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Is the Dissociability of Working Memory Systems for Name Identity, Visual-Object Identity, and Spatial Location Maintained in Old Age?

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The dissociability of working memory for name identity (verbal information), visual objects, and spatial location was explored in 3 experiments. Consistent with previous results, the 3 working memory systems were dissociable in younger adults. Both younger and older adults showed involvement of name identity in an object identity task, and older adults showed this involvement in a spatial memory task. Results were interpreted as showing that the systems are generally separable but that involvement of 1 with another is possible and more likely in older adults. A 4th, correlational study showed that there is generalized decline in working memory systems in old age, with the age differences in memory mediated to a moderate extent by age-related differences in speed of processing. It was speculated that the specific, possibly strategic changes are independent of and take place against a backdrop of generalized loss of nervous system integrity.

There are several separable systems for the temporary maintenance of information. Evidence from infrahuman studies and from lesion analyses and neuroimaging in humans converges on the conclusion that working memory for verbal information, for objects, and for spatial locations is subserved by distinct neural circuits (for a review, see Jonides et al., 1996). Moreover, both anecdotal and scientific evidence indicates that memory performance declines with advancing age, even in healthy individuals (for reviews, see Craik & Jennings, 1992; Light, 1991). How do these distinct working memory systems change with age? Age-related change in a wide variety of cognitive functions—including working memory for verbal information, object identity, and spatial location—appears to be undifferentiated (Salthouse, 1995). Age-related variance in performance on cognitive measures is relatively homogeneous, and the large majority of the variance can be accounted for by measures that reflect the intactness of the nervous system, such as basic processing speed (e.g., Salthouse, Fristoe, & Rhee, 1996) or sensory acuity (e.g., Baltes & Lindenberger, 1997). The questions that we attempt to answer are these: What is the fate of the distinct working memory systems in the apparently undifferentiated decline that accompanies old age? Do the systems remain separable and distinct, although each is impaired, or is the distinctness lost as the integrity of the nervous system is compromised? Alternatively, might the distinctness be blurred as one system is recruited to compensate for losses in another?

Dissociable Working Memory Systems

Baddeley and Hitch (1974) proposed a model of working memory consisting of two memory stores regulated by a central executive whose functions are to allocate incoming information to one of two storage subsystems as well as to coordinate, monitor, and make use of the information in the two subsystems. The two subsystems consist of a memory store for the storage and manipulation of verbal information, the *phonological loop,* and a memory store for the storage and manipulation of visual–spatial information, the *visuospatial scratch pad.* Using the methods of double dissociation and selective interference, researchers have shown these verbal and visual working memory subsystems to be dissociable in behavioral studies of both nonpatient and patient populations (for reviews, see Baddeley, 1986, 1992; Jonides et al., 1996). The visuospatial scratch pad has been divided into two separate memory subsystems for visual and for spatial information. This modification acknowledged single-cell recording studies in nonhuman primates that demonstrated the existence of separate processing streams for visual and spatial characteristics of objects (Goldman-Rakic, 1987; Wilson, O'Scalaidhe, & Goldman-Rakic, 1993) as well as studies of both nonpatient (Tresch, Sinnamon, & Seamon, 1993) and patient (Farah, Hammond, Levine, & Calvanio, 1988) populations demonstrating dissociable visual and spatial processing systems in humans.

The clearest evidence for dissociations among working memory systems comes from neuroimaging studies. In the studies that we describe here, exactly the same stimuli were presented with two different memory instructions. In one

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condition, the individual was to remember one aspect of the stimulus, such as its verbal identity; in the other condition, the individual was to remember a different aspect, such as its location. If the same stimuli generated different patterns of cortical activation under different memory instructions, that is strong evidence for distinct memory systems.

Smith, Jonides, and Koeppe (1996) dissociated verbal and spatial working memory using positron emission tomography (PET). They used a running memory task in which the individual had to determine whether each stimulus matched or did not match the stimulus that had appeared three before in the sequence (called the 3-back task). Upper- and lowercase letters were displayed on the circumference of an imaginary circle. In one condition the match–mismatch judgment was made on the identity of the letter, without regard to spatial location. In the other condition, the judgment was made on the spatial location of the letter in the display, without regard to the identity of the letter. Compared with control conditions, the verbal identity task produced activations in left posterior parietal cortex, in Broca's area (BA), and in dorsolateral prefrontal cortex (DLPFC) in the left hemisphere. By contrast, spatial instructions produced activations in posterior parietal areas and in DLPFC, but in the right hemisphere. Activation was also found in right-hemisphere premotor areas. The clear lateralization of the sites of activation in the two memory conditions is strong evidence that the working memory systems for verbal identity and spatial location are distinct.

