CHANGES IN VISUAL SHORT TERM MEMORY DURING INFANCY

by

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(Under the Direction of Janet Frick)

ABSTRACT

Infants' capacity for visual short term memory improves with age. However, results indicating the kinds of changes that occur during infancy, and how memory may be different for qualitatively different stimuli, are incomplete. Twenty 5-month old and twenty-one 8-month old infants were recruited to investigate differences in memory capacity between two age points, as well as two different types of stimuli and two different set sizes. The results suggest that type of stimulus matters in determining VSTM capacity; specifically, infants have greater difficulty holding faces in short term memory than colored shapes. The implications of the findings are discussed.

INDEX WORDS: Short term memory, Infants, Development, Masters thesis, University of Georgia

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CHAPTER 1

INTRODUCTION

Visual short term memory (VSTM) is memory for visual stimuli over short durations. Work in this area has found that VSTM and the closely-related visual working memory are tied to higher order cognitive functions. While most work has been done with adults, VSTM is also of interest in the developmental literature for its ties to academic success. Although we have some understanding of how memory for visual information can vary in adulthood by the categories of objects used, less of this type of work has been done in children and infants. The purpose of the current study is to understand how VSTM capacity in infancy may be different depending on the ecological salience of visual stimulus.

What Visual Short Term Memory is (and isn't)

Visual short term memory (VSTM) is memory for visual stimuli over short durations. In the absence of rehearsal, this memory tends to decay over the course of 30 seconds (Phillips & Baddeley, 1971; Cermak, 1971; Posner & Konick, 1966). Most adult studies of VSTM find a capacity limit of up to four to five items (e.g., Luck & Vogel, 1997), though the limit can vary depending on the complexity and type of the stimuli (Alvarez & Cavanagh, 2004; Curby & Gauthier, 2007).

A related but conceptually distinct concept, visual working memory (VWM), is one's capacity to manipulate visual information stored in short-term memory, including recall information in the face of distraction. The difference between short-term memory and working memory can be muddled in the literature. This distinction can is especially unhelpful with very young participants, as the types of methodologies used sometimes cannot tap executive functions relevant to working memory. Although the current study is primarily interested in VSTM, some of the articles referenced here may, by name or by procedure, have studied visual working memory instead. Correlational research has not shown consistent differences between VSTM and VWM (see Aben et al., 2012 for review).

Visual short-term memory can also be dissociated from verbal short-term memory. In a study of patients suffering brain damage, Renzi and Nichelli (1975) found that some patients performed as expected on a visual short-term memory task but worse on a verbal short-term memory task, and vice versa. Additionally, loading verbal working memory does not interfere with a visual working memory task (Vogel et al., 2001). It is possible that visual short-term memory is still connected to verbal skills, however. In a study of 3-5 year old children with Specific Language Impairment, a control group performed better on a visual short-term memory task (Menezes et al., 2007); on the other hand, another study did not find a connection between language skills and visual short-term memory in school-age children (Bull et al., 2008).

Existing work on VSTM

The majority of work with VSTM and VWM has been done in adults, usually examining short-term and working memory capacity. One reason for this is the ties found between working memory capacity and various higher order cognitive functions. For example, Fukuda et al. (2010) gave participants a change detection task, where they were briefly presented with arrays of visual stimuli and then asked to report whether another presented visual stimulus matched one of the objects in the previous array. The number of items a participant was able to hold in working memory had a strong correlation with fluid intelligence, $r = 0.66$. Miyake et al. (2001) administered a variety of VSTM and VWM tasks and found high correlations to performance on executive function tasks. Individuals who had higher capacity estimates on letter rotation, dot matrix, dot rotation, and Corsi blocks tests successfully completed Tower of Hanoi problems more quickly and were better at generating random strings of digits, suggesting that VSTM capacity is tied to our ability to plan sequences of actions. Deficits in VSTM and VWM capacity are well known in some disorders, such as schizophrenia (Lee & Park, 2005). Johnson et al. (2013) tested VWM capacity in patients suffering schizophrenia, and not only found that VWM capacity correlates strongly with general intelligence across both patients and healthy controls, it also accounted for a sizable amount of the between group variance on the intelligence measures used. In short, VSTM and VWM capacity have strong ties to our ability to plan and reason about the world.

Developmental Studies on VSTM: Children

VSTM capacity increases with age, though capacity estimates vary from study to study, possibly due to differences in how researchers chose to calculate capacity. Using a visual change detection paradigm, Simmering (2012) found an increase in capacity across the tested age groups of 3-, 4-, 5-, and 7-year olds. Riggs et al. (2006) tested 5-, 7-, and 10-year old children and found increased capacity with age, with 10-year olds being close to the capacity found in young adults. Cowan et al. (2005) found greater capacity in fifth graders over third graders on a similar task, though the fifth graders did not reach the capacity of the adult participants. The capacity estimates of these studies can vary, but all show an increase in capacity at least up until middle-school ages.

