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REMEMBER WHAT? WORKING MEMORY CAPABILITIES IN INFANCY

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ABSTRACT

Research has revealed that both infants (Feigenson & Carey, 2004) and adults (Luck and Vogel, 1997) have similar capacities of about 3-4 items in working memory. However, one dramatic difference exists. Specifically, when infants are presented with groups of similar objects that surpass their working memory limits, they experience the phenomena of catastrophic forgetting (Feigenson & Carey, 2004) while adults will successfully remember up to their memory limit. Catastrophic forgetting is marked by a complete failure of working memory when capacity is exceeded (Feigenson & Carey, 2004, Feigenson & Halberda, 2008). Recent work suggests that when infants are presented with highly varied objects, infants do not experience catastrophic forgetting and instead remember up to their memory limit (Zosh & Feigenson, 2015). To date, infant working memory studies typically used objects or a combination of objects and animals as the targets for working memory. Here, we investigate whether infants have better working memory capabilities for human-like stimuli (dolls). Previous work suggests that infants privilege information about humans over other types of information and that they show enhanced cognitive capabilities when conspecifics (other humans) are used as stimuli (Bonatti, Frot, Zangl, & Mehler, 2002). The current study employs the manual search paradigm (Feigenson & Carey, 2004) to test whether infants experience catastrophic forgetting when confronted with an array of non-identical dolls exceeding their memory capacity.

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Chapter 1 **Introduction**

In order to navigate successfully in the world, an individual must know how to effectively use objects. Which objects are dangerous? Which objects are edible? How do the parts of this object make it different from another object? What happens to those objects when they are no longer visible? How is this ability to flexibly use information about objects in the world limited? Importantly, when do we develop this ability?

Research suggests that both our attention and memory can be considered “object-based”, meaning that visual attention and items a person is presented with are represented as discrete objects in the individual’s mind (Scholl, 2001). Further, objects are not remembered and tracked as clumps of stuff, but as “units of attention” (Scholl, 2001, pp. 2). Luck and Vogel (1997) demonstrated adults’ capacities to represent objects as individual entities in memory while having the ability to recall specific features of the object. Adults were shown to be able to remember up to four objects while also storing multiple features within the representation of each of the object. In the study, adults were briefly shown an array of objects on a computer screen, followed by a delay screen, and then a second array of objects after the delay was presented. Participants were asked to decide whether one or both features (e.g., color and orientation) of objects in the second array differed from those in the first array. While adults could only store four object representations in their memories, they were able to identify changes in one or both of the features for each of the objects remembered. Thus, this study demonstrated how adults have the ability to encode multiple features within the representation of each object. Crucially, they were able to remember four objects each consisting of two features but not eight single-featured objects. This finding speaks to the object representations that allow us to think about and remember objects and the fact that this ability is limited.

The system that underlies our ability to remember and reason about objects that are not directly visible is working memory. Working memory is the span of items a person can "work" on or remember at a given time (Reisberg, 2013). Working memory is our current consciousness—the grocery list, a phone number—tasks or items people have to work on in order to have them stored in their long-term memories (Reisberg, 2013). But as an individual may find when trying to remember a long list of items, working memory has limits.

Despite earlier estimates that working memory capacity was 7 plus/minus 2 items for adults (Miller, 1956), more controlled recent work finds that adult capacity is around 3 or 4 items. Referring back to the previously described study completed by Luck and Vogel (1997), the results demonstrated that adults were not able to identify changes in more than four objects. Yet as it was explained, subjects were able to maintain the shape and color of each object in their working memories. Thus, while adults remembered four objects, memory for objects can include multiple complex features. It should also be noted that this study demonstrated that when adults are presented with more objects than their memory can hold, they are still able to retain representations for up to four objects. This idea has been recently supported by neural evidence suggesting that neural activation in the inferior intraparietal sulcus (an area responsible for object representations) asymptotes once capacity is reached (Xu & Chun, 2006).

When does this ability to recognize objects and hold them in working memory begin? Despite Piaget's assertion that infants do not experience object permanence until about eight months of age, much evidence suggests that even young infants have at least some ability to think about objects and that this ability quickly improves over the first year of life (Kibbe & Leslie, 2008).

Infants must rapidly learn about the endless objects around them and how to effectively use those objects to obtain their goals (e.g., can I use this fork to fling my food off the table?). The process through which infants understand that given objects are separate from each other and that these objects can be tracked over time is called individuation (Xu, 2005). Individuation allows an infant to recognize that the ball that she watched roll behind the couch is still the same ball when it rolled out from the other side. Once the individuation of an object is established, infants can add the item they individuated to an existing mental category of similar objects, or create a new category for the object (Quinn, 2005). Not surprisingly, this organization of objects into mental groups is called categorization (Quinn, 2005). The systems of object individuation and categorization allow infants to understand the functions of objects, the differences between categories of objects, and how to act upon objects (Quinn, 2005; Xu, 2002).

Infants, specifically young infants, represent objects in a slightly different manner than adults. Due to the development of the neural systems involved in object representation, infants tend to be more focused on the spatiotemporal features of objects. The spatiotemporal features of objects can be described as the way an object moves, how it occupies space, and where it is located in space (Xu & Carey, 1996; Káldy & Leslie, 2003). It has been demonstrated that the youngest infants are prone to individuating and representing two objects only if the objects had two spatially distinct locations (Xu & Carey, 1996). If two different objects are shown to an infant, but shared the same spatiotemporal features, infants do not successfully individuate the objects. That is not to say that infants do not recognize the physical features of objects, but that the spatiotemporal features are much more salient and accessible to young infants (Xu & Carey, 1996). As infants get older, this ability changes such that by the time they are ten months of age, they are able to use features to distinguish objects (Xu & Carey, 1996). An example of this would be if an infant watches her mother take a toy truck and a ball and hides them behind a book. At an age younger than ten months, the infant would not be surprised if her mother lifted the book to reveal only one of the objects because the items shared the same spatiotemporal feature, thus the infant could not individuate the objects. Yet at ten months, the infant would be surprised if she saw only one object revealed where she knew two were hiding because the infant could more easily differentiate the features of the objects hidden.