Smith et al. (1995) recorded PET activations in a delayed match-to-sample task with nonsense shapes. In one condition, the task was to determine whether a probe item matched the identity of one of the three objects just presented. The objects were randomly generated shapes and thus not easily named. In the other condition, the task was to determine whether the probe item appeared in the same location as any of the items in the memory set. With spatial memory instructions, activations were found bilaterally in posterior parietal cortex, frontally in the right-hemisphere DLPFC and ventrolateral prefrontal cortex (VLPFC; BA 47), and in the anterior cingulate cortex (ACC). With object memory instructions, the only significant activations were in the left hemisphere, in the posterior parietal cortex, and in inferotemporal cortex. McCarthy et al. (1996) specifically examined activation of regions of interest (ROIs) in prefrontal cortex with functional magnetic resonance imaging (fMRI) using more complex spatial and object working memory tasks than had Smith et al. (1995). They used a running memory task with sequences of 18 or 19 squares or nonsense shapes. The task was to say whether the current stimulus matched the identity (for object memory) or location (for spatial memory) of any prior stimulus. McCarthy et al. examined ROIs in prefrontal cortex and found significant activation in middle frontal gyrus but not superior frontal gyrus or inferior frontal gyrus. In the right hemisphere, they found equal activation of middle frontal gyrus for object identity and location; in the left hemisphere, they found greater activation for object identity than for location. It appears, then, that memory for visual objects results in greater left-hemisphere activation than does memory for spatial location. Results such as these show that Baddeley's (1986, 1992) storage buffer for visuospatial information, the visuospatial scratch pad, can be further subdivided into two functionally and anatomically distinct systems, one for visual-object working memory and another for visual–spatial working memory.

D'Esposito et al. (1998) surveyed experiments reporting imaging of working memory. In tasks that involved simple maintenance of the information, posterior activation tended to be bilateral for spatial working memory but left lateralized for nonspatial working memory. Prefrontal activation tended to be more ventral than dorsal and tended to be right lateralized for spatial working memory but left lateralized for nonspatial working memory. These distinct patterns are not maintained throughout frontal cortex. D'Esposito et al. found for tasks that involved more complex operations than simple maintenance that activation tended to be in DLPFC and was largely bilateral. Postle, Berger, and D'Esposito (1999) argued that processes necessary for working memory storage are primarily posteriorly mediated and are distinct in their pattern of lateralization whereas executive control processes that contribute to working memory function are primarily prefrontal cortex mediated and are not lateralized. In agreement with this conclusion, Postle, Stern, Rosen, and Corkin (2000) found no difference between prefrontal cortical activity associated with spatial working memory and prefrontal cortical activity associated with nonspatial working memory.

Aging and Memory Systems

A few behavioral studies have explored age differences in memory for verbal information (especially name identity) and visual-object identity (Salthouse, 1995; Shelton, Parsons, & Leber, 1982; Tubi & Calev, 1989) or verbal information and spatial location (Salthouse, 1995; Schear & Nebes, 1980). The motivation in each case was to determine whether age-related differences were greater in visuospatial than in verbal memory, using either identical or matched stimulus sets. The results have been mixed. Comparisons of name identity and object identity have used words or letters as verbal stimuli and abstract designs as objects. Shelton et al. found equivalent differences between middle-aged and older adults for paired-associates learning of words and of designs. Tubi and Calev found greater age differences for free recall of designs than of words. Similarly, Salthouse found greater age-related differences for a memory-search task using line figures than using letters. Comparisons of name identity and spatial location have used 5 × 5 grids containing seven letters. When name identity was to be tested, the instructions were to report the letters that were seen; when spatial location was to be tested, the instructions were to report the location of the letters. Schear and Nebes reported equivalent differences between younger and older adults with the two instructions; Salthouse found noticeably greater age-related differences for name identity than for spatial location. In sum, there are only a few studies addressing age differences in the three working memory systems, they use different methods, and they reach different conclusions. Even if there were a large number of results and they converged on clear conclusions, a search for greater age differences in one type of memory than in another provides only a weak test of the hypothesis that the different memory systems remain distinct in old age. Finding clear evidence that one type of memory is more impaired in older adults than another type establishes an age-related dissociation, showing that the two memory systems must remain separable. Finding comparable age-related impairment in the different working memory systems, however, could occur whether memory systems have maintained their separation or have decayed in such a way that they are no longer distinct. Formerly specialized systems that have become functionally interdependent would also show similar age-related change; however, it is also the case that separate memory systems could coincidentally undergo approximately the same change with advancing age.

