

Infants Get Five Stars on Iconic Memory Tests: A Partial-Report Test of 6-Month-Old Infants' Iconic Memory Capacity

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By the late 19th century, tests of adults' short-term visual memory—how much one retains from a briefly presented display—had acquired a familiar character: An alphanumeric array was presented and then removed, and participants were asked to report the items they had seen (Wundt, 1912). These whole-report tests revealed memory capacities of three to four items (Cattell, 1886; Sperling, 1960). However, participants often felt that they had seen more items than they had described, but that they had forgotten those items before making their report. A crucial innovation was the partial report, in which researchers cued participants to sample from their memory (e.g., a high-pitched tone might cue a report of the middle of three rows of letters; Sperling, 1960). If the cues occurred after offset of the displays (*postcues*) and the sampled subsets were random, then accurate reports meant that all the presented items had been stored. This clever methodological change exposed a new early, high-capacity (about nine items), and fast-decaying (half-life of about 200 ms) memory system, dubbed *iconic memory* (Neisser, 1967). In a sense, the study of infants' visual memory is still rooted in the conventions of the 19th century: No one has yet asked infants for a partial report.

Research on infants' visual memory has a similarly long history (e.g., Fagan, 1970; Fantz, 1964; Hunter, 1917; for reviews, see Nelson, 1995; Rose, Feldman, & Jankowski, 2004), and much work has been done on infants' short-term memory (e.g., recency and primacy effects; Cornell & Bergstrom, 1983; Olson, 1979). However, short-term capacity has been studied only recently, and iconic memory not at all. Further, the studies on short-term capacity have revealed a striking limitation: Young infants' short-term memory capacity seems limited to a single object (see Ross-Sheehy, Oakes, & Luck, 2003, for evidence from visual short-term memory with a retention interval of less than 300 ms, and Pelphrey et al., 2004, and Kaldy & Leslie, 2005, for evidence from visual working memory). Thus, although 6-month-olds have sufficiently well-developed visual acuity to distinguish arguably dozens of objects in a single fixation (Teller, 1997), they appear to have short-term memory for only one object—a curiously inimical constraint unless this object is very well

chosen (e.g., by virtue of high salience, task relevance, or cuing). We argue here that iconic memory is the buffer holding the choices, and we report an experiment that estimated its capacity.

Method

Sixty-two healthy, full-term, 6-month-old infants (ages 183.4 ± 20.6 days; 30 males, 32 females) each were tested in two 18-trial blocks. All the trials for a given infant involved the same set size (2, 4, 6, 8, or 10 colored stars), and approximately 12 participants were tested with each set size. For comparison, 5 adults (ages 22–39 years; 2 males, 3 females) were run (adults were tested on all set sizes).

Trials began with an attention-grabbing animation, followed by a fixation cross and then the presentation of a display of colored stars (Fig. 1). The stars subtended 3.0° of visual angle and were distributed around a virtual annulus ($r = 6.5^\circ$) centered on a fixation cross. After 1 s, a random, neighboring pair of stars disappeared. When the stars reappeared (500 ms later), one had a new color, but the other was unchanged. The display remained visible for 2.5 s, during which we monitored gaze with a Tobii T120 eye tracker (Tobii Technology, Stockholm, Sweden). (Adults were instructed to fixate the changed object.) All visual events were accompanied by sound effects.

The sudden offset itself served as the partial-report postcue, triggering selective readout of information about the cued pair from fragile iconic memory into more durable short-term storage (Coltheart, 1980; Gegenfurtner & Sperling, 1993; Graziano & Sigman, 2008), where it would be retained until report (Chun & Potter, 1995). Beyond requiring neither interpretation nor presentation of new visual elements, this kind of cue has the advantage of being a zero-latency postcue, minimizing the decay of the information (as compared with more

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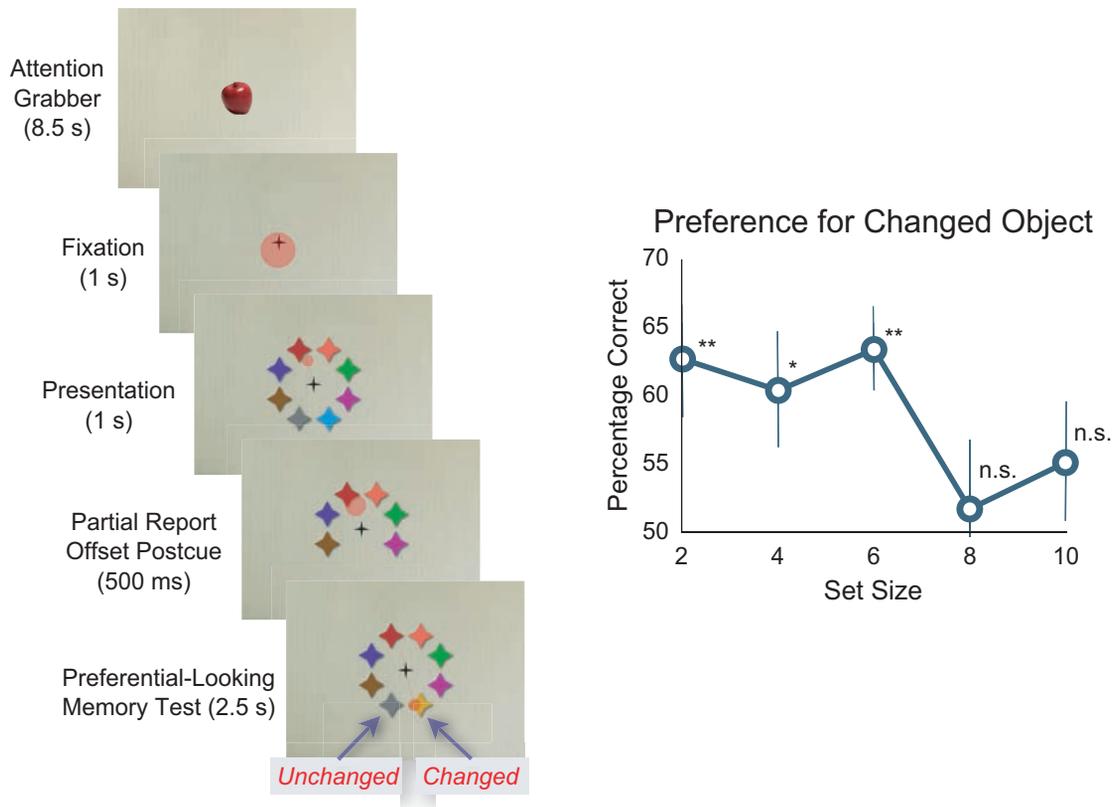