Studies with school-aged children shows trends similar to the adult literature for higher-order cognition; VSTM capacity correlates with scholastic success, especially in math (Bull et al., 2008; Kyttala et al., 2003; Alloway & Passolunghi, 2011). Again, findings related to language skills are mixed. Cowan et al. (2005) found correlations between capacity in a VSTM task and Cognitive Abilities Test (CAT) scores, on both quantitative and verbal subscales, in third and fifth graders. Other studies (e.g., Bull et al., 2008) show math skills, but not reading skills, correlate with VSTM capacity.

Developmental Studies of VSTM: Infants

Most of the studies of infant memory have utilized habituation paradigms in order to study memory accuracy and memory decay over a time course of up to a few minutes (Bornstein & Sigman, 1987; McCall & Carriger, 1993). Habituation studies present a visual stimulus to an infant, and the duration of the infant's looks towards the stimulus are observed; habituation occurs when the infant's level of attention to the stimulus declines over repeated presentations. Various measures can be derived from habituation studies in order to indicate the efficiency of infant habituation; developmental studies generally indicate that infants who habituate more rapidly or efficiently show better evidence of memory for the stimulus they had been viewing (Colombo & Mitchell, 2009). Infants who habituate to a stimulus over less exposure time tend to perform better on later assessments of cognition, as do infants who have shorter looks during habituation, relative to their age group. Habituation studies have also provided a great deal of data indicating that infant memory is predictive of childhood IQ (Sigman et al., 1991; Rose & Feldman, 1997).

Cognitive neuroscience researchers have also examined the patterns of brain activity underlying memory development using a looking-only version of the classic A-not-B task, a task reasoned to involve VWM. In this task, the hiding location of an object is switched after multiple trials in the same location; younger infants tend to search the original location first, even though the object is moved in plain view of the infant. While in the classic version of the task the infant makes their choice by reaching towards the hiding location, in the looking-only version, infants indicate their choice by looking in the direction of one of the hiding locations. This task tends to be a little easier for infants than the original reaching version, especially before 9 months of age (Cuevas & Bell, 2010), likely owing to requiring less developed motor coordination and inhibition, though it taps many of the same brain areas. This line of research has mostly found that fronto-parietal network is activated during this task, consistent with the brain regions activated in children and adults during working memory tasks (see Reynolds & Romano, 2016 for a review). Further, infants make more correct responses (Cuevas & Bell, 2010) and can succeed with longer delays until response (Pelphrey et al., 2014) as they get older, up to at least 12 months of age, suggesting that the contents of VSTM decay more slowly with age. However, these lines of research haven’t been as adequate for understanding changes in VSTM capacity, usually only requiring the infant to remember single stimuli. Further, these traditional paradigms are quite different from the memory tasks used in older children and adults, making it harder to say if these studies are testing the same constructs as they are in older participants.

Some newer paradigms are better equipped for the study of VSTM capacity in infants. In particular, the continuous streams paradigm (Ross-Sheehy et al., 2003) has arisen as a viable test of VSTM capacity for infants (see Figure 1). Originally adapted from an adult visual paired comparison procedure (Luck & Vogel, 1997), the infant is shown a series of paired images. Within each trial, the image on one side remains the same at every presentation, while the other side changes with each presentation. An infant will prefer to look at a changing stream over an unchanging stream if the change can be detected; thus, if the infant spends more time looking towards the changing stream, it can be inferred that their memory capacity is sufficient to hold the information in memory. When the infant does not show preference for the changing stream, it suggests that their memory capacity has been exceeded. This paradigm allows researchers to rapidly test participants on a series of stimuli, and with appropriate timing parameters minimizes involvement from both long term and iconic memory. Additionally, this rapid presentation is particularly useful in infant research, where attrition across the course of even a brief experimental task can be high.

In sum, the continuous streams paradigm is one of the best options for studying VSTM capacity in infancy, as opposed to other methods which may rely more on long term memory, or remembering only a single stimulus at a time. Over the past decade, research using this paradigm has examined changes in VSTM capacity across the first year of life. Infants 4- and 6.5-months old can remember a single shape, while older infants can remember multiple shapes (Ross-Sheehy et al., 2003). Further research found that 6- to 6.5-month olds have difficulty remembering locations (Oakes et al., 2011) or color-location combinations (Oakes et al., 2006; Oakes et al., 2009) when multiple shapes were involved. By 7 to 8 months of age, however, infants are able to compare multiple shapes. Kwon et al. (2014) extended these findings from shapes to objects.

Taken together, these VSTM studies indicate that infants show evidence of being able to hold an object in VSTM within the first few months after birth, but some change occurs around 7 to 8 months of age and they are able to hold multiple objects in their memory. They can bind multiple features of an object together, such as color and location within a display, and there is preliminary evidence that the trajectory of these changes is similar for simple objects, such as squares, and complex objects, such as the made-up objects used by Kwon et al. (2014). Most continuous streams studies, such as those listed above, have focused on the capacity of VSTM and how it differs across ages and among individuals of the same age.

