

Fast decay of iconic memory in observers with mild cognitive impairments

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In a previous clinical report, unusually fast decay of iconic memory was obtained from a subject who later developed Alzheimer's disease. By using the partial-report paradigm, iconic memory (a form of visual sensory memory) in a group of observers with mild cognitive impairments (MCI) was characterized and compared with that of young college-age adults and older controls. Relatively long stimulus exposures were used for all three groups to ensure that older observers could perceive the stimuli. A set of conventional neuropsychological tests assessed cognitive functions of the MCI and older control groups. We found that iconic memory decayed much faster for observers with MCI than for normal controls, old or young, although the two groups of older observers performed at equivalent levels in precue tests (assay of visibility) and tests cued at long delays (assay of short-term memory). The result suggests that fast decay of iconic memory might be a general characteristic of observers with MCI who are at much higher than average risk of developing Alzheimer's disease later in life.

sensory memory duration | Alzheimer's disease | neuropsychological test

Sensory memory refers to the literal, modality-specific neural representation of sensory stimuli in the human brain (1). Much like registers in a computer, sensory memory provides the initial copy ("buffer") of external stimulation to human sense organs that can be processed by subsequent stages of perception and cognition. In the visual modality, iconic memory (1) was first demonstrated by the partial-report superiority effect (2). After a brief presentation of a 3×3 or 3×4 matrix of letters, observers often can report all of the letters in any cued row if the cue occurs immediately after the visual presentation ("partial report"), even though they can report only four to five letters when asked to recall all of the items in the display ("whole report"). Because all rows of the letter matrix are cued with equal probability, reporting all of the items in a randomly cued row implies that the observer has access to all of the items in the matrix at the termination of the display. The partial-report superiority effect (performance advantage of partial-report over whole-report) suggests that a fast-decaying iconic memory exists that can initially hold at least 9–12 items. Numerous studies have established that iconic memory has a large capacity, decays rapidly, and is destroyed by poststimulus masking (1–4). Best reflected in the partial-report superiority effect, the duration of iconic memory has been estimated to be ≈ 300 –500 ms for young adult observers.

In his dissertation research on the electrophysiological correlates of iconic memory, Yang (5) attempted to relate the duration of iconic memory to the habituation time constant of the N100 component of visual evoked potentials. Behaviorally, he replicated the typical partial-report superiority decay function in most of his observers, but he was surprised to find that one observer's iconic memory was unusually short (< 50 ms). Several attempts were made to bring this observer's performance to the normal range, including intensive practice and longer stimulus durations. Yet the same result was obtained: the duration of iconic memory was extremely brief for the observer, although he

was able to identify the target item with 75% accuracy (chance, 25%) in partial-report displays with eight items when he was cued to the target location ≈ 200 ms before the display. The observer reported that he was able to see the stimulus but unable to remember the identity of the item at probe.

Yang's study was conducted in 1997. At the time when the study was conducted, Yang's unusual observer was a healthy 58-yr-old individual who appeared to be normal in every aspect and was performing a very high-profile job. Puzzled by the observation, Yang documented this unusual case in his dissertation without further investigation. We learned in the summer of 1999 that the unusual observer in Yang's study could no longer carry out his job duties because of poor memory functions. He was diagnosed subsequently with Alzheimer's disease (AD).

Although the clinical dementia rating (CDR) and measures of other cognitive abilities of the unusual observer in Yang's study are not available, descriptions in Yang's dissertation suggest that the observer might have had only mild cognitive impairments (MCI) at the time of the partial-report experiments. Was Yang's observation an accidental cooccurrence of restricted iconic-memory function and subsequent development of AD? Or, is fast decay of iconic memory a general characteristic of observers at-risk for or in early stages of AD?

Current cognitive theories explain human memory functions in terms of several independent systems that process different types of information by using distinct encoding, storage, and retrieval operations (6–10). Briefly, sensory-memory systems, including iconic memory and echoic memory, register primary sensation from the environment. Important or relevant sensory information is then selected by attention and further processed in short-term or working-memory systems. Last, information enters long-term memory by means of rehearsal and subsequent encoding in short-term memory. It has been shown that AD does not affect these memory systems uniformly, even though the most prevailing clinical symptoms at beginning stages of the disease are related to various memory failures (11, 12). Mild AD patients generally have significant long-term episodic (13–15) and semantic (16–19) memory deficits, as well as deficits in working-memory tasks (20), but they are, at most, only slightly impaired compared with normal controls in auditory and spatial short-term-memory tasks (12). To our knowledge, no systematic study of iconic memory has been carried out in the AD population, perhaps because of the difficulty of applying the partial-report paradigm to the aging population.

