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Preservation of Episodic Visual Recognition Memory in Aging

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*Visual episodic recognition memory was assessed in young (mean age
22.5 years) and older (mean age 74.1 years) adults. To isolate purely
visual memory, recognition was tested with sets of briefly-presented com-
pound sinusoidal gratings, which minimized age-related differences in
visual processing, and resisted verbal encoding. Recognition was mea-
sured after delays of 1, 2 or 4 seconds. Overall, neither accuracy of rec-
ognition nor speed of response differed significantly between groups, or
with probe delay, which strengthens recent claims that visual memory
tends to be spared during the course of normal aging.*

Studies with rehearsable verbal stimuli such as letters, words, or sentences
suggest that normal adult aging is associated with diminished short-term
memory (e.g., Kausler, 1994; Wingfield & Stine-Morrow, 2000; Wingfield
& Kahana, 2002). However, recent research raises questions about
whether this association extends to memory for other kinds of test mate-
rials. For example, using a match-to-sample procedure, McIntosh et al.
(1999) found that younger and older observers had virtually identical
short-term memory for a single, briefly presented, vertical sinusoidal

grating. Functional neuroimaging studies of the participants' brains led McIntosh et al. to speculate that a compensatory reorganization of neural circuits helped to preserve visual memory in older participants. Subsequently, with a slightly modified test procedure, Bennett, Sekuler, McIntosh, and Della-Maggiore (2001) confirmed the absence of age-related differences in short-term memory for sinusoidal gratings. Such stimuli can be valuable probes of memory because their representations in early vision are known and, because they resist naming or other symbolic encoding, they promote reliance on a form of short-term memory that uses purely visual information (Phillips & Christie, 1977; Phillips, 1974; Kahana & Sekuler, 2002).

Given the importance of this finding one should ask whether the simplicity of the task used by McIntosh et al. (1999) and by Bennett et al. (2001) may have masked age-related changes in short-term visual memory. For example, observers in those studies had to encode and retain only one study stimulus on each trial. The temporal durability of memory for a single stimulus, however, does not guarantee comparable durability when several stimuli must be remembered (Hole, 1996). Moreover, observers in the McIntosh et al. and Bennett et al. studies had to encode just a single attribute of each trial's one stimulus, i.e., the stimulus' vertical spatial frequency.

Conjecturing that age-related differences in visual memory might be better revealed by a more challenging task, we devised a task in which, for each stimulus seen, participants had to encode two independent attributes. We adapted Sternberg's visual recognition paradigm to study episodic recognition memory for two separate, two-dimensional sinusoidal gratings (Kahana & Sekuler, 2002; Zhou, Kahana, & Sekuler, 2004). Our stimuli and procedures were patterned after ones that Kahana and Sekuler used with young adults. Note that in order to minimize rehearsal, each trial's stimuli were brief and followed one another in rapid succession.