On the other hand, there has been a paucity of research on how more meaningful stimuli might affect VSTM capacity. In a study of 16-month olds, working memory capacity for sets of dolls increased when the dolls held a brief social interaction (Stahl & Feigenson, 2014). In visual preference studies, newborns not only begin to show a preference for face-like patterns shortly after birth (e.g., Valenza et al., 1996), but can recognize their mother's face enough to prefer it over a stranger's face within a few days of birth (Bushnell, 2001). In a study of 3- to 11-month olds, infants tested in a preferential looking task showed a preference for faces over toys starting at 5 months of age (Libertus & Needham, 2014). Given the importance of distinguishing people from objects in their environment, as well as distinguishing among different people, it is possible that infants will be better able to retain faces in their VSTM relative to less important objects. The present study investigates how such stimuli might differ from the previously researched stimuli in younger infants.

The Present Study

The purpose of this study was to investigate group level differences in VSTM performance under different conditions. Two groups of infants were recruited to investigate differences in VSTM performance with age: 5-month olds and 8-month olds. These ages were chosen due to the increase in VSTM capacity observed between these two age groups in previous studies. Additionally, two stimulus categories, pictures of colored shapes and pictures of faces, and two set sizes, one stimulus or two stimuli, were tested in every participant. The squares were chosen for the purposes of replication, as almost all of the previous continuous familiarization studies have used these as their stimuli. Faces were tested to see if having a more ecologically relevant stimulus would lead to differences in performance. It was hypothesized that VSTM performance will improve with age, and that VSTM performance will be superior for faces over meaningless shapes. It was also expected that the 8-month old infants will succeed at the memory task at both set sizes, but the 5-month old infants will fail at the larger set size regardless of stimuli used.

CHAPTER 2

METHODS

Participants

A total of 42 participants were recruited from Athens, Georgia and other nearby communities. Infants came into the lab when they were close to 5-months (N = 20; 13 female) or 8-months (N = 21; 11 female) old. One infant was not close to either age at the time of their testing, and thus was excluded from analyses. Two participants were born 3 or more weeks premature, and thus used a testing date based on their due date rather than birth date. The overall sample was predominantly white (N = 35), with some with a mixed race (N = 5) or black (N = 1); the rest (N = 1) did not report their race. No vision problems were reported for any of the participants.

Stimuli

All faces used were originally obtained from the Chicago Face Database (Ma et al., 2015), a collection of faces that may be used for research purposes. The faces chosen were Caucasian female faces with neutral expressions. The images were converted to grayscale and cropped to have the same silhouette, centered on the midpoint between the eyes. The silhouette was shaped such that external facial features, such as ears and hair, were removed, as has been done in some previous infant face comparison studies (Turati et al., 2005; Viola Macchi et al., 2004). The shape stimuli were colored squares created in Microsoft Paint. A total of eight stimuli of each category was used.

Procedure

Participants were brought into the UGA Infant Lab for testing. First, informed consent was obtained from parents. During the consent process, the light level in the room was reduced to allow the infant's eyes to adjust to the darker conditions they would experience in the testing room. Once consent was completed, usually in under 5 minutes, the participant moved to our testing room with their parent.

The testing room was an interior room where the only sources of illumination were a standing lamp placed behind the participant as well as the computer screen in front of the participant. The infant sat in the parent's lap, who in turn sat in a chair facing the computer screen. The chair was adjusted so that the infant's eyes were 70cm away from the computer screen. Atop the computer screen was a Logitech C920 webcam pointed at the infant. Video recordings from this webcam were coded offline. Mirrors placed behind the participant allowed the webcam to capture what was happening on screen.

In the memory task, two variables were tested within each age group. The first variable was set size. At Set Size 1, one image was presented on each side of the screen (two stimuli total). At Set Size 2, two images were presented on each side of the screen (four stimuli total). The second variable was stimulus type. In half of the trials, the stimuli were colored squares (non-social stimuli). In the other half of trials, stimuli were faces (social stimuli).

Participants completed two cognitive tasks, which are not reported here, before doing the memory task (memory task shown in Figure 1). The memory task consisted of eight 20-second trials, with two trials per condition. An orientation phase preceded each trial, wherein a red circle flashed in the center of the screen at 2 Hz while accompanied by a public domain recording of "Maple Leaf Rag". Once the participant was oriented towards the center of the screen, the experimenter began the test phase. Over the course of each 20-second trial, the stimuli were presented for 500ms and followed by a 300ms gap. This cycle of presentation-gap repeated until the end of the trial. On the changing side, one of the stimuli changed to a randomly-selected stimulus with each new cycle. The new stimulus never matched the stimuli used on either side during the previous cycle. On Set Size 2 trials, the stimulus that changed was also selected at random for each cycle. All trials consisted of stimuli of only one type: all faces or all shapes. The black framing remained on screen for the entire duration of the memory task. The squares used were 4.75 x 4.75cm, or 3.89° x 3.89°. The faces were 7.85 x 11.5cm, or 6.42° x 9.39°. The center-to-center eccentricity between the two displays (where the centers were center of objects in Set Size 1 conditions, and the midpoint between both objects on a side in the Set Size 2 conditions) was 33.3cm, or 26.76° visual angle laterally. The center-to-center eccentricity between two objects within the same display was 10.75cm, or 8.78°. These visual angles are similar to those used by Kwon et al. (2014), though faces were somewhat smaller than the objects they used. The squares were somewhat larger than those used by Ross-Sheehy et al. (2003).

