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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' shortterm visual memory—how much one retains from a briefly presented display—had acquired a familiar character: An alphanumeric array was presented, removed, and participants were asked to report the items (Wundt, 1912). These 'whole report' tests revealed capacities of 3-4 items (Cattell, 1886; Sperling, 1960). However, participants often felt they had seen more items, but forgotten them before report. A crucial innovation was to ask for just a 'partial report', cuing participants to *sample* from their memory (e.g. a high-pitched tone might cue report of the middle of three rows of letters) (Sperling, 1960). If the cue occurs after display offset (a 'post-cue') and the sampled subsets are random, then accurate reports mean all the presented items had been stored. This clever methodological change exposed a new—early, high-capacity (~9 items), and fast-decaying (~200 ms half-life)—memory system dubbed 'iconic memory' (Neisser, 1967). In this sense, then, 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.

This leaves a conspicuous gap in our understanding of visual memory development. Research on infants' visual memory has a similarly long history (e.g. Hunter, 1917; Fantz, 1964; Fagan, 1970; for reviews see Nelson, 1995; Rose, Feldman & Jankowski, 2004). And while there has been ample work on infants' short-term memory, for example recency/primacy effects (Olson, 1979; Cornell & Bergstrom, 1983), short-term capacity has been studied only recently (and iconic memory not at all). These studies though 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, <300 ms retention interval, memory; Pelphrey et al., 2004 and Kaldy & Leslie, 2005 for evidence from visual working memory). 6-month-olds, then, have sufficiently well-developed visual acuity to distinguish arguably dozens of objects in a single fixation (Teller, 1997), but short-term memory for only *one*—a curiously inimical constraint unless this object were very well chosen (e.g. by virtue of high salience, task relevance, or cueing). We argue here that iconic memory is the buffer holding the choices.

Methods

62 healthy, full-term, 6-month-old (183.4 ± 20.6 days) infants (32 females) were run in two 18-trial blocks of the same set size (2, 4, 6, 8, or 10 colored stars); ~12 participants per set

size. For comparison, five adults (22-39 years, three females) were run (adults were run in all set sizes).

Trials began with an attention-grabbing animation, followed by display onset (Figure 1). After one second, a random, neighboring pair of objects disappeared. The sudden offset itself served as the partial-report post-cue, 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 is retained until report (Chun & Potter, 1995).

Beyond not requiring interpretation nor presentation of new visual elements, this cue has the advantage of being a zero-latency post-cue (see Supplementary Material for more on methods).

After the 500 ms retention interval, the objects reappeared. One, *Changed*, reappeared with a new color while the other, *Unchanged*, retained its original color. The reappearance prompted ‘report’ by exploiting infants’ novelty preference: Infants should prefer—fixate longer—the Changed object if and only if they note the difference from its remembered color (we tested memory for color instead of using traditional alphanumeric stimuli to sidestep concerns about the contribution of figural after images (Coltheart, 1980); see Supplementary Material).

The display remained visible for 2.5 seconds, during which we monitored infants’ (or adults’) gaze (adults were instructed to fixate the Changed object). Trials where the Changed object was preferred were coded as correct. This coding facilitates comparison between infant and adult data.

Results

We used a Generalized Estimating Equations method to conduct binary logistic regression analyses using the trial-by-trial correct/incorrect measure as the dependent variable, set size as the independent variable, and participant as the subject variable. For infants, the main effect of set size was highly significant (Wald $\chi^2_{5,588} = 28.758$, $P < 0.001$). Results for set sizes 2, 4 and 6 were significantly different from chance (Wald $\chi^2_{1,123} = 8.718$, $P = 0.003$; Wald $\chi^2_{1,131} = 5.558$, $P = 0.018$; Wald $\chi^2_{1,128} = 13.053$, $P < 0.001$, respectively), while for set sizes 8 and 10 they were not (Wald $\chi^2_{1,128} = 0.090$, $P = 0.764$; Wald $\chi^2_{1,78} = 1.339$, $P = 0.247$, respectively). For adults, all Wald χ^2 values were >26 , and P values significant ($P < 0.001$).

When set size is below memory capacity, performance should be maximal, but as it exceeds capacity, it should drop systematically. To quantify, we applied Cowan’s K (Cowan, 2001) to percent correct data: $K = (2 \times \text{percent correct} - 1) \times (\text{set size})$. Unlike adults, infant performance asymptotes not at 100% correct, but instead around 60-65%, consistent with similar measures of infants’ color memory (Ross-Sheehy et al., 2003), likely reflecting infants’ lack of task knowledge and losses during retention in short-term memory. For infant data then, we estimated both asymptotic performance and K . The values that minimize the

sum of squared errors are 61.2% correct and a capacity, K , of 5. For adults, $K = 5.75$ (Supplementary Figure S1).

Discussion

Our results show a five-object iconic memory capacity in 6-month-olds. That this nearly matches adults' six-object capacity points to particularly rapid development—outpacing even that of visual short-term memory (Ross-Sheehy et al., 2003; Oakes, Ross-Sheehy, & Luck, 2006). Recent fMRI studies in adults suggest that iconic memory reflects persistent activation in higher-order visual areas such as occipito-temporal cortex, particularly lateral-occipital complex (LOC) (Ruff, Kristjánsson, & Driver, 2007; Wong, Aldcroft, Large, Culham, & Vilis, 2009). And indeed, the occipital lobe is the earliest maturing part of the cortex (Chugani, 1988; Huttenlocher, 1990), and the area corresponding to LOC in adults has been shown active at 6.5 months of age (Wilcox et al., 2009). Early development strikes us as adaptive. Just as for adults, infants' iconic memory is an essential faculty to a protean visual system faced with too much information and limited resources: A high-capacity but short-lived store from which critical information is selectively rescued.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.

Left panel. Trials began with an attention-grabber (animated apple and fixation cross). Depending on block, a set of 2, 4, 6, 8 or 10 objects was then displayed. Objects subtended 3.0° of visual angle and were distributed around a virtual annulus ($r = 6.5^\circ$) centered on a fixation cross. All visual events were accompanied by sound effects. Gaze was monitored with a Tobii T120 eye tracker during the memory test phase (a typical gaze trace, from a 'correct' trial, is illustrated here by the transparent red disk). *Right panel.* A trial was coded as correct if the *Changed*, as opposed to *Unchanged*, object was fixated longer; average performance for each set size is shown here (if participants did not fixate at least one of the two cued objects, or were already fixating a cued object's location at reappearance, the trial was discarded). Results for set sizes 2, 4 and 6 were significantly better than chance performance (50% correct), while 8 and 10 were not.