Several studies have attempted to use the partial-report paradigm to investigate effects of aging on iconic memory. In one study, Abel (21) used very long (500 ms) stimulus presentations, but the long duration was well outside of the standard methods for measurements of iconic memory among younger adults (22). By using typical stimulus-exposure durations (50

Abbreviations: AD, Alzheimer's disease; MCI, mild cognitive impairments; CDR, clinical dementia rating; SOA, target-cue onset asynchrony; HSD, honest significant difference.

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ms), Salthouse (23) did not obtain much of a partial-report superiority effect (8% and 3%) with older subjects. He attributed the failure to their inability to process short stimuli. In another attempt, Walsh and Thompson (reviewed in ref. 24) used very short displays, and they found that 80% of the older subjects could not perform the task. By using longer visual-stimulus presentations, Gilmore *et al.* (25) demonstrated that it was possible to measure partial-report superiority effects with older subjects. Moreover, the duration of iconic memory was similar for the younger and older observers, even though very different stimulus durations were used (30 and 200 ms for the younger and older observers, respectively). Gilmore *et al.* attributed the different stimulus-exposure requirements to differences in visual acuity between the two groups, not differences in iconic memory. However, several studies have documented that the duration of iconic memory depends critically on stimulus exposure time (3); to remove stimulus exposure time as a confound, it is more preferable to study effects of aging on iconic memory by using the same stimulus parameters across different age groups.

In this study, we characterized iconic memory by using the partial-report paradigm with the same stimulus parameters and experimental procedures in three groups of observers: college-age young adults, observers with MCI, and older controls. To ensure that older observers could perceive the stimuli, stimuli were presented with relatively long exposure (105 ms). Also, a set of conventional neuropsychological tests assessed cognitive functions of the MCI and older control groups. We found that iconic memory decayed much faster in observers with MCI than normal observers, old or young. The result suggests that fast decay of iconic memory might be a general characteristic of observers with MCI.

Materials and Methods

Observers. Three groups of observers were tested. The first group of observers consisted of two male and nine female volunteers, with an average age of 84.8 yr (range, 74–98; SD, 7.2), who were referred by the University of Southern California Alzheimer's Disease Research Center. All of them were diagnosed by the Alzheimer's Disease Research Center as having a CDR of 0.5. By using a questionnaire administered by interviewers through interviews of the observer and a reliable informant or collateral source (e.g., a family member), CDR rated observer-impairment levels in the following six categories of cognitive functions: memory, orientation, judgment, community affairs, home and hobbies, and personal care. A five-point scale is used for each category in CDR, ranging from 0 for normal, 0.5 for questionable impairment, 1 for mild impairment, 2 for moderate impairment, and 3 for severe impairment. A person with a CDR of 0.5 is characterized as having consistent slight forgetfulness, partial recollection of events, and "benign" forgetfulness; being fully oriented except for slight difficulty with time relationships; having slight impairment in solving problems, similarities, and differences, as well as in community activities, home-life, hobbies, and intellectual interests; and being fully capable of self-care. Observers with CDR of 0.5 are considered as having MCI.

The second group of observers consisted of six male and 10 female older people recruited from the communities of Long Beach, CA, and La Jolla, CA, with an average age of 81.9 yr (range, 65–99; SD, 9.7). All of the observers in this group had CDR of 0. They were paid an honorarium for their participation in the investigation.

The third group consisted of five male and 18 female undergraduate students from Loyola Marymount University (Los Angeles, CA), with an average age of 20.4 yr (range, 18–27; SD, 2.2). These students volunteered to participate in the experiment for class credit.

All of the observers reported normal or corrected-to-normal

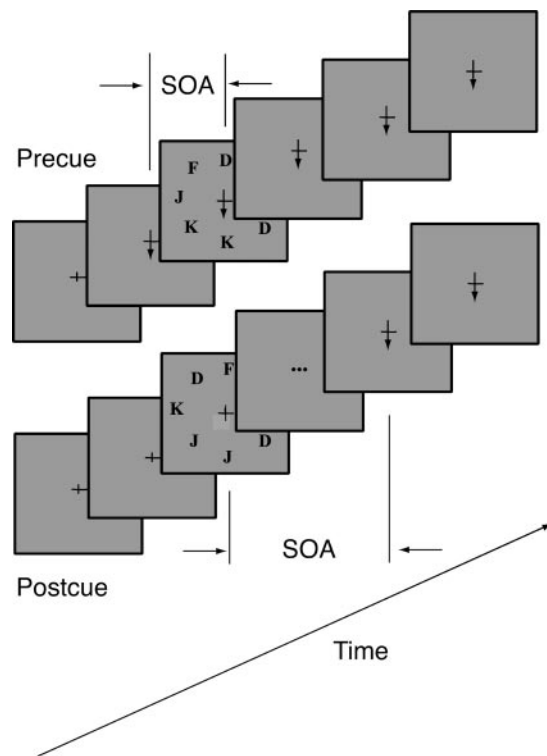


Fig. 1. Display sequence in the precue and postcue (partial-report) conditions.

vision. They all provided informed consent and were debriefed fully after testing.

