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Developmental changes in infants' visual short-term memory for location

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Abstract

To examine the development of visual short-term memory (VSTM) for location, we presented 6- to 12-month-old infants ($N = 199$) with two side-by-side stimulus streams. In each stream, arrays of colored circles continually appeared, disappeared, and reappeared. In the *changing* stream, the location of one or more items changed in each cycle; in the *non-changing* streams the locations did not change. Eight- and 12.5-month-old infants showed evidence of memory for multiple locations, whereas 6.5-month-old infants showed evidence of memory only for a single location, and only when that location was easily identified by salient landmarks. In the absence of such landmarks, 6.5-month-old infants showed evidence of memory for the overall configuration or shape. This developmental trajectory for spatial VSTM is similar to that previously observed for color VSTM. These results additionally show that infants' ability to detect changes in location is dependent on their developing sensitivity to spatial reference frames.

The input to the visual system consists of brief static snapshots during periods of fixation, separated by sudden shifts of gaze during which vision is effectively suppressed (Henderson, 2008). The ability to store information from one fixation and compare it to a subsequent fixation is essential to recognize the correspondence between particular objects in the first and second fixation periods, to determine whether the saccade actually landed on the intended target, and to integrate information acquired from the individual fixations into a coherent representation of the entire scene. Therefore, adults—and infants—need a memory system that can rapidly store information gained from one period of fixation and maintain that information long enough so that it can be integrated with information from the next period of fixation. The adult visual short-term memory (VSTM) system has these properties and is used every time we blink, make a saccadic eye movement, compare two objects that cannot be simultaneously fixated, or observe objects that are momentarily occluded (Hollingworth & Henderson, 2002; Irwin, 1991; Pomplun, Reingold, & Shen, 2001; Pomplun, Sichel Schmidt et al., 2001; Scott-Brown, Baker, & Orbach, 2000). VSTM, therefore, is critically important for infants who encounter an enormous number of new objects and scenes. Because information about objects and scenes is experienced over temporal gaps due to blinks, eye movements, and occlusion, infants would have difficulty

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learning about those object, events, and scenes, if they could not use VSTM to integrate visual information over time.

Research has revealed significant development in VSTM for object identity over the first postnatal year. Given its importance for moment-to-moment visual processing, it is not surprising that VSTM emerges at least by 4 months (Ross-Sheehy, Oakes, & Luck, 2003). However, VSTM at this age is quite limited: 4- to 6-month-old infants can store the features of a single item in VSTM (e.g., the item's color), but they have difficulty storing information about items in multiple-item arrays (i.e., arrays that contain two or more simple items). There appears to be a rapid developmental shift between 6 and 8 months, when infants become able to store the features of multiple items (Ross-Sheehy et al., 2003) and bind these features to their spatial locations (Oakes, Messenger, Ross-Sheehy, & Luck, 2009; Oakes, Ross-Sheehy, & Luck, 2006). Remarkably, Kaldy and Leslie (2003, 2005) observed a transition at this same point in development for infants' memory for object identity and the binding of identity to location using tasks in which objects and events could be encoded over several seconds and must be remembered over tens of seconds. Although our focus here is on VSTM (in which encoding and retention occur over periods of tens or hundreds of milliseconds), the similarity in the developmental trajectory in these two task contexts suggests some similarity in the underlying processes.

The present investigation extends the existing literature by examining infants' VSTM for location information. This extension is important because tasks such as object comparison and eye-movement targeting depend on representing not only *what* items were in the array, but also *where* the items were located. For example, making accurate eye movements requires encoding and maintaining a representation of where items were located in a visual array. Separate dorsal-stream and ventral-stream areas appear to be involved in representing location information and object identity, respectively (Goldman-Rakic, 1996; Jonides, Schumacher, Smith, Lauber, & et al., 1997; Postle & D'Esposito, 1999; Ungerleider, Courtney, & Haxby, 1998). Moreover, these dorsal and ventral pathways appear to undergo different developmental trajectories (e.g., Distler, Bachevalier, Kennedy, & Mishkin, 1996; Kovacs, 2000; Mash, Quinn, Dobson, & Narter, 1998). Thus, our understanding of infants' developing VSTM for item identity may or may not translate to the development of VSTM for location.

In addition, a full understanding of the origins and development of short-term memory requires examining infants' VSTM for spatial information. In Baddeley's influential working memory model, modality-specific *slave systems* are used for storing information, and a *central executive* is used to read, write, and manipulate this information (Baddeley, 1986, 1992; Baddeley & Hitch, 1974; Baddeley & Logie, 1999). Short-term storage of visual information is accomplished by a *visual cache* that is used to store visual object identities, and a separate *visuo-spatial sketchpad* that is used to store spatial information (Baddeley & Logie, 1999). Thus, this model proposes a dissociation between memory for object properties like color and shape, and memory for spatial properties like location. It should be pointed out that Baddeley's work asked whether the memory system that is used in typical STM tasks is a "working memory" (i.e., a memory system that is used for the temporary storage and manipulation of information in the service of complex tasks). Because it is difficult to determine whether the memory system isolated in experimental paradigms used with infants is a working memory (see Reznick, 2007), we use the more conservative term *short-term memory* to refer to the memory system we are studying. However, the task we use to study VSTM in infancy (Oakes et al., 2009; Oakes et al., 2006; Ross-Sheehy et al., 2003) is closely related to a task commonly used in adults to study a short-term memory system that has shown to function as a working memory (see Luck, 2008), and it is therefore very likely that the infant version of this task taps into the developmental origins of the adult

working memory system. A few studies have examined some aspects of infants' working or short-term memory for location information (Gilmore & Johnson, 1995; Reznick, Morrow, Goldman, & Snyder, 2004), but infants' developing VSTM for object identity information has been studied more extensively (Oakes et al., 2009; Oakes et al., 2006; Ross-Sheehy et al., 2003). Thus, an important step in our understanding of this aspect of infants' memory is to document the developmental trajectory of VSTM for location.

Understanding infants' VSTM for location is also important because there are many different reference frames that can be used to encode location, and the salience of those reference frames may vary by context or over development. Locations are coded in a retina-centered reference frame from the retina through the early stages of cortical processing, but this frame is unstable because it shifts every time the eyes move. Consequently, later stages of processing recode information with respect to more stable reference frames. For example, the location of an object can be encoded relative to the highly stable environmental reference frame provided by the ceiling or walls of a room, which do not vary with the viewpoint of the observer or with changes in locations of other objects in the room. Locations can also be coded with respect to reference frames provided by the observer's body or by other objects in the environment, which are less stable than the overall environmental reference frame but are more stable than the retina-centered reference frame.