Recent work also finds that by the time infants are one year old, they can hold one, two, and three individual objects in working memory but not more (Feigenson & Carey, 2004; Feigenson & Halberda, 2008). Feigenson and Carey (2004) demonstrated that when experimenters used a manual search paradigm in which the experimenters hid objects in a box and allowed infants to retrieve either some or all of the objects, that infants could remember up to three objects, but not more. In the study, infants watched experimenters hide one to four objects in a box and then were allowed to search for the objects. On some trials, the box was empty and on other trials, the box still had objects remaining inside. The researchers compared the amount of time spent searching when the box was empty compared to when the box was full. If infants searched more when objects remained in the box compared to when the box was empty, it demonstrated that the infants remembered the number of objects and which objects were hidden. For example, in Feigenson and Carey (2004), infants observed trials during which researchers hid either one object or four objects within a box. In both trial types, infants were able to retrieve one object, thus leaving the box empty in one-item trials or three objects remaining in four-item trials. Infants searched equal amounts of time when the box was empty and when the box contained three objects. The lack of significant differences between searching time reveals that infants failed to store representations for all of the objects presented in a four item array when the objects were identical, thus demonstrating that infants appeared to be unable to remember any of the hidden items – a phenomenon called *catastrophic forgetting*. Catastrophic forgetting is the pattern of results in which infants appear to lose all of their currently represented items in working memory when the number of items they are asked to store is greater than their capacity limit (Zosh & Feigenson, 2015; Feigenson & Carey, 2004). While infants have the ability to remember three objects, they experience catastrophic forgetting when shown four objects.

Thus, research suggests that infant and adult working memory converge in terms of capacity but also diverges when it comes to what happens when presented with a supra-capacity array. A recent study suggests that **what** infants are asked to remember may impact their ability to maintain objects in working memory. Zosh and Feigenson (2015) found that when infants are presented with an array of four very different, or heterogeneous items, infants performed similar to adults when they reached their working memory limits. In the study, the researchers found that when infants were presented with four objects that greatly differed in appearance, they encoded up to three objects and did not experience catastrophic forgetting. Like adults, they stored up to their memory limit of three items. This study demonstrated that the heterogeneity of the object arrays allowed infants to remember up to three objects and hold them in working memory even when presented with a number of objects exceeding their working memory capacities. This demonstrates that under certain conditions an infant's working memory can perform similar to an adult's working memory.

Zosh and Feigenson (2015) suggest that **what** infants are storing in memory impacts **how many** objects infants can remember. This is one of the first studies to show that the contents of what is being stored in working memory can impact how infants perform when faced with arrays exceeding capacity, or supra-capacity arrays. One unexplored question is whether other types of heterogeneity might impact performance. Namely, might some types of stimuli be evolutionarily privileged?

Humans are special in the mind of an infant—from an evolutionary standpoint, being able to identify an individual of your species is extremely pertinent for survival. Yet when reflecting on the process of identifying a human, it would appear to be a daunting task. Humans have specific facial features, certain body construction, and move in a particular fashion (Morton & Johnson, 1991; Surian & Caldi, 2010; Sanefuji et al. 2011; Rostad, Yott & Poulin-Dubois, 2012; Heron & Slaughter, 2012), yet also abide by certain principles that are shared with inanimate objects (Bonatti, Emmanuel, Zangl, Mehler, 2002;Surian & Caldi, 2010). These specific features that allow someone to identify a human being are called conspecifics (Morton & Johnson, 1991). With this in mind, it would appear that understanding humanness is an overwhelming challenge, but current research on this topic suggests that infants may be more efficient at encoding and remember humans than other objects.

Research demonstrates that even newborn infants have the ability to recognize face-like stimuli (Morton & Johnson, 1991; Sanefuji, et al., 2011). Morton and Johnson (1991) looked at newborn, one month old, and two month old infants' abilities to recognize facial stimuli and demonstrated that infants successfully prefer to look at simplified stimuli resembling faces. In the study, researchers had infants sit on a researcher's lap and moved face-like stimuli (i.e., two dimensional oval shapes with simple shapes resembling eyes, nose, and a mouth) around the infant. Some of the facial features were arranged like a human face (two eyes next to each other, a nose below, and a mouth below the nose) or with the features scrambled. The researchers tracked how long the infants followed the object with their eyes. The results of the study demonstrated that infants significantly tracked human-like face configurations for more time on average than other types of stimuli. The results of this study show that young infants are born with the innate ability to track faces and thus illustrate the nascent abilities of conspecific recognition in infancy.