CHAPTER 3

RESULTS

The final sample consisted of 19 5-month olds and 20 8-month olds. To compare VSTM performance, a change preference ratio was computed for each participant per experimental condition. This ratio was the looking time towards the changing side over the total looking time to either the changing or non-changing side. In order for a trial to be included into this calculation, two criteria needed to be met: first, the participant must have looked at both sides; if the participant did not look at one of the sides of the screen during the task, the trial was excluded. Second, the participant must have spent a minimum of 4 seconds (20% of the duration of the trial) looking at the stimuli. If neither trial in a given condition met these criteria, no ratio was calculated for that condition for that participant (Set Size 2, Faces: N = 2; Set Size 2, Shapes: N = 1). Higher values represent a preference for the changing side, while lower values represent a preference for the non-changing side. A ratio of 0.5 represents no preference for either the changing or non-changing side. Outlier data points, here defined as ratios that exceeded the upper or lower quartile by 1.5 times the interquartile range when looking at all participants (Tukey 1977), were excluded from analysis (Set size 1, Faces: N = 1; Set Size 1, Shapes: N = 1; Set Size 2, Faces: N = 4). After all of these procedures, the remaining participants with complete datasets (N = 13 5-month olds, N = 18 8-month olds) were used for ANOVA; means per condition are shown in Figure 2. However, single-sample t-tests that included all remaining data are reported in Table 1.

A two stimulus level (shape vs. face) by two set size level (one vs. two) by two age group (5-months vs. 8-months) ANOVA was performed. There were significant main effects for set size, $F(1,29) = 20.601$, $p < 0.001$, and stimulus type, $F(1,29) = 17.800$, $p < 0.001$, but not for age, $F(1,29) = 0.210$, $p = 0.651$. An inspection of the means used in this calculation shows that change preference was greater at Set Size 1 over Set Size 2, and change preference was greater for shapes compared to faces. There was a significant interaction between age and set size, $F(1,29) = 8.910$, $p = .006$, though post hoc comparisons using Tukey's HSD test revealed that it did not take the expected form. While 5-month olds did not differ between Set Size 1 and Set Size 2, $p = 0.056$, 8-month olds did differ by set size, $p < 0.001$, having a greater change preference at Set Size 1 (Set Size 1, 8-month olds: M = 0.61, SD = 0.13; Set Size 2, 8-month olds: M = 0.46, SD = 0.12). There was also a significant set size by stimulus type interaction, $F(1,29) = 10.107$, $p = 0.004$. Post hoc comparisons using Tukey's HSD test showed that the Set Size 1, Shapes condition (M = 0.68, SD = 0.12) differed significantly from all other conditions, all p's < 0.001. No other comparisons here were significant. Finally, there was a trend towards a three-way age by stimulus type by set size interaction, $F(1,29) = 3.227$, $p = 0.083$.

Examining all valid trials, change preferences were compared to a chance value of 0.50. There was a clear change preference in the Set Size 1, Shapes condition for both age groups, 5 month-olds: $t(17) = 5.06$, $p < 0.001$, 8-month olds: $t(19) = 8.456$, $p < 0.001$. No other ratio was significant here, though there was a trend towards a significant familiarity preference for 8-month olds in the Set Size 2, Shapes condition; M = 0.43, SD = 0.14, $t(19) = -2.072$, $p = 0.052$.

Because the present study presented trials in a fixed order for all participants, it is conceivable that order effects were present in the data. To test this, a series of paired-sample t-tests were run comparing performance on the first vs. second trial within each condition (e.g., first trial of Set Size 1, Shapes versus second trial of Set Size 1, Shapes). There were no significant differences between the two trials of any condition, all *p*'s > 0.16, thus indicating that order or fatigue effects were not influencing the results.

CHAPTER 4

DISCUSSION

In general, while we did replicate some findings from previous studies of infant VSTM, our new hypotheses were not supported. The older, 8-month old infants failed to show greater overall change preference than the 5-month old infants. While there was a main effect of stimulus type, it was for greater change preference for shapes over faces, the opposite of the hypothesized direction. An age by set size interaction was observed, but not in the expected way: there was not a significant effect for Set Size 2 at 8-months of age.

The one clear result from the data was a replication of the Set Size 1, Shapes condition from previous studies (e.g., Ross-Sheehy et al., 2003; Oakes et al., 2011). At both age groups, infants preferred to look at the changing side when comparing colored squares. Contrary to our expectations, there was no change preference in the Set Size 2, Shapes condition for 8-month olds. Infants around this age have been well demonstrated to show evidence of VSTM for set size 2 under conditions highly similar to the ones used in the present study (Oakes et al., 2006; Oakes et al., 2009). The biggest procedural difference between these prior studies and the present study was the inclusion of a second stimulus condition (faces) that did not differ by shape; it's possible that this procedural difference led to differences in response across the session, although we found no evidence of order or fatigue effects. It is worth noting that the standard deviation for the Set Size 2, Shapes condition was larger than the others (see Table 1), allowing more extreme values to be retained in the analysis; most of these values were close to the bottom end of the range of scores.