The adult primate brain uses all of these reference frames (Cohen & Andersen, 2002), depending in which is most useful for a given task (e.g., programming eye movements, reaching for objects, navigating an environment). Infants also use these different types of reference frames in tasks that engage long-term memory (LTM) systems (i.e., when visual arrays are available for inspection over many tens of seconds, or hiding events occur over many seconds or minutes). In such tasks, infants represent object locations relative to other objects in scenes (Acredolo & Evans, 1980; Quinn, 1994), relative to structural features of the environment, such as the edge of a sandbox (Newcombe, Huttenlocher, & Learmonth, 1999), and relative to their own body (Acredolo & Evans, 1980). However, infants' reliance on one encoding strategy over another may be driven by the demands of the task, by development, or both.

In multiple-item arrays, location can be encoded in terms of the overall *configuration*. Here, we use the term "configuration" to mean some kind of shape-based representation, in which the locations define key elements of the shape (e.g., vertices) and in which the locations are defined with respect to the shape. In the two sets of three O's shown below, for example, the location of each O can be remembered (1) relative to one's eye position, (2) relative to the edges of the page, or (3) in terms of its position within the triangle made by the set of three O's (i.e., in terms of the *configuration*). That is, a set of N locations can be represented by an N -sided polygon in which the locations define the vertices of the polygon.

When shown such arrays, adults represent both the configuration and the absolute locations of individual items. For example, adults can detect changes in configuration when the entire array has been moved to a different retinal and environmental location (Jiang, Olson, & Chun, 2000; Phillips, 1974), and when repeatedly given visual search arrays adults implicitly learn the configurations of the arrays, even when that information is irrelevant to the task (Jiang & Song, 2005). Adults also encode the absolute location of individual items. For example, they detect changes in the location of one item even when the other items are

eliminated at the time of test to eliminate configural cues (Jiang et al., 2000). Thus, an important step is to understand the role of the configuration in infants' developing VSTM for multiple item arrays.

In the present investigation, we examined infants' developing VSTM for location using the change preference task that Ross-Sheehy et al. (2003) developed to assess infants' VSTM for object color. In this task, infants are presented with two stimulus streams, side by side (see Figure 1 in the *Method* section). Each stream involves an array of items that repeatedly appears briefly (500 ms) and disappears briefly (300 ms), cycling continually during a 20-s trial. The two side-by-side streams are equivalent in terms of the rate of cycling and the number of items. In the *changing* stream, one (or more) of the items changes in some way from cycle to cycle—in the present experiments, the location of one (or more) item was changed each time the array reappeared. In the *non-changing* stream, the array remained precisely the same from cycle to cycle.

Several aspects of this task ensure that it isolates VSTM from other memory systems. First the retention interval is sufficiently long to minimize contributions from iconic memory (Becker, Pashler, & Anstis, 2000). Second, the brief array duration requires that the items be encoded very rapidly (i.e., within 500 ms), minimizing LTM encoding. Third, we draw the item values from a small set, and as a result the within- and between-trial similarity is very high, which would lead to substantial LTM interference (Murdock, 1961). In addition, previous studies have ruled out perceptual, attentional, and motor limitations as contributing factors in this paradigm (Oakes et al., 2006; Ross-Sheehy et al., 2003)—infants do not fail to distinguish between the changing and nonchanging streams in this paradigm because they are unable to perceive the stimuli, attend to multiple stimuli, or control orienting.

The present study had two main goals. First, we examined the developmental trajectory of VSTM for location by testing 6- to 12-month-old infants, the period during which Ross-Sheehy et al. (2003) observed substantial development of object VSTM. If the developmental changes previously observed are general and independent of the type of feature being represented, we should observe here the same developmental time course as has been observed for other aspects of VSTM. In this case, infants at 6 months should have a limited VSTM for location, apparently not representing the locations of individual items in multiple item arrays, and we should observe a rapid shift between 6 and 8 months for infants' ability to process information from the individual items in such arrays. If, in contrast, there are different developmental trajectories for VSTM for different types of features, perhaps reflecting different developmental trajectories for the dorsal and ventral streams, we may observe that infants' VSTM for location develops earlier or later than their VSTM for color.

Our second goal was to determine how the available frames of reference contribute to infants' encoding of location in VSTM across development. In particular, we hypothesize that the ability to create a stable, environment-centered reference frame from the retinal input is a challenging computational problem, and the ability to use such a reference frame will improve over the first postnatal year. Consequently, young infants will find it difficult to detect changes in location relative to the overall environment unless the environmental reference frame is highly salient. It will also be difficult for infants to use a purely retina-centered representation of individual locations, because eye movements will cause objects to appear to shift locations. However, we propose that young infants will exhibit memory for location when location can be encoded in terms of object configuration. In particular, if the array contains multiple items, and one of the items changes location, the resulting configural change might be detectable by ventral stream object recognition systems (e.g., a change from an equilateral triangle to a right triangle). Because neurons at late stages of the ventral

stream have very large receptive fields, they can represent the shape of an object irrespective of its retinal position (Gross & Mishkin, 1977). Consequently, changes in configuration could be relatively easily distinguished from changes in eye position, and it is therefore plausible that young infants could detect configural changes in arrays containing multiple items even if they cannot detect changes in the absolute position of a single item (we use the term “absolute location” to refer to the x,y location of an item on the video monitor; because the monitor is stationary with respect to the environment, this is largely identical to the environment-centered reference frame).

Such configural changes should be most discriminable at set size 3. No configuration information is present at set size 1 (by definition). At set size 2, a change in the location of one item could be perceived as a change in the orientation of the group rather than a change in the shape of the group, and changes in orientation are less diagnostic because orientation also depends on the tilt of the head. At set size 3, changes in the location of one item will change the shape of the triangle formed by the individual items as well as changing the orientation of the groupings of two of the three pairs of items in the array. Thus, because we propose that 6-month-old infants will rely primarily on configural encoding to represent location information in VSTM, we predict that they will exhibit the greatest sensitivity to changes at set size 3 and little or no ability to detect changes at set size 1. This prediction was tested in Experiment 1. In addition, if 6-month-old infants primarily rely on configural information, then they should have difficulty detecting shifts in the position of a group of 3 items that maintains the configuration of the group. This prediction was tested in Experiment 2. However, if the display contains salient landmarks that provide an easily perceived reference frame, these infants should be able to encode the location of a single item relative to this reference frame and detect changes in the location of this item relative to that reference frame. This hypothesis was tested in Experiment 3.