We took two steps to increase task difficulty over that in the studies of McIntosh et al. (1999) and Bennett et al. (2001). First, we presented not one, but two, briefly presented *Study* stimuli per trial. These study items, which varied from trial to trial, were followed by a *Probe* stimulus, which the participant judged as having been or not been among the just-seen study stimuli. Second, our task forced participants to encode not just one, but two separate aspects of each stimulus. Each stimulus was generated by summing one vertically oriented grating, and one horizontally oriented grating. On each trial, the stimuli differed from one another either in vertical spatial frequency (with horizontal spatial frequency held constant), or vice versa. (Examples of both types of trials are shown in Figure 1.) Random variation in the orientation that differentiated one stimulus from another forced participants to encode the spatial frequency information represented in both orientations. For young adults, at least, this requirement was not expected to have much impact: Vincent and Regan (1995) showed that orthogonal orientations in a compound grating
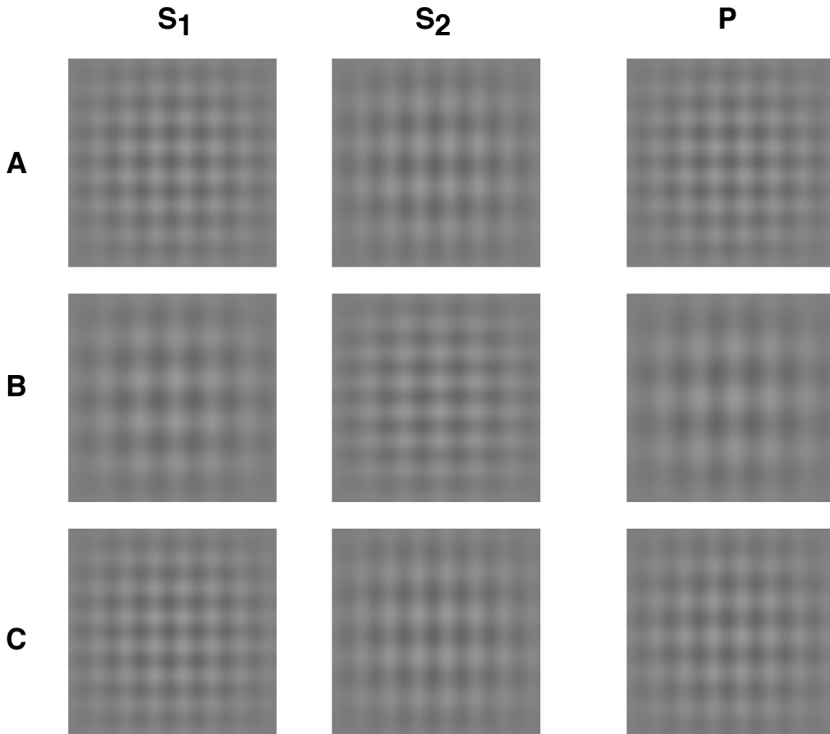
FIGURE 1 Sample stimuli for three trials. In each row, S_1 and S_2 are the study items, P is the probe. *A*, The probe matches S_1; *B*, the probe matches neither of the study items; *C*, The probe's frequency lies midway between that of S_1 and S_2.

could be processed independently of one another, that is, in parallel. Whether the same would hold for older participants is an open question.

We also varied the delay between the study stimuli and the probe, which we call the pre-probe delay. With young participants, delaying the presentation of a probe stimulus for several seconds (Magnussen, Greenlee, Asplund, & Dyrnes, 1990; Kahana & Sekuler, 2002) or longer (Magnussen, Greenlee, Aslaksen, & Kildebo, 2003) has little or no effect on memory for spatial frequency. We were especially interested in the possibility that short-term visual memory's temporal robustness might not hold with older participants. So we measured episodic recognition visual memory for groups of young and older participants with varying delay before presentation of the probe stimulus.

In addition to response accuracy, our data included the response times (RTs) associated with each response. Collecting two dependent measures

afforded converging perspectives on the underlying quality of episodic memory. Moreover, RT can be a more sensitive probe of memory performance than accuracy, especially when accuracy in some or all conditions is high (Kahana & Loftus, 1999). In fact, using stimuli similar to our own, Magnussen, Idas, and Myhre (1998) showed that RTs revealed variations in young participants' recognition memory, even though such variations eluded response accuracy.

METHODS

Participants

Fifteen healthy young adults (aged 19 to 28 years, mean $= 22.5$, $SD = 3.0$) and 15 healthy older adults (aged 64 to 85 years, mean $= 74.1$, $SD = 5.5$) participated in this study for monetary compensation. Of the young participants, nine were male, six female; of older participants, six were male, nine female. All of the participants had post−high school education. The older participants were healthy, community-dwelling volunteers, with good levels of education and verbal ability, and no history of psychiatric disorder. All participants received compensation for their time, and were unaware of the study's purpose.

Participants' acuity and contrast sensitivity were measured. In addition, we used an adaptive psychophysical procedure to measure each participant's spatial frequency discrimination threshold for a sinusoidal gratings. Acuity was measured, for distance, using Landolt C targets; contrast sensitivity was assessed with Pelli-Robson charts (Pelli, Robson, & Wilkins, 1988); frequency discrimination thresholds were measured using an up-down tracking procedure in which participants had to compare the spatial frequencies of two briefly presented gratings (750-ms duration each), which were separated by an interstimulus interval of 400 ms. We did not adjust the stimuli in order to compensate for individual differences in discrimination threshold, as Zhou et al. (2004) did in a study of young participants. However, possible effects of age-related differences in visual encoding were minimized by using only low−spatial frequency test stimuli, which were presented well above detection threshold (Owsley, Sekuler, & Siemsen, 1983).