Neuropsychological Tests. A range of cognitive functions of all of the older observers was examined by using a subset of the tests from the standard neuropsychological test battery routinely administered in the Alzheimer's Disease Research Center. The tests included digit-span forward and digit-span backward tests for short-term memory, a digit-ordering test for working memory (26), the California verbal learning test for short-term memory (27), a verbal-fluency test for linguistic access (28), a mental rotation test for executive function, the Boston naming task for ability to name object from line drawings (29), and trail-making test for visual-conceptual and visual-motor tracking, including motor speed and attention functions.

Visual Stimuli. Visual stimuli were presented on an iMac computer controlled by a MATLAB program based on PSYCHTOOLBOX (30), and they were viewed by the observers at ≈ 88 cm in a darkened room. In each trial, eight letters appeared simultaneously for 105 ms on the screen. Each $1.29^\circ \times 1.29^\circ$ letter was chosen randomly and independently from the set ["D," "F," "J," and "K"] and shown in uppercase letters with 0.11° -wide strokes at 0 cd/m² on a gray background (24.9 cd/m²). The eight letters were arranged on a circle (radius, 3.50°) around the fixation point (Fig. 1).

Procedure. For the two groups of older observers, the neuropsychological test battery lasted < 1 h, and it was administered on a separate day before the partial-report procedure.

Each partial-report trial started with a fixation cross at the center of the display. After 400 ms, eight letters appeared simultaneously for 105 ms. Observers were cued to report one of the letters with an arrow in the center of the display pointing to the target location. Eight target-cue onset asynchronies (SOA)

Table 3. Mean parameter performance for three groups of subjects

Parameter	Young (<i>n</i> = 25)	Older normal (<i>n</i> = 16)	MCI (<i>n</i> = 11)
a_0	1.06 ± 0.33 ^a	0.85 ± 0.23 ^b	0.75 ± 0.27 ^b
a_1	2.81 ± 0.39 ^a	1.78 ± 0.59 ^b	2.31 ± .98 ^c
τ	0.34 ± 0.16 ^a	0.30 ± 0.19 ^a	0.073 ± 0.06 ^b

Means in the same row with different subscripted letters differ significantly, as determined by Tukey's HSD test ($P < 0.05$).

than the older groups ($P < 0.05$). The result suggests that the two older groups were approximately equally able to transfer items into short-term memory without the benefit of cuing.

Time Course of Iconic Memory. The following exponential-decay function was fit to the partial-report data to characterize the temporal properties of iconic memory (2):

$$d'(\text{SOA}) = a_0 + a_1 e^{-\text{SOA}/\tau}. \quad [1]$$

In this three-parameter function, a_1 is the fast-decaying sensitivity that reflects the initial visual availability of stimulus information, τ is the time constant of the fast-decay sensitivity that represents the duration of iconic memory, and a_0 is the sensitivity at long delays that reflects the amount of information transferred into short-term memory without the benefit of cuing (2–4). The best-fitting exponential decay functions for the three groups are shown as smooth curves in Fig. 2.

Table 3 summarizes the best-fitting parameters for each of the three groups. A one-way ANOVA was conducted to compare each of the three best-fitting model parameters among the three groups. All three parameters varied significantly across the three groups [a_0 , $F(2, 47) = 5.00$ and $P < 0.01$; a_1 , $F(2, 47) = 12.87$ and $P < 0.001$; τ , $F(2, 47) = 11.71$ and $P < 0.001$]. Tukey's HSD post hoc tests indicated that (i) there was no significant difference between the MCI and the older control groups ($P > 0.25$) in terms of a_0 , although the younger group was significantly better than both the older normal ($P < 0.05$) and MCI ($P < 0.01$) groups; (ii) all three groups are significantly different in terms of a_1 ($P < 0.05$); and (iii) the MCI group had significantly shorter iconic memory than the young ($P < 0.001$) and older normal ($P < 0.001$) groups, even though the duration of iconic memory was not significantly different between latter two groups ($P > 0.25$). Compared with the older control group, the MCI group showed a significant deficiency in iconic memory duration (τ), defined as the time constant of the exponential decay of iconic memory (Eq. 1); i.e., after a delay of τ , d' in partial report reduces to 37% of that of simultaneous cueing. Averaged across observers, the mean iconic memory duration for the MCI group was ≈ 0.07 s, less than one-fourth of that of the young (0.34 s) and

the older normal (0.30 s) groups. Box plots of the best-fitting parameters for individual observers are shown in Fig. 3.