We also hypothesize that older infants will be better able to take advantage of less salient or more computationally demanding reference frames, such as those provided by the infant's own body, the edges of the monitor, and the room. Consequently, we predict that these infants will be able to detect changes in the location of a single item or group of items even in the absence of highly salient landmarks. In addition, these infants should also be able to detect changes at set sizes 2 and 3, using either multiple absolute object locations or a configural representation. These predictions were tested in Experiments 1 and 2.

Experiment 1

Experiment 1 assessed infants' detection of location changes at set sizes 1, 2, and 3 in the absence of salient nearby landmarks. Previous studies indicate that VSTM for features such as color is sophisticated by 10 to 12 months of age (Oakes et al., 2006; Ross-Sheehy et al., 2003), and in Experiment 1A we tested 12-month-old infants to provide a comparison point for the subsequent experiments, which examine the performance of younger infants. Experiment 1B examined the development of the ability to represent location in VSTM by testing 6- and 8-month-old infants.

General Method

Participants—All infants in all experiments reported here were healthy at the time of testing, born at full term, and had no known vision or neurological problems. None of the boys had a maternal family history of colorblindness. Infant names were obtained from a professional list broker or from the state vital records office. Parents were sent general informational letters and indicated their interest in volunteering by telephone, e-mail, or return postcard. When infants approached the appropriate age, parents were contacted by

telephone or e-mail to schedule an appointment (infants participated at only one age across all experiments reported here).

In Experiment 1A, the final sample consisted of 24 healthy 12-month-old infants ($M = 380.13$ days, $SD = 6.92$; 14 boys). Twenty of the infants were Caucasian and 4 were of mixed race. Five infants were reported to be Hispanic. All mothers had graduated high school, 23 mothers had some college, 14 of whom had earned at least a Bachelor's degree. An additional 4 infants were tested but became too fussy to complete the session.

In Experiment 1B, the final sample consisted of 38 6-month-old infants ($M = 195.24$ days, $SD = 8.31$; 18 boys) and 38 8-month-old infants ($M = 244.76$ days, $SD = 7.36$; 24 boys). An additional 9 infants were tested but excluded from the final sample due to fussiness ($n = 1$), interference from a parent or sibling ($n = 2$), failure to look at both monitors on half of the trials or more ($n = 5$), or extreme side bias ($n = 1$). In the final sample, 54 infants were Caucasian, 1 was African American, 3 were Asian, 13 were mixed race, and 4 did not report race or were listed as other. Fifteen infants were Hispanic. Seventy-five of the mothers had graduated from high school, 71 had at least some college, and 51 of those mothers had a bachelors or more advanced degree

Apparatus—A Macintosh G5 computer was used to present the stimuli on two 17-in LCD Dell computer displays, each with viewable surface of 18° (w) by 13.5° (h) at a viewing distance of 100 cm. The two monitors were positioned side by side with a 22 cm (12.5°) gap between them. The total width of the two displays and gap was approximately 88 cm (47.5°). Thus, there was $>30^\circ$ distance between the centers of the monitors; at this distance, fixating one display would put the other display far enough into the periphery that there would be extensive crowding within the non-fixated display (Farzin, Rivera, & Whitney, in press; Pelli, Palomares, & Majaj, 2004). Thus, the monitors were sufficiently far apart so infants could detect that there was a stimulus on the non-fixated display while they attended to a fixated monitor, but they could not perceive the details of the non-fixated display. When performing this task, therefore, infants are focused on one monitor at any given moment rather than attending to both stimulus streams at the same time.

Stimuli—A schematic depiction of the stimuli is presented in Figure 1. Each stimulus stream involved an array of one, two, or three colored circles, 2.5 cm high by 2.5 cm wide ($1.4^\circ \times 1.4^\circ$), on a gray background. The colors of the circles were selected from a set of eight highly discriminable values (red, green, cyan, white, yellow, black, brown, and blue). The set of possible locations was derived from a virtual 3×3 grid (each cell in the grid was approximately 11 by 9 cm, or 6.3° by 5° visual angle). Circles could appear in any one of these cells with the exception of the center cell. To ensure that the arrays were somewhat irregular, circles were not drawn at the center of the cell, but rather were drawn offset 2 cm (1.14°) at a randomly chosen angle from the center of the cell. When an item changed location, it moved to any unoccupied cell (except the center cell), resulting in a change ranging from 5 cm (2.8°) to 24 cm (13°).

The items within a given array were different colors, but each item retained its color from cycle to cycle. For example, a red and a green item would appear, disappear during the retention period, and the same red and green items would reappear on the next cycle.

Each stimulus stream was 20 s, during which an array of one, two, or three colored circles continually appeared and disappeared (visible for 500 ms, off for 300 ms, visible for 500 ms, and so on). In *changing streams*, the location of a different randomly chosen circle changed each time the array appeared (location randomly drawn from the pool of the unoccupied cells). If infants encode the location of individual items in relation to its absolute spatial

location (e.g., distance from the edge of the monitor), then they should be able to detect changes if there is only one item in the array. If infants solely respond to changes in the overall configuration or shape, on the other hand, change at set size 3 will be the most salient. If infants encode both configural and individuated spatial information, they may respond approximately equivalently to changes at all three set sizes. The *non-changing streams* were identical to the changing streams in every way with the exception that the locations of the circles remained constant from cycle to cycle.

The timing parameters were chosen to minimize the extent to which the task could be solved via the perception of apparent motion between the location of an item in one array and the next. In adults, the perception of apparent motion falls off rapidly when the temporal gap between two items exceeds approximately 75 ms (Kolers & Pomerantz, 1971). Thus, the 300-ms gap used in the present study should be enough to minimize apparent motion even if infants can tolerate a substantially longer gap than adults.

Procedure—Infants sat on a parent's lap 100 cm in front of a large black curtain that obscured their view of the experimental apparatus. Parents wore occluding glasses to obstruct their view of the stimuli as they held their infants, thus minimizing their influence on infants' looking. Holes in the curtain revealed the 2 computer monitors, a small black box positioned between the monitors, and the lens of a video camera below the black box. To direct infants' attention between the two monitors at the start of each trial, and thereby reduce side bias, the black box produced a flashing light and beeping tone between trials.