There is evidence both from behavioral and from neuroimaging studies consistent with a loss of specialization with age of memory systems for verbal and for spatial information. Salthouse (1995) administered a variety of verbal and spatial memory tasks. Factor analysis of performance extracted separate Verbal and Spatial Memory factors, but those two factors correlated .98, so the data were well-fit by a single memory factor. The tasks used by Salthouse comprised a series of matched pairs of verbal and spatial tasks. He found that when the variance accounted for by one modality was removed from the matching task in the other modality, only a small amount of unexplained variance remained. If separate memory systems were coincidentally undergoing the same average change, the changes would not be expected to be highly correlated. High correlations between verbal and spatial memory are more consistent with memory systems that have become interlinked.

Reuter-Lorenz, Stanczak, and Miller (1999) obtained more direct behavioral evidence of greater interaction between specialized systems in the left and right hemispheres in older adults. In letter-matching tasks, the target and the probe could be in the same or different visual hemifields (thus projecting to the same or different cerebral hemispheres). Older adults generally performed better with bilateral than with unilateral presentation; younger adults showed a more modest advantage—and then only for the most difficult version of the task. Thus, older adults appear to benefit when multiple processing systems are activated by bilateral presentation. Reuter-Lorenz et al. concluded that rather than a generally deleterious dedifferentiation, there may instead be neural recruitment across systems that partially compensates for age-related declines in the efficiency of systems that are more separated in young adults. The letter-matching task makes only the most limited of demands on working memory, but the apparent interaction of processing systems located in different cerebral hemispheres raises the possibility of interactions between memory systems that are similarly separated in the brain.

Neuroimaging of cortical activity during cognitive tasks shows that activation is more task-specific in younger than in older adults. Grady et al. (1992, 1994) obtained PET activation patterns in younger and older adults during match-to-sample tasks for objects (human faces) and spatial locations. In both age groups, face matching activated a more ventral processing stream involving occipital areas (BA 18, 19) and occipitotemporal areas (BA 37), whereas location matching activated a more dorsal stream involving more posterior occipital areas and superior parietal areas (BA 7). In addition, however, the older adults showed greater activation than younger adults in the face-matching task in left occipitotemporal areas. In the location task, older adults showed greater activation in occipitotemporal and inferior parietal cortex bilaterally. In both tasks, older adults showed greater activation in superior temporal (BA 22) and prefrontal cortex (BA 46, 47). The difference was particularly strong for left DLPFC. A later study exploring the effect of introducing a delay between the target and the probe in the face recognition task showed that the delay exaggerated the age differences in left DLPFC. In addition, Grady (1998) recently reported that a structural model of the face-matching data (Grady et al., 1994) showed feedback from prefrontal cortex to extrastriate areas in the older adults but not in the younger adults.

Reuter-Lorenz et al. (2000) also obtained PET activation patterns for younger and older adults. The task was a memory search involving either letter identity or spatial location. From prior studies on younger adults, they identified cortical volumes of interest (VOIs) for the identity and location tasks. Examination of posterior brain VOIs showed left-side but not right-side activation in the letter identity task and bilateral activation in the spatial location task. This pattern held for both younger and older adults. In contrast to the posterior sites, the patterns for the two age groups were quite different for anterior sites. Young adults showed left-side activation (but not right-side) for the letter identity task and right-side activation (but not left-side) for the spatial location task, whereas older adults showed bilateral frontal activation for both tasks. Isolating VOIs in DLPFC showed that younger adults had greater left-side than right-side activation in the identity task and the opposite pattern in the location task. Paradoxically, the activation pattern was reversed in older adults, with greater right-side activation in the identity task and left-side activation in the location task.

Grady et al. (1992, 1994) and Reuter-Lorenz et al. (2000) found bilateral prefrontal activation in older adults in tasks that elicit less anterior and more lateralized activity in younger adults. Reuter-Lorenz et al. speculated that this anterior activity may reflect a reduced ability in old age to engage specialized posterior systems, resulting in a need to activate more general frontal systems. Grady (1998), on the other hand, speculated that it may reflect greater demands on storage and maintenance in older adults or an increased need to elaborate stimulus representations that have been less well encoded (Grady, 1998). A third possibility, not inconsistent with either of the preceding, is that posterior maintenance systems are unaffected by age but that frontal executive control processes are selectively impaired in older adults. The effort to marshal all available executive cortical resources results in greater general frontal activation. This could result in activation in older adults of frontal areas available to younger adults but not usually called on. The presence of bilateral prefrontal cortex activation in tasks both high and low in demands on memory is suggestive of general executive processes not devoted exclusively to working memory.