Fig. 1. Trial sequence and infants' experimental results. As shown in the left panel, trials began with an attention-grabbing animation and a fixation cross. A set of 2, 4, 6, 8, or 10 colored stars was then displayed. The disappearance of two neighboring stars served as the postcue; when the two stars reappeared after 500 ms, one was changed in color. Memory was tested by preferential looking, and a typical gaze trace from a "correct" trial is illustrated here by the transparent red disk. The graph shows average percentage correct (preference for the novel color) for each set size. Asterisks indicate performance significantly better than chance (* $p < .05$, ** $p < .01$).

delayed postcues) from iconic memory. (For more information regarding method, see the Methods portion of the Supplemental Material available online.)

The reappearance of the missing stars prompted "report" by exploiting infants' novelty preference: Infants would prefer—and fixate longer—the changed object if and only if they noted the difference from its remembered color. Thus, a trial was coded as correct if the changed object was fixated longer than the unchanged object. This coding facilitated comparison between infant and adult data. (If participants did not fixate at least one of the two cued objects, or if they were already fixating a cued object's location when it reappeared, the trial was discarded.) We tested memory for color instead of using traditional alphanumeric stimuli to sidestep concerns about the contribution of figural afterimages (Coltheart, 1980; see Methods in the Supplementary Material).

Results

We examined the pattern of performance using a generalized estimating equations method to conduct binary logistic regression analyses. In these analyses, trial result (correct/incorrect)

was the dependent variable, set size the independent variable, and participant the subject variable. For infants, the main effect of set size was highly significant, Wald $\chi^2(5, N = 588) = 28.758, p < .001$. Performance for set sizes 2, 4, and 6 was significantly better than chance, Wald $\chi^2(1, N = 123) = 8.718, p = .003$; Wald $\chi^2(1, N = 131) = 5.558, p = .018$; and Wald $\chi^2(1, N = 128) = 13.053, p < .001$, respectively; performance for set sizes 8 and 10 was not, Wald $\chi^2(1, N = 128) = 0.090, p = .764$, and Wald $\chi^2(1, N = 78) = 1.339, p = .247$, respectively. For adults, all Wald χ^2 values were greater than 26, and all p values were significant ($p < .001$).

When set size is below memory capacity, performance should be maximal, but as set size exceeds capacity, performance should drop systematically. To quantify capacity, we calculated Cowan's (2001) K : $K = (2 \times \text{percentage correct} - 1) \times (\text{set size})$. Unlike adults, infants cannot be expected to exhibit performance asymptotes at 100% correct; indeed, infants' asymptotes were around 60 to 65%, a level consistent with similar measures of infants' color memory (Ross-Sheehy et al., 2003). This result likely reflects infants' lack of task knowledge and losses during retention in short-term memory. For infants, we estimated both asymptotic performance and

K by finding the values that minimized the sum of squared errors. The resulting estimates were 61.2% correct for asymptotic performance and a capacity, K , of 5. For adults, K was 5.75. Data fits using these estimates for both infants and adults are shown in Figure S1 in the Supplemental Material available online.

Discussion

Our results show a five-object iconic memory capacity in 6-month-olds. That this value nearly matches adults' six-object capacity points to particularly rapid development—outpacing even that of visual short-term memory (Oakes, Ross-Sheehy, & Luck, 2006; Ross-Sheehy et al., 2003). Recent functional magnetic resonance imaging studies in adults suggest that iconic memory reflects persistent activation in higher-order visual areas such as the occipito-temporal cortex, particularly the lateral-occipital complex (LOC; Ruff, Kristjánsson, & Driver, 2007; Wong, Aldcroft, Large, Culham, & Vilis, 2009). Indeed, the occipital lobe is the part of the cortex that matures earliest (Chugani, 1988; Huttenlocher, 1990), and the area corresponding to LOC in adults has been shown to be active at 6.5 months of age (Wilcox et al., 2009).

In short, early development strikes us as adaptive. Infants' iconic memory—just like adults'—is an essential faculty to a protean visual system faced with too much information and limited resources. It is a high-capacity but short-lived store from which critical information is selectively rescued.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Supplemental Material

Additional supporting information may be found at <http://pss.sagepub.com/content/by/supplemental-data>

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