All infants received six 20-s trials. On each trial, a *changing stream* was presented on one monitor and a *nonchanging stream* was presented on the other. Infants received two trials at each set size, one trial in which the changing stream was on the left and a second trial in which the changing stream was on the right. The order of these 6 trials, and the particular stimuli presented, was randomly determined for each infant with the constraint that the changing stimulus could never appear on the same monitor for more than 3 trials in succession. A trained observer, unaware of whether the changing stream was on the right or left on each trial, recorded infants' looking time to each monitor by pressing computer keys and using software developed for the Macintosh for this purpose (Cohen, Atkinson, & Chaput, 2000-2002). A second trained observer recoded the looking time off-line for 24 randomly chosen infants. The average correlation between the two observers' looking times was high, $r = .96$, with an average difference in recorded looking on each trial of 0.73 s.

Experiment 1A Results

To provide a basis for comparison with younger infants, this experiment examined 12-month-old infants' preference for the changing stream at each set size (1, 2, and 3). Our primary dependent measure was infants' *change preference score* at each set size, calculated by dividing the duration of looking to the changing stream at that set size by the total duration of looking to changing and non-changing streams at that set size. For example, to determine an infants' change preference at set size 2, we divided the duration of their looking to the changing stream at set size 2 with their combined looking to the changing and non-changing streams at that set size (recall that the changing and non-changing streams at each set size were presented side-by-side). If infants divide their looking equally to the changing and non-changing streams at a given set size, this score will be .50 (chance). If infants look longer at the changing stream, in contrast, their preference score at that set size will be greater than .50. In general, infants prefer more complex and dynamic stimuli (Brennan, Ames, & Moore, 1966; Shaddy & Colombo, 2004); thus we expect infants will prefer the changing stream if they can remember the locations of the items and detect the changes in locations. Preference scores can show substantial compression when they

approach the extremes of 0 and 1; however, the scores in the three experiments reported here did not approach 0 or 1, so we report the untransformed raw preference scores. The results of analyses of the data following an arcsine-root transformation were virtually identical to those reported here.

The mean change preference scores at each set size are shown in the leftmost panel of Figure 2. Infants preferred the changing stream at all three set sizes, with no systematic differences in preference across set sizes. A one-way ANOVA on infants' change preference score at set sizes 1, 2, and 3 revealed no effect of set size, $F(2, 46) = 1.21$, $p = .31$, $\eta_p^2 = .05$. We also compared infants' change scores at each set size to chance (.50) and found that they preferred the changing stream significantly more than expected by chance at set size 1, $t(23) = 2.83$, $p = .01$, $d = .58$, at set size 2, $t(23) = 4.67$, $p < .001$, $d = .95$, and at set size 3, $t(23) = 3.46$, $p = .002$, $d = .71$. These significant deviations from chance confirm that infants reliably detected the change at all three set sizes. As discussed earlier, this is the pattern of results that would be expected if the infants stored information about the absolute locations of the items (or if they used a combination of absolute location at set size 1 and configural information at larger set sizes).

Finally, to examine how infants' looking *in general* varied with the number of items in each array, we conducted an ANOVA on the total looking time (looking to the changed and unchanged streams combined) with set size (1, 2, 3) as the within-subjects factor. This analysis revealed a main effect of set size, $F(2, 46) = 4.73$, $p = .01$, $\eta^2 = .17$ (see Table 1). Infants looked longer when there were more items in each array. Comparisons between infants' looking at each set size revealed that infants looked longer overall when there were 3 items in each array than when there was only 1 item in each array, $t(23) = 3.34$, $p = .003$, $d = .68$, but the difference between 1 and 2 items did not reach significance, $t(23) = 1.10$, $p = .28$, $d = .22$, nor did the difference between 2 and 3 items, $t(23) = 1.90$, $p = .07$, $d = .39$. Thus, in general, 12-month-old infants looked longer at arrays with more items.

Experiment 1B Results

This experiment examined change preference scores in 6- and 8-month old infants at set sizes 1, 2, and 3. Mean change preference scores are presented in middle and right panels of Figure 2. The pattern of significant change preference differed across the 6- and 8-month-old infants. At 8 months, infants had scores that were significantly greater than chance at set size 1, $t(37) = 3.43$, $p = .001$, $d = .56$, set size 2, $t(37) = 4.69$, $p < .001$, $d = .76$, and set size 3, $t(37) = 4.04$, $p < .001$, $d = .66$. Thus, like the 12-month-old infants in Experiment 1, these 8-month-old infants responded to the change at all three set sizes, confirming previous findings that infants at this age can detect changes in multiple-item arrays (Oakes et al., 2009; Oakes et al., 2006).

Six-month-old infants, in contrast, had scores above chance only at set size 3, $t(37) = 2.93$, $p = .006$, $d = .47$. Their scores did not differ from chance at set size 1, $t(37) = 1.43$, $p = .16$, $d = .23$, or at set size 2, $t(37) = .93$, $p = .36$, $d = .15$. Thus, these infants responded most when the overall configuration or shape changed rather than to a change in the location of a single, isolated item.

To determine how change preference varied by age and/or set size, we next entered infants' change preference scores at each set size into an ANOVA with set size as a within-subjects factor and age as a between-subjects factor. This analysis revealed a significant main effect of age, $F(1, 74) = 4.10$, $p = .05$, $\eta_p^2 = .05$. That is, collapsed across the three set sizes, 8-month-old infants had a significantly greater change preference score ($M = .59$, $SD = .08$) than did 6-month-old infants ($M = .55$, $SD = .0$). The set size by age interaction was not significant, $F(2, 148) = .87$, $p = .42$, $\eta_p^2 = .01$. However, the main effect of age does

suggest that overall 8-month-old infants were more responsive to changes in these stimuli than were 6-month-old infants. The main effect of set size was not significant, $F(2, 148) = 1.29$, $p = .28$, $\eta_p^2 = .03$. This, coupled with the lack of a significant set size by age interaction, indicates that although 6-month-old infants appear to have scores that differed at different set sizes, the pattern was not significant.