Regression Analyses. Regression analyses were performed to study the potential residual influences of age in comparing the observers with MCI and the older controls. In the first set of analyses, both groups of the older observers were included. The first two rows of Table 4 give correlations between all of the test scores and CDR [which was either 0 (for normal controls) or 0.5 (for observers with MCI)] and between all of the test scores and age, respectively. Partial correlations between the test scores and CDR were computed by using both CDR and age as predictors in a regression analysis. With age factored out, the partial correlations between the test scores and CDR gauge the amount of variance accounted for by CDR alone (Table 4, third row). The partial correlations are significant for California verbal learning, digit-span forward, digit ordering, mental rotation test, verbal-fluency test, Boston naming task, but not for digit-span backward and trail-making tests. Most important, the partial correlation between iconic memory duration (τ) and CDR remained significant after age was factored out. We plot iconic memory duration (τ) as a function of age for the two older groups of observers in Fig. 4.

Summary and Discussion

In this study, we found that (i) consistent with their interview-based CDR rating, observers with MCI performed significantly worse in a number of neuropsychological tests including California verbal learning, digit-span forward, digit-span backward, digit ordering, mental rotation test, verbal-fluency test, and Boston naming task, even after age was factored out; (ii) both the MCI and the older control groups performed $>90\%$ correct in the precuing and simultaneous-cuing conditions with no significant difference, indicating approximately equal visual and task abilities. There was also no significant performance difference between the two groups at the longest target-cue SOAs, indicating approximately equal ability in transferring items to short-term memory; and (iii) the decay of the iconic trace was much faster for the observers with MCI (0.07 s versus 0.30 s). This difference between the MCI and the older normal control groups remained significant after age was statistically controlled. The combined results suggest that the two older groups of observers are approximately equivalent in terms of visual letter recognition and the ability to transfer items into short-term memory, but the MCI group has significantly shorter iconic memory.

Studies have shown that visual acuity and spatial frequency contrast sensitivity decline in similar ways in aging and AD (e.g., ref. 32). Many studies have found it difficult or impossible for old observers to perform the partial-report procedure (22–25). By using displays with relatively long durations, we made it possible

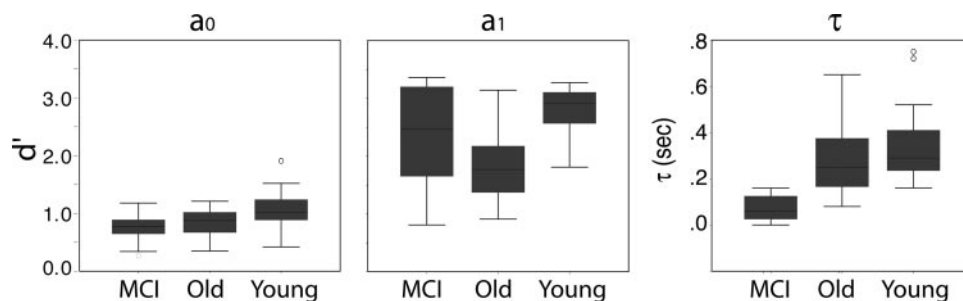


Fig. 3. Box plots of the best-fitting parameters for the three groups of observers. The plots are based on the median, quartiles, and extreme values. The box represents the interquartile range, which contains 50% of the values. Whiskers extend from the box to the highest and lowest values, excluding outliers. A line across the box indicates the median.

ther work is required to conclude that fast decay of iconic memory is a possible precursor for AD; tracking subsequent AD outcomes will be required. However, observers with MCI are much more likely to develop AD later in life. Although figures vary among reports, the average conversion rate from MCI to AD is 12% per yr; in contrast, the conversion rate to MCI or AD in healthy old controls is $\approx 1\text{--}2\%$ per yr (51, 52). In fact, $>80\%$ of patients with MCI develop AD within 10 yr (53). The standard neuropsychological tests that are commonly used in the diagnosis of AD are relatively insensitive to cognitive changes in the early stages of the disease. An observation of impaired iconic memory without deficits in perception or short-term memory may add important information to the evaluation. In nonclinical settings,

AD may be incorrectly diagnosed clinically in 25–40% of cases (54, 55). There has been renewed interest in developing more sensitive tests. Is an abnormally short iconic-memory lifetime a reliable early sign of AD? The results of the current study are highly suggestive. A careful longitudinal study of observers with MCI and their definitive AD diagnosis is necessary to fully assess the potential clinical value of using the duration of iconic memory in predicting AD.

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