Procedure

On each trial, a participant saw two study stimuli, S_1 and S_2, each 750 ms in duration, and separated by an interval of 400 ms. Then, after a variable pre-probe delay, a warning tone sounded, and the probe was presented for 750 ms. To compare the rate at which young and

older participants lost information from memory, pre-probe delays of 1, 2, or 4 seconds were used. The mean luminance of the display was 22.4 cd/m^2.

On each trial, one orientation, either horizontal or vertical, was randomly selected to be the *irrelevant* orientation. For the grating component with that irrelevant orientation, spatial frequency was held constant across all the stimuli on that trial. The spatial frequency of dummy orientation was randomized, uniformly ranging from 0.25 to 4.35 cycles/degree. The spatial frequency of the trial's other, *critical* orientation component, was allowed to vary from one stimulus to another. The spatial frequency of the critical component ranged from 0.25 to 6.3 cycles/degree. Within each trial, the critical frequency was randomized under several constraints: the critical components in S_1 and S_2 always differed by 45% (on half the trials, S_1 was higher in frequency than S_2; on half the trials, the situation was reversed); the probe's critical component either matched that of either S_1 or S_2 (illustrated in Figure 1*A*), or differed from them by one of three different amounts. On one third of nonmatch trials, the probe's critical frequency was 45% above the spatial frequency of the higher frequency study item; on another one third of the nommatch trials, the probe's critical frequency was 45% below that of the lower frequency study item. This case is illustrated in Figure 1*B*. On the remaining one third of nonmatch trials, the probe's critical spatial frequency fell midway between the spatial frequencies of S_1 and S_2. This placed the probe's spatial frequency 22.5% away from each the frequency of each study item. This last case is illustrated in Figure 1*C*.

A participant viewed the stimulus display from a distance of 114 cm, head supported by a chin cup and forehead rest. All trials were self-paced. On each trial, a participant used a computer keyboard to signal a judgment of whether the probe had or had not been among the study items.

After each response, one of two tones sounded, providing immediate feedback about response correctness. No instructions were given about the speed with which participants should respond. Trialwise variation in stimulus spatial frequency forced participants to base their judgments on the most recently seen study items; hence the requisite memory can be described as episodic.

Each participant was tested on 288 trials, which were distributed across two 20-min sessions. Trials were equally and randomly distributed between probes that matched or did not match one of that trial's study stimuli. In addition, we randomized and equalized the frequency of the five probe types, the three pre-probe delay times, and the critical orientation (horizontal or vertical).

Screening

Table 1 summarizes the visual screening and frequency discrimination results for each group. Note that on most measures, the two groups were

TABLE 1 Summary of Visual Screening Results

Young participants	
Age	Mean = 22.5 (*SD* = 3.0)
Contrast sensitivity	Mean = 1.88 (*SD* = 0.10)
Visual acuity	Mean = 20/20.7 (*SD* = 7.3)
Discrimination threshold	Mean = 13.8 (*SD* = 2.3)
Older participants	
Age	Mean = 74.1 (*SD* = 5.5)
Contrast sensitivity	Mean = 1.66 (*SD* = 0.13)
Visual acuity	Mean = 20/30.3 (*SD* = 7.1)
Discrimination threshold	Mean = 15.9 (*SD* = 5.6)

remarkably similar. Most importantly, the difference between the two groups' discrimination thresholds was not significant, $t(28) = 1.14$, $p > .30$. The groups' similarity on this visual function is important because it means that perceptual differences between stimuli should be roughly comparable between the two groups of participants (Zhou et al., 2003). As expected from previous reports, the two groups differed significantly on both Pelli-Robson contrast sensitivity and on visual acuity, $t(28) = 3.64$ and $t(28) = 5.26$, respectively, both $p < .001$. Because these measures emphasize high spatial frequency visual responses, and our stimuli were exclusively low frequency and well above detection threshold, these group differences should be inconsequential for recognition performance.

Design and Dependent Variables

The design was a $2 \times 5 \times 3$ mixed factorial with age (young and older adults) as the between-subject factor. Within subject factors were the relative difference between the spatial frequency of probe and study items (45% different from S_1, equal to S_1, midway between S_1 and S_2, or 45% different from S_2), and the pre-probe delay (1, 2, or 4 s). The dependent variables were proportion of correct recognition judgments, and the mean response time associated with correct judgments.