Finally, as in Experiment 1A, we examined total looking time at each set size, entering the data collapsed across the change and no-change sides into an ANOVA with age (6, 8) as a between-subjects factor and set size (1, 2, 3) as a within-subjects factor. This analysis revealed no significant effects or interactions (see Table 1). Thus, whereas the 12-month-old infants exhibited longer overall looking times as the set size increased, the 6- and 8-month-old infants showed no significant effect of set size. Moreover, 6- and 8-month-old infants exhibited nearly identical overall looking times, so any developmental differences in the pattern of change preference scores cannot be due to age differences in infants' general level of interest in the task.

Discussion

Together, Experiments 1A and 1B revealed that both 8- and 12-month-old infants exhibited a significant change preference at set sizes 1, 2, and 3, just as in previous studies examining VSTM for color in a nearly identical paradigm. Because they significantly preferred the changing streams at set size 1, this Experiment shows that 8- and 12-month-old infants can store absolute location information in VSTM. Moreover, at these two ages infants can detect changes in the location of one item in arrays containing two or three items. We cannot know whether these changes in 2- and 3-item arrays were based on representations of the configuration of the group or the individuated locations of the items (or both). However, it seems likely that these infants can remember multiple individuated locations, because by 8 months infants can remember bindings of color and location in a task that cannot be solved by means of simple configural memory (Oakes et al., 2006).

In contrast, the 6-month-old infants in this Experiment exhibited a significant change preference only at set size 3. Thus, these younger infants appear to be unable to store absolute location information in VSTM, detecting changes in the locations of objects only when those changes also correspond to configural changes. The overall pattern of change preferences observed here is consistent with a developmental change from 6 to 8 months in infants' representation of location in VSTM. This is precisely the timing that has been observed for developmental changes in other aspects of infants' VSTM and working memory (Kaldy & Leslie, 2003, 2005; Oakes et al., 2009; Oakes et al., 2006), and similar timing was observed by Kirkham, Slemmer, Richardson, and Johnson (2007) for infants' use of location to learn predictable spatiotemporal sequences. However, this conclusion is based on the failure of 6-month-olds to exhibit significant change preference at set sizes 1 and 2, and the age by set size interaction failed to reach significance. Thus, the conclusion of a developmental difference must be considered tentative.

On the surface, the pattern of results observed for spatial memory in 6-month-old infants observed here, in which changes were detected only at set size 3, seems very different from the pattern observed previously at this age for color memory, in which changes were detected only at set size 1 (Ross-Sheedy et al., 2003). However, these superficially different patterns can be easily accommodated by the hypothesis that 6-month-old infants can store only a single object in VSTM (along with the additional hypothesis that 6-month-old infants cannot easily store absolute location information). That is, the finding of significant location detection at set size 3 but not at set size 1 is exactly what would be expected if (a) 6-month-old infants have difficulty using a stable reference frame to represent the absolute location of a single object at set size 1, and (b) these infants can store a single object in memory and

detect changes based on relative location information (e.g., changes in the shape of a triangle formed by three items). Experiments 2 and 3 provided direct support for these proposals by showing that (a) 6-month-old infants fail to detect changes when a set of 3 items moves together, producing a large absolute change but no change in shape (Experiment 2), and (b) 6-month-old infants can detect changes in the location of a single item when salient nearby landmarks are present to facilitate the use of relative location information (Experiment 3).

Experiment 2

In Experiment 2, we examined 6- and 8-month-old infants' change preferences at set size 3 when all items in the array moved together as a unit, yielding a large change in absolute location but no change in configuration. In such stimulus streams, location changes can be detected only if location was encoded relative to a stable reference frame. That is, even though the overall location signal is larger for these changes than for the situation in which only one of the three items is moved (because all three items move), an individual who represents only configural information would be unable to detect the changes in the present experiment. Moreover, the change in retinal input when all three items move together as a unit is identical to the change in retinal input that would be caused by an eye movement; consequently, the use of a retina-centered frame of reference would make it difficult to distinguish between eye movements and true changes in the locations of the items.

Thus, this experiment will directly test the hypothesis that the ability to represent absolute location information about multiple individual items improves between the ages of 6 and 8 months. If both older and younger infants represent only configural information at set size 3, then all infants will fail to detect changes when all items change location but the configuration is preserved. However, infants of a given age represent the locations of the individual items relative to a stable reference frame (in combination with or instead of the configural information), then they will prefer changing streams in which all three items change location even if the configuration remains the same.

Because we hypothesize that 8-month-old infants can store nonconfigural location information, we predicted that they would be able to detect these nonconfigural location changes. However, because we hypothesize that 6-month-old infants are primarily sensitive to configural information, we predicted that they would be unable to detect these nonconfigural location changes. That is, even though 6-month-old infants in Experiment 2 exhibited a significant preference when only one of three items changed location on each cycle (producing a change in configuration), we predicted that they would not prefer streams in the present experiment in which all three items changed location (but the configuration was preserved).

Method

Participants—The final sample included 32 6-month-old ($M = 192.16$ days, $SD = 9.89$; 16 boys) and 32 8-month-old infants ($M = 238.84$ days, $SD = 6.91$; 16 boys). An additional 12 infants were tested but excluded from the final analyses because they failed to complete the session due to fussiness ($n = 2$), parental interference ($n = 3$), failure to look at both monitors on more than half the trials ($n = 1$), and 90% of total looking to either the left or right monitor ($n = 4$). One additional infant was excluded as an outlier (his or her change preference score was more than 3 SD different from the mean preference score for the entire group of infants).

In the final sample, 31 infants were Caucasian, 1 was Asian, 1 was African American, 23 were mixed race, and 2 did not have race reported. Eighteen infants were Hispanic. All

mothers had graduated from high school, 59 had at least some college, and 44 of those had earned at least a bachelor's degree.

Stimuli—The stimuli were similar to the set size three events used in Experiment 1 and are depicted schematically in Figure 3. However, in the changing streams in Experiment 2, all three items moved together as a group on each cycle, preserving the configuration. Specifically, on each cycles all three items moved 6 cm (3.44 degrees visual angle) in the same randomly chosen direction (but a different randomly chosen direction from cycle to cycle). Thus, if infants encode the independent locations of each item, these changing streams will be salient because they involve three changes (as opposed to the single location change in the set size 3 changing streams in Experiment 1). If infants only encode the overall configuration, in contrast, these changing streams do not involve a change at all.

Apparatus and procedure—The apparatus and procedure were identical to those in Experiment 1. In the present experiment, however, infants received stimulus streams at set size 3 on four 20-s trials (left-right position of the changing stream determined randomly for each trials). Reliability as assessed by a second trained observer recording the looking times for 17 randomly selected infants was good; average correlation for the duration of looking on each trial was $r = .98$, and the average difference in the recorded amount of looking on each trial was .62 s.