To bridge working memory research and infant perception of human conspecifics, two main studies, that are guiding the main hypothesis of this paper, have been completed. The first of these two studies, completed by Bonatti et al. (2002), generated a hypothesis termed the "Human First Hypothesis". The "Human First Hypothesis" states that infants understand humans as privileged stimuli and are therefore more efficient at encoding human-like stimuli. In the study, researchers replicated that young infants could not efficiently encode simple shape stimuli in a particular type of discrimination task, but could succeed on the discrimination task when the stimuli were a doll head and toy dog head. When further testing the abilities of young infants to encode two different human doll heads and hold them in working memory, infants failed. It was hypothesized that infants succeeded with the dog versus human task, but not the human versus human task due to a less specified system for discriminating humans. The researchers speculated that while infants failed the human versus human task, they had a general category of "human" available to them, which allowed them to succeed on the human versus dog task (p. 419). Thus, this study illustrates the "Human First Hypothesis" as the way humans are privileged stimuli in infant working memory in comparison to other objects. Again, the research demonstrates that infants can process human-like stimuli more efficiently than other types of stimuli and can succeed in tasks that they would typically fail due to the type of stimuli presented. These results suggest that infants not only have highly developed identification of physical human features and social behavior, but that infants can also use these human qualities to more efficiently remember objects.

The second study guiding the current paper was completed by Stahl and Feigenson (2014), in which researchers illustrated how 16-month-old infants recognize human social cues and use them to remember a supra-capacity amount of individuals. In the study, infants observed social interactions and spatial grouping of dolls to remember four dolls in manual search paradigm trials. Infants were shown four identical dolls interacting in social pairs of two or as four individual dolls interacting with the infant. The four dolls were then hidden in a box, researchers removed two of the four dolls and then infants were allowed to search for the remaining dolls. The results of the experiment revealed that infants searched significantly longer for the remaining dolls when they were presented in social pairs than when they were presented as four individuals. The results of this study illustrated that infants recognized social features of human behavior and could use them in order to overcome their limited memory capacities. However, it is important to note that the dolls here were featurally identical.

These studies exhibit the complex understanding that young infants have when discriminating human stimuli and indicate that humans may be privileged in the minds of infants. Findings from the previously discussed studies raise the question as to whether human-like stimuli may be processed more efficiently in working memory, and propose the possibility that infants may be able to overcome deficits in working memory when confronted with an array of human-like stimuli.

The present study aims to further infant working memory research by exploring the limits of infant working memory when encoding humans. Namely, this study seeks to uncover what occurs in working memory when infants are confronted with four non-identical human-like objects. The previous research has demonstrated that infants have a working memory capacity of up to three individual identical objects, but that they experience catastrophic forgetting when arrays exceed this limit. The hypothesis for this current study is that infants will not experience catastrophic forgetting when confronted with a supra-capacity array of dolls, but that infants will experience catastrophic forgetting when confronted with a supra-capacity array of non-human control objects (i.e., cat figurines as replication of Feigenson & Halberda, 2008).

Chapter 2 **Methods**

Participants

The study included 16 participants (five males, 11 females). Age of participants ranged from 11 months, 9 days to 32 months, 27 days. Average age was 17 months, 22 days. An additional 17 children participated but were not included in the final sample. Eight children were included as part of a pilot study, two were excluded for fussing, and one for technical issues. The infants were recruited from the Delaware Children's Museum, outreach events, and the Middletown Free Library. Infants who participated were given a certificate and a sticker for their time. This research and recruitment sites were approved by the Institutional Review Board of Penn State University (PRAMS00032918).

Apparatus

In order to test infants' memory abilities, the manual search paradigm was used (Feigenson & Carey, 2004). The apparatus used in this experiment was a black box constructed of black foam-core with the dimensions of 31.5 x 25 x 12.5 cm. The inside of the box was lined with felt and the hole at the front of the apparatus was covered with brightly colored spandex measuring 14 x 7.5 cm. The brightly colored spandex allowed for easier discrimination of reaching during offline coding and kept the infant from being able to see inside the box (Zosh & Feigenson, 2015). The other end of the box was open with a felt flap covering the back so the researcher could discretely hold stimuli from an infant's reach during searching measurements.

Materials

During testing trials, the stimuli presented to infants were dolls (human-like stimuli) and cat figurines (the control). The dolls were Pinypon figurines and measured 3.5 inches by 1.5 inches. The dolls were dressed in brightly colored outfits and had differently colored hair. The cat toys were realistic figurines that measured 3.5 inches by 2.5 inches. The cat figurines had different positions and all had different fur colorations. During familiarization trials, toy keys were used to attract infants' attention and familiarize them with the manual search paradigm. See Figure 1.

Figure 1. Doll and cat stimuli used in experiment.

Procedure

Infants sat in a small highchair or on a parent's lap during the experiment. Parents of children were given instruction that they could verbally praise their children when the researcher also praised their child, but were instructed that they should not encourage or discourage their children to search during measurement periods. No feedback was given during any measurement period.

Familiarization trials. Infants were positioned in front of the box so that they could easily reach inside the box but were unable to see its contents. The researcher then shook a set of toy keys and verbally called their attention to the keys. Once the researcher knew the infants were looking, she pushed the toy keys into the front of the box and encouraged the infant to retrieve the keys. Once the infants retrieved the keys twice, the researcher began the test trials.

Test trials. Once infants were familiarized with the process of reaching in the box, researchers began the test trials. There were 16 possible conditions in which an infant could participate, and these conditions were chosen randomly before the infant was tested. Each infant experienced two blocks of trials. One block of trials contained an array that was within capacity (1 and 2 objects) and the other block of trials contained an array that exceeded capacity (2 and 4 objects). Half of the infants were exposed to the within-capacity array with dolls and the supra-capacity array with cats. The other half of the infants were exposed to the opposite conditions. There were eight total trials (four per block) and 12 measurement periods total. Trials in which items remained inside the box had two measurement periods because researchers would measure how long infants search when items remained in the box, and then again after those items were removed. Searching time was measured during each measurement period. An infant was considered to be searching when the second knuckle of his or her hand was inside the box.