RESULTS

Accuracy

Overall, the two groups did not differ significantly in recognition accuracy. The mean proportion of correct responses was 0.68 (*SEM* = 0.01) for young participants, and 0.66 (*SEM* = 0.01) for older participants,

$F(1, 28) = 3.12, .05 < p < .10$. As Figure 2*A* shows, the pre-probe delay did not significantly affect overall recognition accuracy, $F(2, 56) < 1$. The interaction of pre-probe delay and age, including the small downward trend for older participants seen in Figure 2*A*, also failed to reach statistical significance, $F(2, 56) < 1$.

For a more detailed analysis, we separated overall accuracy according to the relationship between the probe's frequency and the frequencies represented in the study items. As Figure 2*C* shows, response accuracy varied with the spatial frequency relationship between the probe and the study items, $F(4, 112) = 169.56, p < .001$. This effect of the probe's spatial frequency has two noteworthy aspects. First, the effect of frequency did not differ significantly between groups, $F(4, 112) = 1.77$, $p = .15$. Second, accuracy was by far poorest when the probe's frequency fell midway between that of S_1 and S_2. Under this condition, the probe was most easily mistaken for one of the non-matching study items, $F(1, 28) = 363.74, p < .001$, by a Helmert test.

Possible differences between correct recognition of the two study items, S_1 and S_2, were of special interest, because prior studies with similar stimuli produced reliable recency effects (Kahana & Sekuler, 2002; Zhou et al., 2004). As expected, when the probe matched the second study item, S_2, recognition accuracy was significantly higher than when the probe matched the first study item, S_1, 0.79 versus 0.70, $t(29) = 4.40, p < .01$. As Figure 2*E* shows, this recency effect varied with the pre-probe delay, which produced a significant interaction $(F(8, 224) = 3.63, p < .01)$ This interaction arose from a small, but statistically reliable decrease in the recency effect with the pre-probe delay (see Figure 2*E*). This point was confirmed by a trio of paired-sample *t* tests on target trials. These Bonferonni-corrected tests showed that correct recognition of S_1 and S_2 target trials differed significantly at pre-probe delay = 1 and 2 $(t(29) = 4.59$ and 4.31, respectively, both $p < .001)$, not with pre-probe delay = 4 s $(t(29) = 1.34, p > .15)$ Finally, we should note that the three-way interaction involving age, pre-probe delay and the probe frequency was not significant, $F(8, 224) < 1$.

Response Time

To decrease the skew of the RT distributions (Ratcliff, 1993), RTs associated with correct recognition judgments were log-transformed. The mean for each participant and condition was found, and the antilogs of the means, expressed in milliseconds, were used in all statistical analyses. Overall, mean correct response times for young participants was 1093.91 ms *SEM* = 82.52); the mean correct response for older participants was 1371.34 ms $(SEM = 78.72)$, a statistically significant difference, $F(1, 28) = 6.40, p < .02$. As Figure 2*B* suggests, the pre-probe delay did not significantly affect the overall RT, $F(2, 56) < 1$. Note that
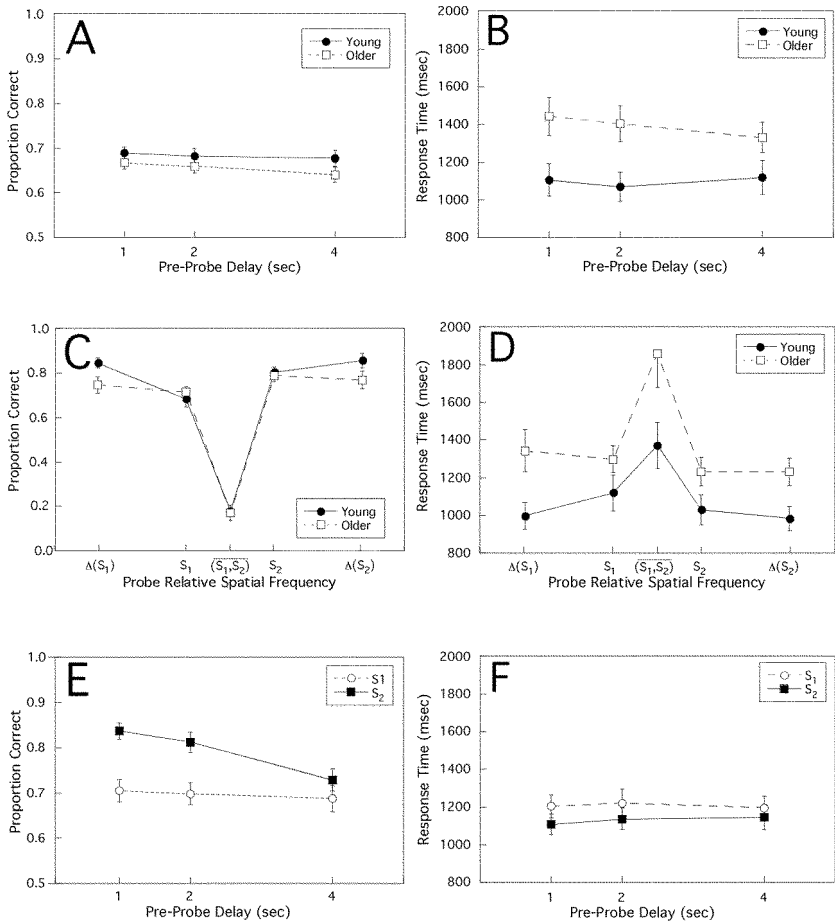
FIGURE 2 *A*, Overall proportion of correct recognition responses as a function of the pre-probe delay. Separate curves represent performance by young and older participants. In this and other panels, $\pm$ one standard error of the mean is shown for each data point. *B*, Overall mean response times associated with correct responses as a function of the pre-probe delay. Results are separated by age group. *C*, Recognition accuracy as a function of the spatial frequency relationship between the probe and study items. Results are separated by age group. *D*, Mean response times associated with correct responses as a function of the spatial frequency relationship between the probe and study items. Results are separated by age group. *E*, Response accuracy as a function of pre-probe delay when the probe matched S_1 (*open symbols*) and when the-probe matched S_2 (*filled symbols*). *F*, Mean response times associated with correct responses as a function of pre-probe delay. Open symbols represent case in which the probe matched S_1, and filled symbols represent case in which the probe matched S_2.