Results

The average change preference score at each age is presented in Figure 4, and it is clear that 6- and 8-month-old infants exhibited different change preference patterns. Six-month-old infants did not prefer the changing stream more than expected by chance, $t(31) = .59$, $p = .56$, $d = .10$, whereas 8-month-old infants did prefer the changing stream more than expected by chance, $t(31) = 4.28$, $p < .001$, $d = .76$. Moreover, the change preference was significantly greater in the 8-month-old infants than in the 6-month-old infants, $t(62) = 2.63$, $p = .01$, $d = .66$. To determine whether 6-month-old infants' responding in Experiment 2 was indeed different from that in Experiment 1B, we compared infants change preference scores across the two experiments. Given the differences in procedures, these comparisons should be considered with caution, but 6-month-old infants' in Experiment 1B at set size 3 had a significantly greater than the 6-month-old infants in Experiment 2, $t(68) = 2.10$, $p = .03$, $d = .53$. The corresponding comparison for the 8-month-old infants in Experiment 1B and Experiment 2 was not significant, $t(68) = .98$, $p = .33$, $d = .24$. Thus, it does appear that 6-month-old infants were more responsive in Experiment 1B—in which a single item of an array of 3 items changed location, changing the overall configuration—than in Experiment 2, in which all three items in an array moved locations, preserving the overall configuration. In contrast, 8-month-old infants preferred the changes approximately equally in these two conditions.

As in Experiment 1, we calculated the overall looking time (changing plus non-changing stream combined) on each trial; the average of the four trials at each age is presented in Table 1. Infants looked for approximately the same duration on each trial at 6 months and 8 months, $t(46) = .23$. Thus, the displays were equally interesting to the infants at the two ages.

Discussion

In this experiment, all three items changed location in the changing stream on every cycle, but the spatial configuration remained constant. The changes should have been salient if the absolute locations of each item (or the absolute location of the overall configuration) were stored in VSTM. Eight-month-old infants reliably preferred the changing stream, suggesting

that they did indeed encode absolute location information. However, the 6-month-old infants showed no evidence of the ability to store absolute location information in VSTM. Thus, this experiment provides direct evidence for the hypothesis that the ability to store absolute location information in VSTM improves between 6 and 8 months of age. Moreover, the difference between the 6- and 8-month-old infants was statistically significant, providing confidence that the similar developmental trend observed in Experiment 1B was real even though it failed to reach statistical significance.

The failure of 6-month-old infants to show evidence of spatial VSTM when all three items changed locations on every cycle—despite the fact that infants in this age range showed a significant change preference at set size 3 when only one of the three items changed in Experiment 1B—is consistent with the proposal that these infants have difficulty storing absolute spatial information and succeeded at set size 3 in Experiment 1B by encoding a single configural representation in VSTM.

Experiment 3

The failure of 6-month-old infants to prefer changes in the location of a single item in Experiment 1 or changes in the location of a cluster of items in Experiment 2 could be taken as evidence that these infants are completely unable to store nonconfigural spatial information in VSTM. This would mean that the developmental trajectory for spatial VSTM is quite different from that for object VSTM. However, it is possible that these results reflect difficulty in using an environmental reference frame to encode absolute spatial locations, forcing the infants to rely solely on configural information. Experiment 3 tested this hypothesis by making the environmental reference frame more salient. Specifically, we used items identical to those in Experiment 1 but presented them on a grid that outlined 9 distinct locations on the screen (see Figure 5). Thus, when an item moved from one cycle to the next, it changed its relative location with respect to this highly salient reference frame. We predicted that the addition of this grid would allow 6-month-old infants to detect changes in the location of a single item. We further predicated that the presence of the grid would interfere with the ability to form a configural representation, reducing change preference at set size 3.

Method

Participants—We tested 35 6-month-old infants ($M = 189.71$ days, $SD = 4.83$; 15 boys). Two additional infants were tested but excluded from the final analyses due to fussiness ($n = 1$) or experimenter error ($n = 1$). In the final sample, 16 infants were White, 1 infant was Black, 2 infants were Asian, 11 infants were mixed race or other, and race was not reported for 4 infants. Six infants were Hispanic. All mothers had graduate high school and had some college; 25 mothers had earned at least a Bachelor's degree.

Stimuli—The stimuli were created in exactly the same manner as were the stimuli in Experiment 1. The only difference was that a visible grid formed by 2 black horizontal lines and 2 black vertical lines was used to demarcate 9 distinct locations (see Figure 5); this grid was visible even during the delay period.

Apparatus, design, and procedure—The apparatus, design and procedure were identical to Experiment 1. We assessed reliability for 8 infants' data. Agreement between the original observer and the off-line coding was good: correlation for the duration of looking between the two coders was high, average $r = .96$, and the difference in the duration of looking recorded on each trial was low, $M = 0.65$ s.

Results

Mean change preference scores are presented in the rightmost panel of Figure 2. Clearly, the inclusion of the visible grids influenced infants' preference for the changing streams—the pattern of change preference is quite different from the pattern of change preference by 6-month-old infants in Experiment 1, shown in the middle panel of Figure 2. Infants did not prefer the changing streams more than expected by chance at set sizes 2, $t(34) = 1.58$, $p = .12$, $d = .27$, or 3, $t(34) = -.09$, $p = .93$, $d = .02$. They did prefer the changing stream more than expected by chance at set size 1, $t(34) = 2.56$, $p = .02$, $d = .43$, suggesting that given sufficient contextual support infants at 6 months can encode the location of a single item. However, a repeated measures ANOVA with set size as the within-subject factor was not significant, $F(2, 68) = 1.42$, $p = .25$, $\eta_p^2 = .04$, so we cannot conclude with confidence that performance varied across set sizes. An ANOVA on overall looking time, collapsed across the change and no-change sides, did not reveal a significant main effect of set size (mean looking times are in Table 1).

To directly assess the effect of the grid on infants' encoding of location, we conducted targeted comparisons to determine whether infants' responding differed across Experiments 1B and 3. It is important to keep in mind that the location changes were identical in these two experiments; the only difference was the presence of the grid in Experiment 3 and the absence of the grid in Experiment 1B. We therefore asked whether there were significant differences between experiments at set sizes 1 and 3. In addition, we provided converging evidence by assessing the number of infants who showed a preference of greater than chance (.5) at a given set size in each experiment.