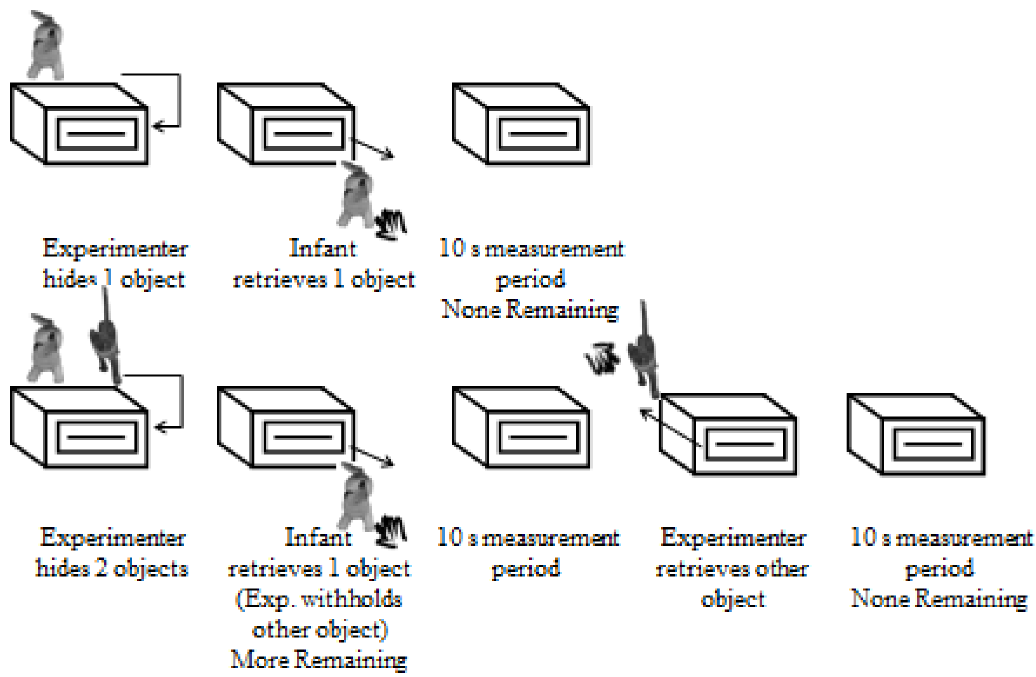

Figure 2. 1 vs. 2 manual search trials.

1 vs. 2 Block. All infants were give four trials in a one vs. two block in which they were shown either one or two cats, or one and two dolls (See Figure 2). In the One object, None Remaining Trial, the researcher placed the object on top of the box, pointed at it with her finger and said "Look at that! See that?" and then placed the object inside the box. The infant was then allowed to retrieve the object. Once the object was removed from the infant's hand, a 10 second measurement period began and the researcher put her head down so that she would not influence the infant to search. Once the search period ended, the researcher picked up the box and shook it to show the infant that there was nothing left inside the box. In the Two object, More Remaining Trial in a one vs. two block, the researcher placed two objects on top of the box and gave the same gestural and verbal cues to each item. She pointed to each object in turn as said "Look at that! See that?" Then the researcher placed both objects simultaneously inside the box. The researcher held one of the objects at the back of the box so that the infant could not reach it.

Once the infant removed the first object from the box and the researcher took it from his or her hand, the 10 second measurement period began. After the 10 second measurement period ended, the researcher pulled the second item that they were withholding out of the box, showed it to the infant and said “Were you looking for this?”. The research then moved the item out of view of the infant and a 10 second measurement period began (2 Objects, None Remaining). Once the 10 second measurement period ended, the researcher picked up the box and shook it to demonstrate that there was nothing left in the box.

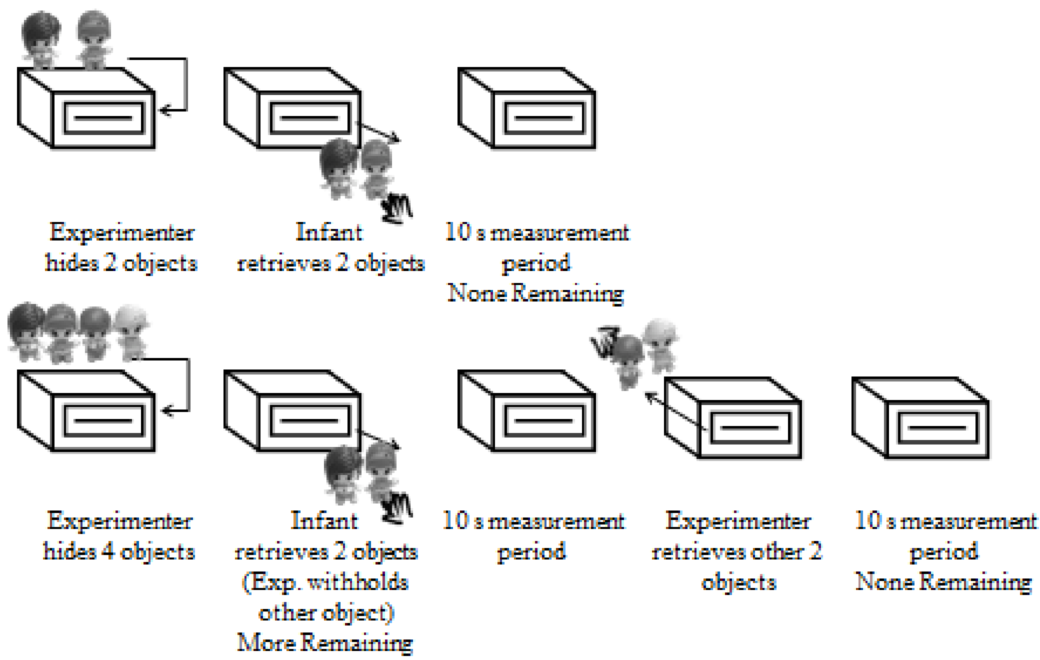

Figure 3. 2 vs. 4 manual search trials.