Assuming the results for the face conditions were not just due to task characteristics, the Set Size 1 data is some of the first evidence in this line of infant VSTM research for capacity differing by object type. Capacity is known to differ by object type in adults (Alvarez & Cavanagh, 2004), though there are reported advantages for faces when adults are tested (Curby & Gauthier, 2007). In infants, the Kwon et al. (2014) study of made-up objects extended previous results for squares rather than find differences. Taken together, the results suggest that VSTM in infants does not treat faces the same way that other complex objects are treated, and despite faces having a VSTM capacity advantage in adulthood, they may have a disadvantage in infancy.

Why did the infants have greater difficulty remembering faces? The faces may have had too many features to be remembered; for example, Oakes and colleagues have demonstrated that changing a square along a single dimension, such as color or location in space, can be challenging for younger infants to remember when increasing set size. To differentiate faces based on their internal features, as was tested in the present study, infants must consider multiple smaller details, such as the shape of eyes, the mouth, the nose, etc.; remembering any one feature may not have been enough to rapidly tell two faces apart. The study by Kwon et al. (2014) tested memory for objects that differed by more than one dimension: the entire appearance of the objects was quite different from one object to another, including in color. However, the objects also differed by silhouette. Given the reported preference for using external features of a face in identification of unfamiliar faces at older ages, infants may rely on external features for recognizing complex objects. All of this should be interpreted cautiously; although we failed to find significant change preference for faces at Set Size 1, infants can obviously store at least one face in their short-term memory, given that even younger infants than those reported here can recognize faces.

It is also possible that faces are difficult for younger infants to remember in enough detail to rapidly compare. Using a visual paired comparison paradigm, Simpson et al. (2014) familiarized infants to a face for 20 seconds before presenting it alongside the same face with manipulated internal or external features on a series of trials. The 4-6 month-old infants did not prefer to look at the novel face, though the 9-12 month-old infants did for both types of manipulation. Thus, younger infants may struggle to discriminate between two faces differing in internal features when derived from the same person; though the present study compared faces from different people, this could indicate that younger infants would have had difficulty relying on facial internal features for discrimination of faces in a rapid presentation format such as the continuous streams paradigm.

An alternative explanation for our face results could be the construction of the face stimuli. As stated earlier, the face stimuli were created by removing external features such as hair and eyes. Preschoolers (Sugimura, 2013), as well as adults (Ellis et al., 1979), tend to rely more on external features of a face (e.g., hairstyle) when discriminating between unfamiliar faces. That said, infants do react differently to face-like stimuli which differ only by internal features (Goren et al., 1975; Ichikawa et al., 2013; Turati et al., 2005). In these studies, however, infants did not need to remember a stimulus over a gap, and had more continuous time to process the stimuli they were presented. Because the stimuli in the present study minimized the influence of external features, by giving all faces the same shape and mostly removing hair, infants may not have had the necessary processing time to learn the different internal features (e.g., eyes, mouth, nose) of the faces presented. In their study of adult VSTM, Curby & Gauthier (2007) found that more encoding time allowed participants to retain more faces in their memory. Using faces unfamiliar to the participants was important for reducing the role of long term memory in the current study, though a follow-up study with faces that show hair would be a useful next step.

There were a few limitations to this study. One divergence of the present study from previous studies is that the memory trials were presented in a predetermined sequence for all participants. Although trials within each condition did not differ significantly, a follow-up with random ordering of trials could clarify order effects that might be present across conditions.

Notably, coders were neither blind to the conditions they were coding, nor to the research questions of the study. The contents of the viewing screen were always visible to coders observing the participants' looking behavior. This was done for practical considerations, to allow the coder to plainly see the exact time the program advanced between trials while using a single video feed. Alternative setups, or at the very least naïve coders, may be preferable for future studies. Given the lack of support found for our hypotheses, effects on the end data, if any, seem limited.

Although efforts were made to maintain a constant lateral distance between the participants and the computer screen, there was less control of the participant's head height. Because the 8-month old infants tended to be larger, age-related differences observed in the data could have been related to systematic differences in height (and thus, differences in viewing angle) rather than cognitive abilities.

This study set out to replicate previous findings for infant VSTM at 5- and 8-months of age, and explore VSTM capacity for pictures of faces. Our findings did agree with previous work at Set Size 1, though not Set Size 2. Our data also supported a deficit in VSTM capacity for faces; however more work will be needed to clarify if these findings can be generalized. Now that there is evidence for one category of objects having a different capacity from others in infancy, exploring other categories may help researchers understand how infant VSTM differs from VSTM later in life.

REFERENCES

Aben, B., Stapert, S., & Blokland, A. (2012). About the distinction between working memory and short-term memory. *Frontiers in psychology*, *3*.

