recall of unorganized and sequentially organized verbal material. *Journal of Experimental Psychology*, 54(3), 180-187.
- Feigenson, L., & Carey, S. (2003). Tracking individuals via object-cues: evidence from infants' manual search. *Developmental Science*, 6, 568-584.
- Friedman, O., & Leslie, A.M. (2004a). A developmental shift in processes underlying successful belief-desire reasoning. *Cognitive Science*, 28, 963-977.
- Friendman, O., & Leslie, A.M. (2004b). Mechanisms of belief-desire reasoning: Inhibition and bias.. *Psychological Science*, 15(8), 547-552.
- Gordon, A., & Olson, D.R. (1998). The relation between acquisition of theory of mind and the capacity to hold in mind. *Journal of Experimental Child Psychology*, 68, 70-83.
- Hale, C. M., and Tager-Flusberg, H. (2003). The influence of language on theory of mind: a training study. *Developmental Science*, 6(3), 346-359.

- Hickling, A.K., Wellman, H.M., & Gottfried, G.M. (1997). Preschoolers' understanding of others' mental attitudes towards pretend happenings. *British Journal of Developmental Psychology*, 15(3), 339-354.
- Keenan, T. (1998). Memory span as a predictor of false belief understanding. *New Zealand Journal of Psychology*, 27(2), 36-43.
- Keenan, T., Olson, D.R., & Marini, Z. (1998). Working memory and children's developing understanding of mind. *Australian Journal of Psychology*, 50(2), 76-82.
- Kibbe, M.M., & Leslie, A.M. (2011). What do infants remember when they forget? Location and identity information in six-month-old's memory for objects. *Psychological Science*, 22, 1500-1505.
- Kibbe, M.M., & Leslie, A.M. (2013). What's the object of object working memory in infancy? Unraveling 'what' and 'how many'. *Cognitive Psychology*, 66, 380-404.
- Koos, O., Gergeley, G., Csibra, G., & Biro, S. (1997, April). *Why eating Smarties make you smart? Understanding false belief at the age of 3*. Poster presented at the meeting of Society of Research in Child Development, Washington, D.C.
- Leslie, A.M. (1987b). Pretence and representation: The origins of "theory of mind." *Psychological Review*, 94, 412-426.
- Leslie, A.M. (1994a). Pretending and believing: Issues in theory of ToMM. *Cognition*, 50, 211-238. Reprinted in J. Mehler and S. Franck (Eds.), *COGNITION on cognition*, 193-220. (1995). Cambridge, MA: MIT Press.
- Leslie, A.M., & Polizzi, P. (1998). Inhibitory processing in the false belief task: Two conjectures. *Developmental Science*, 2, 247-253.
- Leslie, A.M., Xu, F., Tremoulet, P.D., & Scholl, B. (1998). Indexing and the object concept: developing 'what' and 'where' systems. *Trends in Cognitive Sciences*, 2(1), 10-18.
- Miller, G.A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, 63, 81-97.
- Murdock, B. (1962). Serial position effect of free recall. *Journal of Experimental Psychology*, 64(2), 482-488.
- Olson, D.R. (1989). Making up your mind. *Canadian Psychology*, 30, 617-627.
- Onishi, K., & Baillargeon, R. (2005). Do 15-month-old infants understand false beliefs? *Science*, 308, 255-258.
- Onishi, K.H., Baillargeon, R., & Leslie, A.M. (2007). 15-month-old infants detect violations in pretend sequences. *Acta Psychologica*, 124, 106-128.
- Pascual-Leone, J. (1970). A mathematical model for the transition rule in Piaget's development stages. *Acta Psychologica*, 32, 301-345.
- Perner, J. (1991). *Understanding the representational mind*, MIT Press.
- Perner, J. (1995). The many faces of belief: Reflections on Fodor's and the child's theory of mind. *Cognition*, 57, 241-269.
- Perner, J., & Ruffman, T. (2005). Infants' insight into the mind: How deep? *Science*, 308, 214-216.
- Premack, D., & Woodruff, G. (1978). Does the chimpanzee have a theory of mind? *The Behavioral and Brain Sciences*, 4, 515-526.
- Pylyshyn, Z. (1978). When is attribution of beliefs justified? *The Behavioral and Brain Sciences*, 1, 592-293.

- Pylyshyn, Z., & Storm, R. (1988). Tracking multiple independent targets: Evidence for both serial and parallel stages. *Spatial Vision*, 3, 179-197.
- Rakoczy, H. (2010). Executive function and the development of belief-desire psychology. *Developmental Science*, 13(4), 648-661.
- Rakoczy, H., Warneken, F., & Tomasello, M. (2007). "This way!", "No! That way!" – 3-year olds know that two people can have mutually incompatible desires. *Cognitive Development*, 22, 47-68.
- Scholl, B.J., & Pylyshyn, Z.W. (1999). Tracking multiple objects through occlusion: Clues to visual objecthood. *Cognitive Psychology*, 38, 259-290.
- Southgate, V., Senju, A., & Csibra, G. (2007). Action anticipation through attribution of false belief by 2-year-olds. *Psychological Science*, 18, 587-592.
- Southgate, V., & Vernetti, A. (2014). Belief-based action prediction in preverbal infants. *Cognition*, 130, 1-10.
- Underleider, L.G., & Mishkin, M. (1982). Two cortical visual systems. In D.J.Ingle, R.J.W. Mansfield, and M.A. Goodale (eds.), *Analysis of Visual Behavior*. Cambridge, MA: MIT Press.
- Villiers, J., & Pyers, J. E. (2002). Complements to cognition: a longitudinal study of the relationship between complex syntax and false-belief-understanding. *Cognitive Development*, 17, 1037-1060.
- Wellman, H., Cross, D., & Watson, J. (2001). Meta-analysis of theory of mind development: The truth about false belief. *Child Development*, 72, 655-684.
- Wimmer, H., & Perner, J. (1983). Beliefs about beliefs: Representation and constraining function of wrong beliefs in young children's understanding of deception. *Cognition*, 13, 103-128.
- Wyman, E., Rakoczy, H., & Tomasello, M. (2009). Young children understand multiple pretend identities in their object play. *British Journal of Developmental Psychology*, 27, 385-404.
- Zaitchik, D. (1991). Is only seeing really believing?: Sources of true belief in the false belief task. *Cognitive Development*, 6, 91-103.