2 vs. 4 Blocks. All infants were give four trials in a 2 vs. 4 block in which they were shown either 2 or 4 cats, or 2 and 4 dolls. See Figure 3. <u>In the 2 Objects, None Remaining Trial</u>, the researcher placed the object on top of the box, pointed at each item with her finger and said “Look at that! See that” and then placed the objects inside the box. The infant was then allowed to retrieve both of the objects. Once the object was removed from the infant’s hand, a 10 second measurement period began and the researcher put her head down so that she would not influence the infant to search. Once the search period ended, the researcher picked up the box and shook it to show the infant that there was nothing left inside the box. In the 4 Objects, More Remaining Trial in a 2 vs. 4 block, the researcher placed 4 objects on top of the box and gave the same gestural and verbal cues to each item. The research pointed to each object individually and said "Look at that! See that. Then the researcher placed both objects simultaneously inside the box. The researcher held two of the objects at the back of the box so that the infant could not reach it. Once the infant removed two of the objects from the box and the researcher took them from the infant's hand, the 10 second measurement period began. After the 10 second measurement period ended the researcher pulled the remaining two item that out of the box, showed it to the infant, and said "Were you looking for this?" The research then moved the items out of the infant's view and an additional 10 second measurement period began (4 objects, None Remaining). Once the 10 second measurement period ended, the researcher picked up the box and shook it to demonstrate that there was nothing left in the box.

Coding

The search times for all 12 measurement periods were recorded. The videos were then uploaded and coded offline using the PrefLook program (Libertus, 2011). Both a primary and secondary coder coded the videos. Infants were considered to be reaching when the second knuckle of any finger was within the spandex opening of the box. Any reaches that lasted past the 10 second measurement period were permitted to continue until the child removed his or her hand from the box.

Chapter 3 **Results**

Each infant was presented with a 1 vs 2 block (within capacity) and a 2 vs 4 block (supra-capacity). Because infants were presented with dolls on only one of these blocks, we examined searching for each block separately. For each Block (1 vs. 2 or 2 vs. 4) we conducted a repeated measures ANOVA that included the within-subject variables of Trial Type (first None Remaining period, More Remaining period, second None Remaining period) and Pair (first vs. second instance of a measurement period), and the between-subject variable of Stimuli Type (whether infants were presented with dolls or cats) and Age (under 18 months or over 18 months).

For the 1 vs. 2 Block, there was a marginal effect of Trial Type, $F(2,22) = 2.37$, $p = 0.11$ with infants searching longer on More Remaining measurement period (M = 2.49 sec) than on either the first Expected Empty Trial (M = 1.61 sec) or the second Expected Empty Trial (M=.0.92 sec) two measurement periods (see further analyses below). Because the number of objects hidden in this Block were within capacity, we did not expect to find, nor did we find, a significant impact of Stimuli Type, $F(1,11) = 0.02$, $p = 0.90$. However, we did find significant interactions between Pair and Stimuli Type, $F(1,11) = 8.03$ $p < 0.05$, reflecting that infants reached more on the first pair of trials when dolls were hidden and more on the second pair of trials when cats were hidden. There was also a significant interaction of Pair and Trial Type $F(2,22) = 4.21$, $p < 0.05$, reflecting that children reached more on the first presentation of the More Remaining trial than on any other trial. Finally, there was an interaction between Pair x

Trial Type X Age Group, $F(2,22) = 3.90$, $p = 0.05$, reflecting that those children in the older age group exhibited pronounced reaching (M = 5.58 sec) on the first More Remaining trial than on the second (M= 1.65 sec). Critically, there was not a significant interaction between Trial Type and Stimuli Type reflecting that infants performed similarly regardless of the type of object used, $F(2,22) = 1.25$, $p = 0.31$.

For the 2 vs. 4 Block, there was a main effect of Trial Type, $F(2,22) = 4.02$, $p < 0.05$ with infants searching longer on More Remaining measurement period (M = 4.34 sec) than on the either the first Expected Empty Trial (M = 1.82 sec) or the second Expected Empty Trial (M= 1.75 sec) two measurement periods (see further analyses below). Critically, there was a marginally significant interaction between Trial Type x Age Group X Stimuli Type, $F(2,22)$ 2.99, $p = 0.079$ reflecting the trend that children in the older age group reached longer on the More Remaining trial for the dolls compared to any other trial. There was also a significant interaction of Pair x Trial Type, $F(2,22) = 4.29$, $p < 0.05$, reflecting that children reached more on the first presentation of the More Remaining trial than on any other trial. There was also a significant interaction between Pair x Trial Type x Age, , $F(2,22) = 4.96$, $p < 0.05$, reflecting that older children reached most on the second presentation of the More Remaining trial while younger children exhibited the most reaching on the first presentation of the More Remaining trial. There was also a significant interaction between Pair x Trial Type x Stimuli Type $F(2,22) = 5.05$, $p < 0.05$, reflecting that the first presentation of the More Remaining trial with the dolls was the largest while the pattern was stronger on the second presentation of the More Remaining trials with the cats. Finally, there was a significant 4-way, uninterruptable interaction between Pair, Age Group, Trial Type, and Stimuli Type , $F(2,22) = 9.68$, $p < 0.01$.

To further examine reaching patterns, graphs were created to reflect reaching across conditions (dolls vs. cats) for each measurement period (See Figure 4). These graphs show that on average, children reached most on the More Remaining trials.