Alloway, T. P., & Passolunghi, M. C. (2011). The relationship between working memory, IQ, and mathematical skills in children. *Learning and Individual Differences*, *21*(1), 133-137.

Bornstein, M. H., & Sigman, M. D. (1986). Continuity in mental development from infancy. *Child development*, 251-274.

Bull, R., Espy, K. A., & Wiebe, S. A. (2008). Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Developmental neuropsychology*, *33*(3), 205-228.

Bushnell, I. W. R. (2001). Mother's face recognition in newborn infants: Learning and memory. *Infant and Child Development*, *10*(1-2), 67-74.

Colombo, J., Mitchell, D. W., Coldren, J. T., & Freeseman, L. J. (1991). Individual differences in infant visual attention: are short lookers faster processors or feature processors?. *Child development*, *62*(6), 1247-1257.

Colombo, J., & Mitchell, D. W. (2009). Infant visual habituation. *Neurobiology of learning and memory*, *92*(2), 225-234.

Cuevas, K., & Bell, M. A. (2010). Developmental progression of looking and reaching performance on the A-not-B task. *Developmental Psychology*, *46*(5), 1363-1371.

Curby, K. M., & Gauthier, I. (2007). A visual short-term memory advantage for faces. *Psychonomic bulletin & review*, *14*(4), 620-628.

Ellis, H. D., Shepherd, J. W., & Davies, G. M. (1979). Identification of familiar and unfamiliar faces from internal and external features: Some implications for theories of face recognition. *Perception*, *8*(4), 431-439.

Fukuda, K., & Vogel, E. K. (2009). Human variation in overriding attentional capture. *The Journal of Neuroscience, 29*(27), 8726-8733.

Fukuda, K., Vogel, E., Mayr, U., & Awh, E. (2010). Quantity, not quality: The relationship between fluid intelligence and working memory capacity. *Psychonomic bulletin & review*, *17*(5), 673-679.

Goren, C. C., Sarty, M., & Wu, P. Y. (1975). Visual following and pattern discrimination of face-like stimuli by newborn infants. *Pediatrics*, *56*(4), 544-549.

Ichikawa, H., Tsuruhara, A., Kanazawa, S., & Yamaguchi, M. K. (2013). Two-to three-month-old infants prefer moving face patterns to moving top-heavy patterns. *Japanese Psychological Research*, *55*(3), 254-263.

Jackson, M. C., & Raymond, J. E. (2008). Familiarity enhances visual working memory for faces. *Journal of Experimental Psychology: Human Perception and Performance*, *34*(3), 556.

Johnson, M. K., McMahon, R. P., Robinson, B. M., Harvey, A. N., Hahn, B., Leonard, C. J., Luck, S. J., & Gold, J. M. (2013). The relationship between working memory capacity and broad measures of cognitive ability in healthy adults and people with schizophrenia. *Neuropsychology*, *27*(2), 220.

Kwon, M. K., Luck, S. J., & Oakes, L. M. (2014). Visual short-term memory for complex objects in 6-and 8-month-old infants. *Child development*, *85*(2), 564-577.

Kyttälä, M., Aunio, P., Lehto, J. E., Van Luit, J., & Hautamäki, J. (2003). Visuospatial working memory and early numeracy. *Educational and Child Psychology*, *20*(3), 65-76.

Lee, J., & Park, S. (2005). Working memory impairments in schizophrenia: a meta-analysis. *Journal of abnormal psychology*, *114*(4), 599.

Libertus, K., & Needham, A. (2014). Face preference in infancy and its relation to motor activity. *International Journal of Behavioral Development*, *38*(6), 529-538.

Luck, S. J., & Vogel, E. K. (1997). The capacity of visual working memory for features and conjunctions. *Nature*, *390*(6657), 279-281.

Ma, D. S., Correll, J., & Wittenbrink, B. (2015). The Chicago face database: A free stimulus set of faces and norming data. *Behavior research methods*, *47*(4), 1122-1135.

McCall, R. B., & Carriger, M. S. (1993). A meta-analysis of infant habituation and recognition memory performance as predictors of later IQ. *Child development*, *64*(1), 57-79.

Menezes, C. G. D. L., Takiuchi, N., & Befi-Lopes, D. M. (2007). Visual short-term memory in children with specific language impairment. *Pró-Fono Revista de Atualização Científica*, *19*(4), 363-369.

Miyake, A., Friedman, N. P., Rettinger, D. A., Shah, P., & Hegarty, M. (2001). How are visuospatial working memory, executive functioning, and spatial abilities related? A latent-variable analysis. *Journal of experimental psychology: General*, *130*(4), 621.

Nikolić, D., & Singer, W. (2007). Creation of visual long-term memory. *Perception & psychophysics*, *69*(6), 904-912.

Noland, J. S., Steven Reznick, J., Stone, W. L., Walden, T., & Sheridan, E. H. (2010). Better working memory for non-social targets in infant siblings of children with Autism Spectrum Disorder. *Developmental science*, *13*(1), 244-251.