the interaction of the pre-probe delay and age, despite the slight downward trend of young participants' data in Figure 2*B*, also failed to reach statistical significance, $F(2, 56) = 1.69$, $p > .15$.

As we did with response accuracy, to achieve a more detailed analysis of RTs, we separated overall accuracy according to the relationship between the probe's frequency and the frequencies represented in the study items. As Figure 2*D* shows, RT varied significantly with the probe's spatial frequency relative to those of the study items, $F(4, 112) = 20.02$; $p < .001$. In particular, RT tended to be longest when the probe frequency lay between that of S_1 and S_2, $F(1, 28) = 29.55$, $p < .001$, by a Helmert test. Although older participants' mean response times were longer than those of young participants, the effect of the probe frequency on RT did not differ significantly between age groups, $F(4, 112) = 1.819$, $p > .15$, or as a function of the pre-probe delay, $F(8, 224) < 1$.

As we found with response accuracy, RT also showed a recency effect: Correct responses when the probe matched S_2 were faster than when the probe matched S_1 (Figure 2*D*), $t(29) = 3.50$, $p < .001$. As Figure 2*F* shows, the recency effect declined somewhat as the pre-probe delay lengthened; that is, the difference between matches to S_1 and S_2 declined. When the pre-probe delay = 1 s, RTs for matches to S_1 and S_2 differed significantly from one another, $t(29) = 4.08$, $p < .001$; but at a pre-probe delay = 2 and 4 s, RTs for S_1 and S_2 were only marginally so, $p > .06$. Finally, we found that the three-way interaction among age, the pre-probe delay, and probe frequency was not significant, $F(8, 224) = 1.01$, $p > .35$.

Variation in Criterial Orientation

As indicated earlier, the orientation whose frequency differentiated one stimulus from another varied randomly from trial to trial: on some trials, this critical orientation was horizontal, on others it was vertical. This random variation meant that half of all pairs of successive trials shared the same critical orientation, but remaining trial pairs differed in that respect. To determine if this change in critical orientation affected recognition, we compared each group's performance on both types of trial pairs. Recognition accuracy was essentially the same for the two types of trial pairs, $F(1, 28) < 1$. Moreover, the interaction of this variation with age was not statistically significant, $F(1, 28) = 1.88$, $p = .18$. Mean proportion correct for each combination of trial pair type and age were: Young, No-Switch = .70 (*SEM* = .02); Young, Switch = .67 (*SEM* = .02); Older, No-Switch = .65 (*SEM* = .01); and Older, Switch = .66 (*SEM* = .02). Repeating this analysis revealed essentially the same pattern for RT data. The mean RT for each combination of trial pair type and age were: Young, Switch = 1033.99 (*SEM* = 75.57);