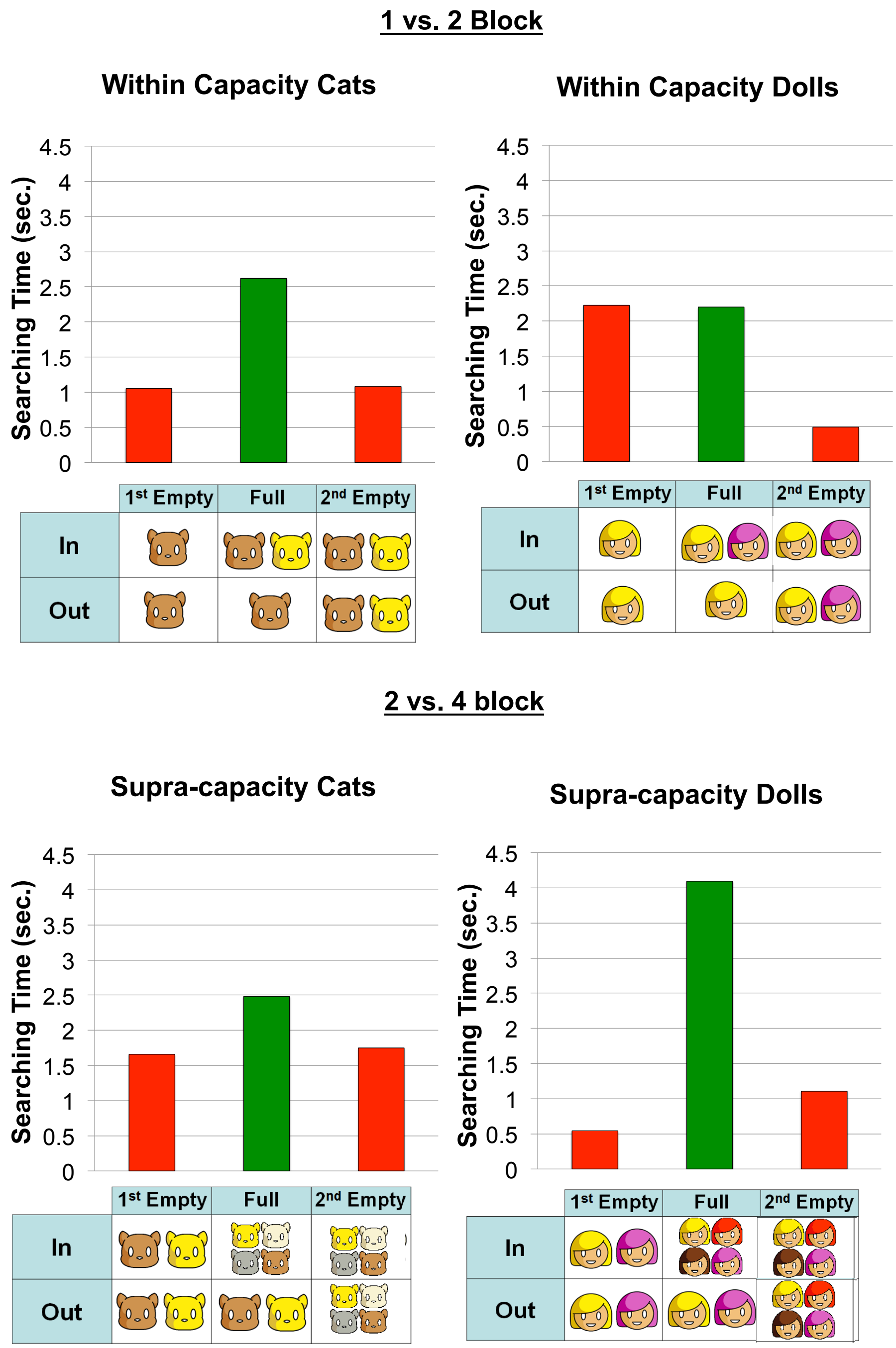

Figure 4. Graphs depicting reaching times for array of dolls and cats.

Chapter 4 **Discussion**

Infant memory capacity is surprisingly similar to adult working memory. Adult working memory can store up to four items (Luck & Vogel, 1997), while infant memory can store up to three items (Feigenson & Carey, 2004; Zosh & Feigenson, 2015). One of the biggest differences between working memory in these two populations is what happens when capacity is exceeded. Until recently, it was thought that infants experienced catastrophic forgetting when presented with supra-capacity arrays (Feigenson & Carey, 2004) but that adults would store up to their memory limit (Luck & Vogel, 1997). However, Zosh and Feigenson (2015) found that when presented with arrays of very different, non-identical items (e.g., a cat, ball, spoon, and shoe), infants stored up to their memory limits. One previously unexplored question is whether certain types of information, in this case, humans, was privileged in working memory such that infants might be able to store up to their memory capacity.

The study presented here investigated whether the specific type of object an infant stored in working memory impacts performance when presented with supra-capacity arrays. Specifically, I hypothesized that infants would show privileged abilities when storing information about human-like stimuli over non-human stimuli (cats). As expected, when presented with arrays within capacity (in the 1 vs. 2 block), the type of stimuli hidden did not impact searching behavior. However, in the 2 vs. 4 block, Stimuli Type interacted with Trial Type and Age suggesting that the type of objects infants are storing impacts their ability to remember. It appears that when older infants are presented with 4 human-like stimuli, they are able to store up to their memory limits. This suggests that the hypothesis that infants may privilege humans over other types of objects is correct, but perhaps not until 18 months of age.