Oakes, L. M., Hurley, K. B., Ross-Sheehy, S., & Luck, S. J. (2011). Developmental changes in infants' visual short-term memory for location. *Cognition*, *118*(3), 293-305.

Oakes, L. M., Messenger, I. M., Ross-Sheehy, S., & Luck, S. J. (2009). New evidence for rapid development of colour–location binding in infants' visual short-term memory. *Visual cognition*, *17*(1-2), 67-82.

Oakes, L. M., Ross-Sheehy, S., & Luck, S. J. (2006). Rapid development of feature binding in visual short-term memory. *Psychological Science*, *17*(9), 781-787.

Pelphrey, K. A., Reznick, J. S., Davis Goldman, B., Sasson, N., Morrow, J., Donahoe, A., & Hodgson, K. (2004). Development of visuospatial short-term memory in the second half of the 1st year. *Developmental psychology*, *40*(5), 836-851.

Phillips, W. A., & Baddeley, A. D. (1971). Reaction time and short-term visual memory. *Psychonomic Science*, *22*(2), 73-74.

Posner, M. I., & Konick, A. F. (1966). Short-term retention of visual and kinesthetic information. *Organizational Behavior and Human Performance*, *1*(1), 71-86.

Reynolds, G. D., & Romano, A. C. (2016). The development of attention systems and working memory in infancy. *Frontiers in systems neuroscience*, *10*, 15.

Riggs, K. J., McTaggart, J., Simpson, A., & Freeman, R. P. (2006). Changes in the capacity of visual working memory in 5-to 10-year-olds. *Journal of experimental child psychology*, *95*(1), 18-26.

Rose, S. A., & Feldman, J. F. (1997). Memory and speed: Their role in the relation of infant information processing to later IQ. *Child Development*, *68*(4), 630-641.

Rose, S. A., Feldman, J. F., & Jankowski, J. J. (2002). Processing speed in the 1st year of life: a longitudinal study of preterm and full-term infants. *Developmental psychology*, *38*(6), 895.

Ross-sheehy, S., Oakes, L. M., & Luck, S. J. (2003). The development of visual short-term memory capacity in infants. *Child development*, *74*(6), 1807-1822.

Sigman, M., Cohen, S. E., Beckwith, L., Asarnow, R., & Parmelee, A. H. (1991). Continuity in cognitive abilities from infancy to 12 years of age. *Cognitive Development*, *6*(1), 47-57.

Simmering, V. R. (2012). The development of visual working memory capacity during early childhood. *Journal of experimental child psychology*, *111*(4), 695-707.

Simpson, E. A., Jakobsen, K. V., Fragaszy, D. M., Okada, K., & Frick, J. E. (2014). The development of facial identity discrimination through learned attention. *Developmental psychobiology*, *56*(5), 1083-1101.

Slater, A., & Morison, V. (1991). Visual attention and memory at birth. In M. S. Weiss, P. R. Zelazo, M. S. Weiss, P. R. Zelazo (Eds.) , *Newborn attention: Biological constraints and the influence of experience* (pp. 256-277). Westport, CT, US: Ablex Publishing.

Stahl, A. E., & Feigenson, L. (2014). Social knowledge facilitates chunking in infancy. *Child development*, *85*(4), 1477-1490.

Sugimura, T. (2013). Young children’s difficulty in disregarding information from external features when matching unfamiliar faces. *Journal of experimental child psychology*, *116*(2), 296-308.

Tukey, J. W. (1977). *Exploratory data analysis* (Vol. 2). Reading, MA: Addison-Wesley.

Turati, C., Valenza, E., Leo, I., & Simion, F. (2005). Three-month-olds’ visual preference for faces and its underlying visual processing mechanisms. *Journal of experimental child psychology*, *90*(3), 255-273.

Valenza, E., Simion, F., Cassia, V. M., & Umiltà, C. (1996). Face preference at birth. *Journal of experimental psychology: Human Perception and Performance*, *22*(4), 892.

Viola Macchi, C., Turati, C., & Simion, F. (2004). Can a nonspecific bias toward top-heavy patterns explain newborns' face preference?. *Psychological Science*, *15*(6), 379-383.

Table 1: Change preference scores by condition. Means and standard deviations of the change preference scores, separated by age group, set size (SS), and image type. A mean of 0.50 indicates equal looking time between the novel and unchanging sides, with higher values indicating preference for the novel side. *Denotes means that differed from 0.50 at the p < .05 level.