At set size 3, the change preference score was significantly greater for 6-month-old infants in Experiment 1B than for infants of the same age in Experiment 3, $t(70) = 2.09$, $p = .04$, $d = .49$. This matches the finding that the preference was significantly greater than chance in Experiment 1B but not in Experiment 3. Moreover, 71% of the 6-month-old infants in Experiment 1B had change preference scores that were greater than .50 at set size 3; in contrast, only 40% of the 6-month-old infants in Experiment 3 had preference scores greater than .50 at set size 3. This was a significant difference, $\chi^2(1) = 5.93$, $p = .015$. Thus, 6-month-old infants were more responsive to the change at set size 3 in Experiment 1B, when the arrays were displayed without a grid.

At set size 1, 6-month-old infants showed a significant change preference in Experiment 3 but not in Experiment 1B, but the difference in means was not very large (see Figure 2). Consequently, the difference between Experiments 1B and 3 did not reach significance, $t(70) = .61$, $p = .54$, $d = .15$. However, 74% of the 6-month-old infants in Experiment 3 and only 53% of the 6-month-old infants in Experiment 1 had a change preference score at set size 1 that was greater than .50, and this difference was marginally significant, $c^2(1) = 2.80$, $p = .095$.

Discussion

From the pattern of statistical significance within and across Experiments 1B and 3, we can draw the following strong conclusions. First, the finding of a significant change preference at set size 1 in Experiment 3 demonstrates that infants at 6 months *can* store the location of a single item in VSTM if the environmental reference frame is sufficiently salient. Second, the presence of the grid led to significantly lower change preference at set size 3 in Experiment 3 than in Experiment 1B, presumably because it made the configural information less salient. Third, the absence of a significant change preference at set sizes 2 and 3 in Experiment 1B is consistent with previous evidence that 6-month-old infants are unable to store the locations of items in multiple-item arrays. Together, these results are consistent

with our general hypothesis that 6-month-old infants can store only a single object in VSTM, whether the task requires spatial memory or object memory (although they can detect location changes at set size 3 by means of a configural representation of a single shape).

General Discussion

These experiments revealed several key features of infants' VSTM for location information. Specifically, these results showed that by 6 months infants can represent location information in VSTM, that substantial development in this ability occurs between 6 and 8 months, and that there are changes over this period in infants' ability to use absolute reference frames for representing location. These findings therefore provide insights into the developmental time course of spatial VSTM.

Developmental time course of infants' VSTM for location

We found clear evidence that infants' VSTM for location information emerges by 6 months: by this age, infants can detect changes in the spatial configuration of three items (Experiment 1B) and changes in the location of a single item within a grid (Experiment 3). These findings add to a general literature revealing that infants can remember aspects of location between 4 and 6 months of age. For example, when exposed to the same event over tens of seconds and on several trials, infants 6 months and younger can remember the locations objects hidden in a continuous sandbox or one of multiple discrete locations (Newcombe et al., 1999; Wilcox, Rosser, & Nadel, 1994). Even on a shorter timescale, between 4 and 6 months infants can use location memory to plan eye movements to a sequence of targets (Gilmore & Johnson, 1997a, 1997b, 1998) or to learn predictable sequences of events presented at two distinct locations (Haith, Wentworth, & Canfield, 1993). Thus, by 6 months infants can remember location in a variety of contexts that likely engage different memory systems.

Moreover, infants' VSTM for location appears to develop over the same time period as VSTM for identity information (e.g., color, see Ross-Sheehy et al., 2003), between 6 and 8 months. Specifically, the overall pattern of results across experiments in the present study indicates that 6-month-old infants can store only a single location in VSTM, whereas 8- and 12.5-month-old infants can store multiple locations. However, the evidence for this is made complicated by the fact that infants, like adults, appear to engage in configural encoding, in which multiple locations are represented implicitly by means of a single shape representation. Specifically, 6-month-old infants were able to detect changes in the location of one item in an array of three items (Experiment 1B), which changes the configuration of items, but they were unable to detect changes in the locations of all three items that preserved the configuration (Experiment 2). In contrast, 8-month-old infants could detect changes in both of these conditions (Experiments 1B and 2). Moreover, 6-month-old infants were unable to detect changes in the location of a single item within an array of three items when a grid was placed on the screen to make the absolute locations of the items more salient and the configuration less salient (Experiment 3). Thus, the present results are consistent with the hypothesis that 6-month-old infants can store the color, location, or shape/configuration of a single item VSTM, whereas 8-month-old infants can store multiple colors or locations (and possibly multiple shapes).

Two caveats are necessary, however. First, we cannot rule out the possibility that the older infants used configural information to detect changes at set sizes 2 and 3 rather than retaining multiple individuated locations in VSTM (see further discussion in a later section). Second, some of the age differences in the present study failed to reach statistical significance. However, the overall developmental pattern observed here was remarkably

similar to that observed previously in multiple studies of object VSTM, in which a clear transition in storage capacity occurs between 6 and 8 months (Oakes et al., 2009; Oakes et al., 2006; Ross-Sheehy et al., 2003), as well to that observed as other studies revealing transitions over this age range in other related memory systems (Gilmore & Johnson, 1997a; Kaldy & Leslie, 2003, 2005). The only substantial difference between previous studies examining infants' object VSTM and the present study is that 6-month-old infants in Experiment 1B of the present study were able to detect changes at set size three, whereas 6-month-old infants in prior studies did not detect changes at set size three. However, the ability of 6-month-old infants to detect changes at set size 3 in Experiment 1B appeared to reflect the use of configural encoding, and infants of this age were unable to detect changes at set size 3 in Experiment 3. Thus, we tentatively conclude that the developmental time course of VSTM is the same for spatial and nonspatial features.

Infants' use of different frames of reference to encode location into VSTM

As described in the Introduction, the locations of individual objects can be encoded relative to any of several frames of reference. The present data provide insight into infants' developing use of these frames of reference to store locations in VSTM. Specifically, young infants appear to have difficulty encoding spatial information using an absolute reference frame, such as that provided by the monitor, ceiling, and floors. The use of this kind of environment-centered, non-retinal reference frame requires significant computational effort to combine multiple sources of information, and substantial evidence indicates that these computations occur within higher-level regions of the dorsal stream (Cohen & Andersen, 2002). Consequently, these higher-level dorsal stream areas may not yet fully functional by 6 months. Younger infants could, however, use such absolute reference frames to encode location if they were made highly salient by means of a visible grid on the monitor. Note that in this case, because the changes always involved movement from one cell in the grid to the other, changes could have been detected on the basis of categorical representations of location. This type of coding may not require the same kinds of computational effort and precision required to encode location relative to more global, and distal, landmarks such as the edge of the monitor, the floor, etc.