Previous evidence found that infants experience catastrophic forgetting when remembering 4 non-identical cats (Feigenson & Halberda, 2008). The interactions found significant here suggest that there IS a difference between storing cats and human-like stimuli but the apparent trend towards success in all cases (See Figure 3) – even with 4 cats – is somewhat surprising. There are a number of differences between the study presented here and the other study. One reason that infants may have succeeded with both stimuli types could have been due to the fact that infants, especially older infants, actually have privileged processing for animate kinds. Supporting evidence for this idea is found with even younger infants. Surian and Caldi (2010) found that when ten-month-old infants were shown an animate object that appeared to move on its own freewill and an inanimate object that seemed to be moved by a force, infants had the ability to make a distinction between animate and inanimate movement. These findings demonstrate the complex understanding young infants have when categorizing objects and agents by the type of movement they exhibit and not just considering whether it has human features.

While Surian and Caldi (2010) provided infants with objects that had animate and inanimate movements, Rostad, Yott and Poulin-Dubois (2012) created a study with the aim of observing if 14-month-old infants could separate objects into animate and inanimate categories based on these distinctions of conceptual or taxonomic features. This study had infants categorize multiple animate objects (e.g. human, dog) and inanimate objects (boat, bed), and found that 14-month-olds could successfully distinguish between the two groups, even though perceptually the objects in the same categories shared few physical features with each other. In the other experiments of the study, they rearranged the features of the objects across the animate and inanimate categories (e.g. horse with wheels instead of legs, boat with horse legs), and had infants match the objects to their respective categories (i.e. mixed feature objects paired with normal animate object). The results of this study demonstrated that infants have a complex understanding of animate and inanimate objects, which is not ruled by the individual features of an object, but a deeper conceptual understanding of the two categories. The two studies looking at infant understanding of animate and inanimate classification demonstrate that infants develop a system for sorting animate individuals. The complex understanding infants have for animate and inanimate objects demonstrate a possible reason why infants may have trended towards success with both dolls and cats. If infants develop systems to efficiently identify animate and inanimate objects in early life, then it may not be until slightly later in infancy that they become more focused on human-like stimuli. Thus, it is possible that younger infants are good at representing agents as individuals regardless of whether they are human-like. However, while infants have developed an extensive understanding of face-like stimuli and a distinction between animate and inanimate objects by feature and movement, it is important to note that there are still significant deficits in the interpretation of humans and animate objects. Kuhlmeier, Bloom, and Wynn (2004) demonstrated that 5-month-olds do not initially attribute humans to having object qualities. This study demonstrated this by showing infants a violation of expectation task involving objects, and it was demonstrated that infants expected the objects to have continuity. When humans were put in place of the objects in the same task, it was revealed that the 5-month-olds did not expect humans to have the same continuity properties as the objects. This finding is interesting because it demonstrates a gap in infants' understandings of humans—it illustrates that while humans are clearly important to an infant, they do not realize at 5-months-old that they share physical properties with other objects.

Thus far, I have reviewed evidence about how infants represent individual items in working memory and reviewed similarities and differences between infant and adult memory. Another commonality in working memory shown across the lifespan is an impressive ability to operate flexibly within the confines of this limit – namely, both infants (Halberda & Feigenson, 2008; Moher, Tuerk, & Feigenson, 2012) and adults (Halberda & Feigenson, 2008) utilize 'chunking,' or grouping similar items together into a 'unit' – effectively allowing them to store more information in working memory (Reisberg, 2013). Importantly, capacity limits in working memory are identical for individual objects and chunks (Zosh & Feigenson, 2015; Halberda & Feigenson, 2008). Chunks are meaningful units through which object arrays are segmented in order to provide better retention in working memory (Reisberg, 2013; Feigenson & Halberda 2008). Feigenson and Halberda (2008) presented infants with two sets of conceptually similar objects (e.g. two cars and two cats). The researchers found that when they hid all four objects and allowed infants to retrieve two of the objects (one from each conceptually similar category) infants would continue to search for the remaining two objects. This result was even observed when infants were presented with non-identical group members (e.g. two different looking cats and two different looking cars). Thus, infants can overcome their memory limit of four objects if presented with conceptually grouped objects. In another condition within one of the experiments, it was demonstrated that when infants were presented with four non-identical objects from the same category, they failed. These results demonstrate that infants have the ability to create conceptual chunks in order to encode a number that exceeds their working memory limits.

Taken together, the results presented here in conjunction with the existing research on working memory in infancy demonstrate how working memory is not just a 'dumb' system that takes in information and spits it back out. Instead, it is an active system whose capacity is somewhat flexible based on what is being stored and infants' and adults' abilities to flexibly manipulate what is being stored.

Limitations and Future Directions

There are multiple factors that should be noted in consideration of the results presented here. One factor that could have had an impact on the results is the age of the participants. Most of the other studies using this paradigm involve children at the youngest portion of the age range used here. For instance, most studies use 12 (Feigenson & Carey, 2004) 14, (Halberda & Feigenson, 2008), or 18 month olds (Zosh, & Feigenson, 2012). Given the interaction with age shown here, it would be interesting to further examine how performance on these types of tasks changes over age. One might expect that older infants would be more likely to chunk items conceptually without perceptual clues but that younger infants might require multiple cues to chunk objects. In fact, in a related study looking at chunking with very young infants, it was found that multiple cues to chunking were necessary to allow infants to chunk objects (Moher, Tuerk, & Feigenson, 2012). In the study, researchers hid three objects with contrasting features (two objects with the same features and one with different features or all three objects with the same features), separate spatial locations (two screens separating the objects or one screen hiding all three objects), or both different features and separate spatial locations. When the three objects were hidden behind screens and then the occluders were removed, infants either saw three objects (the expected outcome) or two objects (the unexpected outcome) revealed. Infants only successfully remembered all three objects when the objects had both separate spatial locations and features. This study demonstrated that infants need more cues in order to chunk objects and thus encode them into working memory (Moher, Tuerk, & Feigenson, 2012). Given the fact that older infants responded to the greatest extent with the human stimuli, it would be interesting to run more children within smaller age groups (e.g., 18-20 months, 20-22 months, 22-24 months, 24-26 months, etc.) to examine the developmental trajectory of this effect.