Age Group	N	Condition	Mean (SD)
5 Months			
	18	SS1 Faces	0.49 (0.09)
	18	SS1 Shapes	0.69 (0.14)*
	15	SS2 Faces	0.50 (0.09)
	18	SS2 Shapes	0.48 (0.20)
8 Months			
	20	SS1 Faces	0.54 (0.12)
	20	SS1 Shapes	0.69 (0.10)*
	18	SS2 Faces	0.49 (0.10)
	20	SS2 Shapes	0.43 (0.14)

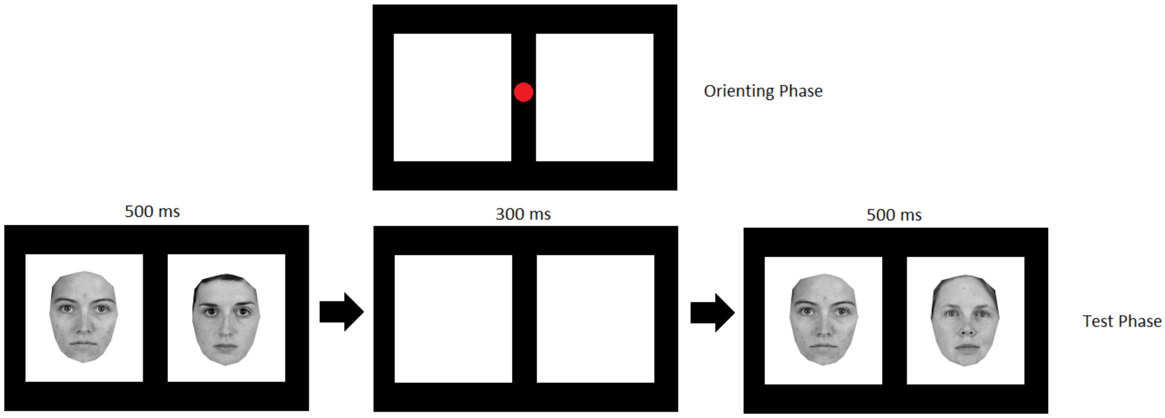

Figure 1: Depiction of the time course of a memory trial (not to scale). Prior to each trial, a red circle flashed at a rate of 2 Hz to orient the infant's attention to the center of the screen. The experimenter began the trial proper once they judged that the infant was attending to the middle of the screen. Over the course of each 20 second trial, the infant was shown a pair of displays (500ms), followed by blank displays (300ms), and then a new pair of displays (500ms). This cycle repeated until the end of the trial. Within each trial, one display never changed (non-changing stream), while the other display changed with each presentation (changing stream).

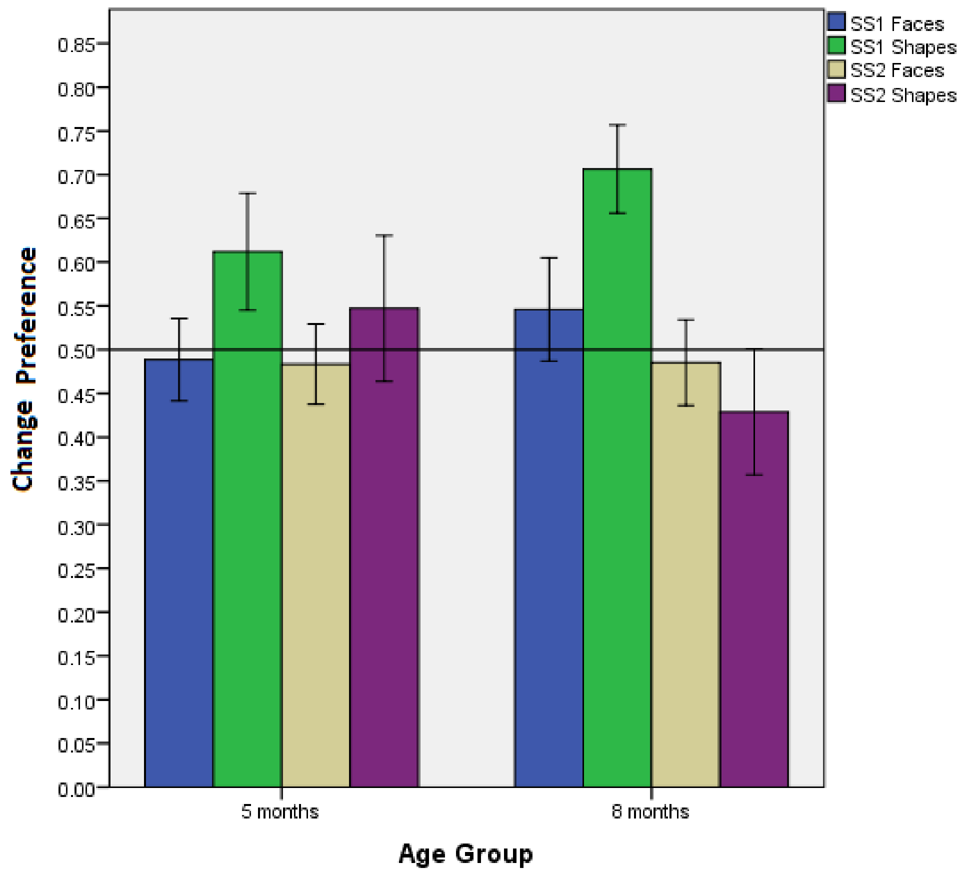

Figure 2: Change preference ratios separated by age and condition. Bars include 95% confidence intervals. A change preference at 0.50 indicates no preference for looking towards either the changing or non-changing side.