Young, No-Switch = 1026.37 (SEM = 74.32); Older, Switch = 1242.32 (SEM = 62.77); and Older, No Switch = 1245.59 (SEM = 67.67). Neither the main effect of trial pair type, nor the interaction of trial pair type with age was significant, each $F(1, 28) > 0.5$.

DISCUSSION

As might be expected from the general slowing of responses with normal aging (Kausler, 1994), older adults took significantly longer to make their recognition judgments. However, their ability to discriminate study items from nonstudy items was not reliably worse than that of young adults. We found also that for both young and older participants, between-trial variation in the critical orientation had no effect on response accuracy or RT. This null result extends to older participants the idea that information along both orientations is processed in parallel (Zhou et al., 2004; Vincent & Regan, 1995). Also, for either group of participants, delaying the presentation of the probe had only a small effect, either on overall recognition accuracy or on response time. Recognition's overall robustness in the face of increasing, and unpredictable, pre-probe delay, is consistent with results others have reported, though for young participants only (Kahana & Sekuler, 2002).

We noted earlier that participants had particular difficulty making correct recognition judgments when the probe's spatial frequency lay midway between the frequencies of S_1 and S_2. This midway probe was between one and two discrimination thresholds away from each study item. Testing young participants with similar compound stimuli, (Zhou et al., 2004) found that comparable visual similarity between a probe and study items led to only 20% to 30% correct recognition responses, as we found here. More specifically, the young participants' thresholds in Table 1 mean that a probe midway between study items was on average 1.63 discrimination threshold units away from either study item; the corresponding thresholds for older participants mean that the midway probe was about 1.42 threshold units away from either study item. Although not statistically significant, this small difference between groups means that correctly recognizing that the midway probe had not been among the study items could have been a bit more difficult for the older participants. Both RTs and accuracy data hinted at such an age difference, but the difference was not statistically reliable for either dependent variable. To ensure that any group differences in visual memory are actually memory based, care must be taken to minimize age-related differences in visual discriminability. This can be achieved either by careful design of stimuli and task, the route we chose, or by judicious selection and screening of participants (Gilmore, Allan, & Royer, 1986). Additionally, one could achieve much the same goal by scaling the

memory test materials so as to reflect and compensate for age-related individual differences in visual discriminability when they are present (Zhou et al., 2003).

The present study confirmed and extended the principal results reported by McIntosh et al. (1999) and Bennett et al. (2001): When visual memory is assayed in heathy older adults tested under conditions that minimize effects of age-related changes in vision, visual recognition memory seems to be unaffected by aging. Our result is consistent with the hypothesis, grounded in behavioral and neuroimaging studies, that compensatory reorganization in the aging brain protects visual memory (McIntosh et al., 1999; Bennett et al., 2001), presumably by recruiting or coopting neural structures that in young subjects do not participate in visual memory. This account of age-related compensation implies that sparing of visual memory comes at the expense of other forms of memory (McIntosh et al., 1999; Bennett et al., 2001). Clearly, this speculation needs to be examined critically, for example, in combined behavioral and neuroimaging studies, which assess not only visual but also nonvisual memory, examining both of these as a function of age. Such studies would attempt to trace the developmental course followed by brain network changes, which presumably make possible the sparing of visual memory.

Obviously, one cannot rule out the possibilty that this hypothesized compensation has limits, which would be worthwhile identifying on their own. But such studies would not by themselves identify the crucial properties of task or stimuli that determine whether a form of memory will or will not be spared during aging. For example it may turn out that aging impacts visual memory less than it does verbal memory simply because the visual stimuli are of lower dimensionality, or because studies with verbal stimuli do not control encoding differences that arise from sensory limitations. These possibilities suggest the value of repeating our study's basic design, substituting high-dimensional stimuli for the compound gratings we used. Human faces are one obvious example of such stimuli, but if this proposed study were carried out, it would be crucial to use faces whose metric properties could be controlled in a metric fashion, as we did with compound gratings. Wilson, Loffler, and Wilkinson (2002) recently introduced novel computer-synthesized human faces that seem quite suitable for this purpose.