It is also important to note that before drawing strong conclusions, there was a large degree of variability of the searching times between the subjects, with some subjects reaching for .2 seconds and others for 10 seconds. Due to this variability, a greater number of participants would be necessary for more conclusive results.

If the effect holds, namely, that older children appear to privilege information about humans over that of other animate or inanimate objects, I would be very interested in conducting this study with a typically developing population and a population of infants that are at high risk for developing autism. Akechi, Kikuchi, Tojo, Osanai and Hasegawa (2014) found that individuals in the autism spectrum have reduced neural response in the brain areas associated with facial and social perception in a face perception task when presented with objects that have face-like stimuli. Using EEG, the researchers found that while typical populations and autism spectrum populations both have similar neural responses to face stimuli, the ASD populations had less of a neural response when discriminating faces within objects relative to typical populations. Thus, we may see that typically developing have abilities to remember supra-capacity arrays of dolls and/or cats, but individuals with autism may not be able to do that. If so, this might represent a possible screening tool that could be used in conjunction with other methods.

In sum, the research presented here extends the current body of working memory research. The study found that older infants succeeded with supra-capacity arrays of human-like stimuli. This suggests not only that infant working memory capacity is impacted by what is encoded, but also that humans become privilege stimuli in working memory as infants develop.

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ACADEMIC VITA

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Education

The Pennsylvania State University Spring 2015
Bachelor of Arts Degree in Psychology

Research Experience

Research Assistant and Schreyer Honors Scholar Spring 2014- Spring 2015
Pennsylvania State University, Brandywine Campus, Media, PA

- Currently authorized to complete a yearlong research thesis project titled "Working Memory Abilities in Infancy" under advisement of Dr. Jennifer M. Zosh
- Involved in IRB re-approval process
- Subject recruitment, running behavioral study with children ages 10-24 months of age
- Running manual search paradigm with infants
- Use PrefLook coding program to measure searching times
- Will complete data analysis using SPSS
- Will complete thesis and graduate with Honors in Spring 2015
- Created written instructions for multiple ongoing studies
- Met weekly to discuss current scholarly articles with lab team

Teaching Assistant- Introduction to Developmental Psychology Fall 2014
Pennsylvania State University, Brandywine Campus, Media, PA

- Tutored students and reviewed material
- Graded assignments, managed course grade book using learning management system
- Guest lecture on: Moral Development in Early Childhood

Research Assistant Summer 2014
Infant Language Project, Newark, DE

- Recruited participants at on-campus and off-campus locations
- Aided Ph.D. student in running bilingual and cognitive flexibility experiments
- Entered coded data for multiple studies
- Reordered verbal instructions for language study stimuli
- Met weekly to discuss current scholarly articles with lab team
- Edited scholarly articles and book references

Awards and Honors

- Undergraduate Research Award — Spring 2015
- Evan Pugh Scholar Award — Spring 2015
- Undergraduate Research Grant ($500) — Spring 2015
- Phi Kappa Phi Member — Spring 2015
- Schreyer Honor Scholar — Fall 2013-Current
- Edna R. Schwab Memorial Scholarship Fund — Fall 2013
- President's Freshman Award — Spring 2013
- Academic Achievement Award — Spring 2013
- Dean's List — Spring 2012-Current
- Jane E. Cooper Honor Student — Fall 2012-Spring 2013

Employment Experience

Sales Lead — Fall 2014- Spring 2015
LOFT at the Brinton Lakes, Glen Mills, PA

- Maintaining a positive attitude and providing excellent customer service
- Supervising and assigning tasks to associates
- Effectively communicating management goals to associates
- Keeping hourly records of sale metrics
- Closing registers and handling money

Family Room Volunteer — Summer 2013-Spring 2014
Ronald McDonald House of Delaware, Wilmington, Delaware

- Checked guests into and out of the house
- Accommodated and met the needs of families that stay at the facility
- Utilized effective communication skills
- Cleaned and organized the facility

Teaching Assistant — Fall 2009-Spring 2011
Kesher Israel Religious School, West Chester, PA

- Assisted teacher with lessons for a class of 20 first grade students
- Created and taught lessons
- Organized creative classroom activities
- Cleaned and organized classroom

Camp Counselor — Summer 2010
Concord Township Camp, Glen Mills, PA

- Organized fun and creative camp activities
- Was responsible for taking care of multiple children
- Managed conflicts that arose during camping activities
- Cleaned and organized camp facilities

Activities

- Will present a poser at Sigma Xi Research Symposium   Spring 2015
- Will present a poster at EURECA   Spring 2015
- Presented a poster at the 2015 Undergraduate Exhibition   Spring 2015
- Attended EPA Annual Conference   Spring 2015
- Attended SRCD Biennial Conference   Spring 2015
- Helped host table at Brain Awareness Week   Spring 2014
- Created proposal for Honors Organic Garden on campus   Summer 2013-Fall 2013

Certifications

- CITI Research with Children - SBR Course   Spring 2014
- 2014 Building a Safe Penn State: Reporting Child Abuse Course   Spring 2014
- Red Cross Adult/Child AED, CPR & First Aid Certification   Spring 2013
- CITI Social and Behavioral Human Subjects Research (IRB) Course   Fall 2012