Older infants could remember location as defined by these more global absolute landmarks, suggesting a developmental change in the second half of the first year in how infants use frames of reference to encode location in VSTM. This development is consistent with findings reported by Gilmore and Johnson (1997a, 1997b, 1998) for infants planning sequences of saccades to multiple locations. In this task, Gilmore and Johnson found significant change in the reference frame used to plan these sequences between 3 and 7 months of age. Moreover, Kaufman, Gilmore, and Johnson (2006) found that under some stimulus conditions even young infants could adjust the frame of reference they used to plan eye-movements. Similarly, we found in Experiment 3 that when infants were provided more salient stable frames of reference, 6-month-old infants could store the location of an individual item. Together, these studies delineate how the use of reference frames develops and how it depends, in part, on contextual support.

VSTM for configuration versus locations in multiple item arrays

In addition to these developmental changes, our data suggest that under some circumstances infants encode the overall configuration of these arrays, rather than the locations of the individual items that comprise that configuration. This conclusion is based on the idea that a set of three locations can be encoded by storing a single triangular configuration in the object VSTM system. Infants then detect changes in the shape of this triangle when one of the three locations changes. This hypothesis is quite plausible given the studies described previously, which have shown that adults spontaneously encode configural information even

when it is deleterious for performance. Moreover, even though a typical adult has approximately three VSTM “slots” (Rouder, Morey, Cowan, C. E., & Pratte, 2008; Zhang & Luck, 2008), it is possible to store multiple geometric objects in VSTM (Alvarez & Cavanagh, 2004; Wheeler & Treisman, 2002), even though multiple bits of spatial information define each object (e.g., the relative locations of the vertices of each object). Thus, an infant with only one slot could presumably store a triangular configuration in this slot and use this single shape representation to detect location changes at set size 3. In contrast, it does not appear to be possible to store multiple colors in a single slot (Xu, 2002a, 2002b), which explains why 4- and 6-month-old infants do not show a significant preference at set size 3 for color changes. Thus, this highly plausible proposal can explain why 6-month-olds exhibit a significant change preference at set size 3 for location changes but not for color changes.

Experiment 2 tested this hypothesis by asking whether infants could detect changes at set size 3 when all three items moved together, preserving the configuration. Although this involved a change in all three locations, 6-month-old infants failed to exhibit a significant preference for the changing stream, but 8-month-old infants exhibited a significant preference (and a significantly greater preference than the 6-month-old infants). Moreover, 6-month-old infants’ detection of a change at set size 3 was significantly impaired by presenting the arrays on a visible grid that was designed to interfere with the perception of the overall configuration. This provides direct evidence that the 6-month-old infants can detect configural changes but not nonconfigural changes.

The question remains whether older infants represent the individual item locations at set size 3 or represent the configuration. This is a difficult question to address given that adults encode both absolute location of individual items and configural information depending on the context (Jiang et al., 2000; Jiang & Song, 2005). Thus, evidence that older infants apparently processed the configuration cannot rule out the possibility that they encoded the individual items as well or in other contexts. However, because infants responded to the changes at set size 2, we do have evidence that they responded to changes in individual locations in multiple item arrays—there is little configural information to encode in these arrays, and therefore sensitivity to changes at set size 2 suggests that infants have encoded multiple individual locations. In addition, infants 7.5 months and older are sensitive to changes in features of the individual items, such as the binding between the color and location and the color of each individual items (Oakes et al., 2009; Oakes et al., 2006; Ross-Sheehy et al., 2003). Thus, even if these older infants do encode the configuration or spatial layout of the items in multiple arrays in some contexts, unlike infants 6 months and younger, they clearly encode the features of the individual items in those arrays in some contexts. A question to be addressed in future research is how older infants, like adults, balance encoding the configuration and the features of the individual items.

Conclusions

In summary, the present work adds to previous findings about infants’ VSTM for color, providing a more complete characterization of infants’ VSTM. In general, these results are consistent with substantial developmental changes during the first year that allow infants to overcome two limitations in their ability to represent information in VSTM: the ability to maintain multiple independent representations in VSTM and the ability to represent location in relatively abstract, environment-centered reference frames. We have previously proposed that the ability to maintain multiple independent representations in VSTM depends on circuitry within the intraparietal sulcus (Oakes et al., 2009; Oakes et al., 2006), and this is the same general region of posterior parietal region that appears to be responsible for computing transformations across reference frames (Bonda, Petrides, Frey, & Evans, 1995; Vallar et al., 1999). Thus, it is possible that both of these abilities develop over the same

time period—between 6 and 8 months—because they are implemented in the same cortical circuitry. This is an intriguing possibility that awaits future test.

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Figure 1.
Schematic depiction of the stimulus streams in Experiment 1.

Figure 2.

Mean *change preference* scores at each set size for infants in Experiments 1A, 1B, and 3. Error bars represent 95% confidence intervals. Means significantly different from chance are indicated by *, $p < .05$; **, $p < .01$.

Figure 3.
Schematic depiction of the stimulus streams in Experiment 2.

Figure 4.

Mean *change preference* scores for the 6- and 8-month-old infants in Experiment 3. Error bars represent 95% confidence intervals. Means significantly different from chance are indicated by **, $p < .01$.

Figure 5.
Schematic depiction of the stimulus streams in Experiment 3.

Table 1Mean total looking times (and *SD*) in seconds

	Age	<i>N</i>	Set Size		
			One	Two	Three
Experiment 1A	12 months	24	9.49 (3.38)	10.26 (3.57)	11.43 (3.73)
Experiment 1B	8 months	38	10.57 (3.51)	11.00 (3.53)	10.95 (3.75)
Experiment 1B	6 months	38	10.16 (3.48)	10.73 (3.18)	11.16 (3.68)
Experiment 2	8 months	32	---	---	12.88 (2.09)
Experiment 2	6 months	32	---	---	12.58 (3.10)
Experiment 3	6 months	35	11.89 (2.60)	11.94 (2.97)	12.87 (3.03)