Alternatively, there may be an entirely different explanation for aging's modest impact upon visual memory. In particular, it may be that visual memory, at least with rapid presentation of confusable stimuli, is less rehearsal dependent, which would eliminate outcome differences from age-related differences in rehearsal. Whatever compensatory mechanisms are at work, those mechanisms are robust enough to withstand the enhanced stimulus and task complexity introduced in the present experiment. Future studies using stimuli that vary along

perceptual dimensions, including nonvisual dimensions, could serve to distinguish among alternative accounts of memory sparing with age, and to further enrich our general understanding of the complex pattern of age-related change and age-related invariance in memory.

REFERENCES

Bennett, P. J., Sekuler, A. B., McIntosh, A. R., & Della-Maggiore, V. (2001). The effects of aging on visual memory: Evidence for functional reorganization of cortical networks. *Acta Psychologica*, *107*, 249−273.

Gilmore, G. C., Allan, T. M., & Royer, F. L. (1986). Iconic memory and aging. *Journal of Gerontology*, *41*, 183−190.

Hole, G. J. (1996). Decay and interference effects in visuospatial short-term memory. *Perception*, *25*, 53−64.

Kahana, M. J. & Loftus, G. (1999). Response time versus accuracy in human memory. In R. J. Sternberg (Ed.), *The nature of cognition* (pp. 322−384). Cambridge, MA: MIT Press.

Kahana, M. J. & Sekuler, R. (2002). Recognizing spatial patterns: A noisy exemplar approach. *Vision Research*, *42*, 2177−2192.

Kausler, D. H. (1994). *Learning and memory in normal aging*. San Diego: Academic Press.

Magnussen, S., Greenlee, M. W., Aslaksen, P. M., & Kildebo, O. O. (2003). High-fidelity perceptual long-term memory revisited—and confirmed. *Psychological Science*, *14*, 74−76.

Magnussen, S., Greenlee, M. W., Asplund, R., & Dyrnes, S. (1990). Perfect visual short-term memory for periodic, patterns. *European Journal of Cognitive Psychology*, *2*, 345−362.

Magnussen, S., Idas, E., & Myhre, S. H. (1998). Representation of orientation and spatial frequency in perception and memory: A choice reaction-time analysis. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 707−718.

McIntosh, A., Sekuler, A. B., Penpeci, C., Rajah, M., Grady, C., Sekuler, R., & Bennett, P. (1999). Recruitment of unique neural systems to support visual memory in normal aging. *Current Biology*, *9*, 1275−1278.

Owsley, C., Sekuler, R., & Siemsen, D. (1983). Contrast sensitivity throughout adulthood. *Vision Research*, *23*, 689−699.

Pelli, D. G., Robson, J. G., & Wilkins, A. J. (1988). Designing a new letter chart for measuring contrast sensitivity. *Clinical Vision Sciences*, *2*, 187−199.

Phillips, W. A. (1974). On the distinction between sensory storage and short-term visual memory. *Perception & Psychophysics*, *16*, 283−290.

Phillips, W. A. & Christie, D. F. M. (1977). Components of visual memory. *Quarterly Journal of Experimental Psychology*, *29*, 117−133.

Ratcliff, R. (1993). Methods for dealing with reaction time outliers. *Psychological Bulletin*, *114*, 510−532.

Vincent, A. & Regan, D. (1995). Parallel independent encoding of orientation, spatial frequency, and contrast. *Perception*, *24*, 491−499.

Wilson, H. R., Loffler, G., & Wilkinson, F. (2002). Synthetic faces, face cubes, and the geometry of face space. *Vision Research*, *42*, 2909−2923.

Wingfield, A. & Kahana, M. J. (2002). The dynamics of memory retrieval in older adults. *Canadian Journal of Experimental Psychology*, *56*, 187−199.

Wingfield, A. & Stine-Morrow, E. (2000). Language and speech. In F. Craik & T. Salthouse (Eds.), *The handbook of aging and cognition*, (2nd ed., pp. 359−416). Mahwah, NJ: Lawrence Erlbaum Associates.

Zhou, F., Kahana, M. J., & Sekuler, R. (2004). Short-term episodic memory for visual textures: A roving probe gathers some memory. *Psychological Science*, *15*, 112−118.