The three experiments reported here tested the hypothesis that memory systems for name identity, for object identity, and for spatial location do not maintain their distinctness in old age. The approach we used was to attempt to establish double dissociations. We manipulated variables, V_1 and V_2, where V_1 was expected to affect process P_1 but not process P_2, whereas V_2 was expected to affect P_2 but not P_1. In each experiment, running memory span tasks were used. In Experiment 1 the task was to determine whether the stimulus on a trial matched or did not match the stimulus that came two before. We term this the *2-back task.* In Experiments 2 and 3 a 1-back task was used, requiring that the present stimulus be matched to the one immediately before. In each experiment the same stimuli were used with two different instructions, requiring that the match be based on one of two criteria selected from name identity (verbal working memory), object (or physical) identity (visual-object working memory), or spatial location (spatial working memory). Because the materials were exactly identical and only the memory instruction differed, we avoided the criticism leveled against some earlier studies that different materials were used to assess different types of memory (Salthouse, 1995; Tubi & Calev, 1989). Thus, for example, conditions with name identity and spatial location instructions were used in Experiment 1, although the stimuli presented in the two conditions were identical. Also, in each memory instruction condition of each experiment, we manipulated two variables, one expected to affect one type of memory and one expected to affect the other. In Experiment 1 we manipulated whether the letters in the set were phonetically similar or not—expected to affect memory for name identity—and the physical proximity of the probe to the target (the stimulus two back)—expected to affect memory for spatial location. In Experiment 2 we manipulated the physical proximity and the visual similarity of the items—expected to affect memory for object identity. In Experiment 3 we manipulated physical proximity and the similarity of the names assigned to unfamiliar objects (Arabic characters)—expected to affect memory for name identity. Following these three dissociation experiments, we report a study in which all three memory tasks were administered to the same persons, along with additional measures of speed of processing, allowing us to explore structural models of the relations between memory performance and potential predictors of performance.

The double-dissociation approach provides a stronger test of the separability of memory systems than does the approach of looking for greater age differences in one type of memory than another. If the memory systems become more interdependent in old age, this should be evident from failures to find double dissociations in older adults that are seen in younger adults. Although the absolute size of age differences may be instructive, our approach removes any necessity that we demonstrate convincingly that our different memory tasks are equally demanding. We simply note that in each experiment we used exactly the same stimuli to test two different types of memory so that extraneous factors should be completely equated.

Experiment 1

This experiment tested memory for name identity and spatial location in younger and older adults using the 2-back task. The stimuli were English letters, randomly varying between upper- and lowercase, appearing one at a time on the circumference of an imaginary circle. For name identity, participants were instructed to determine whether the current letter matched the identity of the letter two before (irrespective of case). For spatial location, participants were instructed to determine whether the current letter appeared in the same location as the letter two before (irrespective of the identity of the letter). Both types of memory were tested with two stimulus sets: In one set, the letters were phonetically similar; in the other set, the letters were phonetically dissimilar. Phonetic similarity was expected to impair memory for name identity by increasing confusibility in subvocal rehearsal. In addition, locations were chosen so that they exactly matched the location two back, so that they were a near miss (15° to 30° apart around the imaginary circle), or so that they were far apart (40° to 55° apart). Spatial proximity was expected to affect the difficulty of the spatial location memory task. A double dissociation would be demonstrated if phonetic similarity affected performance under the name identity instructions but not the spatial location instructions whereas physical proximity affected performance under the spatial location instructions but not the name identity instructions.

Method

Participants. The characteristics of the participants in each of the experiments reported here are given in Table 1, including age, years of education, visual acuity, and self-rated health. Visual acuity was determined by obtaining the individual's complete contrast sensitivity function (Vision Contrast Test System, Vistech Consultants, Dayton, OH) and then converting to conventional Snellen units. Participants rated their health at present using a 10-point scale on which 10 was *excellent.* Young adults were college students, most participating as one option for extra credit in an introductory psychology course. Older adults were volunteers from the local community, some recruited from senior citizens lunch programs or retirement communities, others through other participants by word of mouth. Older adults were paid for their participation at a rate of $10 per hour. Older participants were selected from a larger pool that had already completed the screening instrument for medical conditions likely to affect cognition developed by Christenson, Moye, Armson, and Kern (1992). Younger adults completed the instrument at the time of testing. The only deviations from the exclusion criteria recommended by Christenson et al. were that 2 older adults who had undergone heart surgery more than 5 years prior to testing and were without subsequent complications were accepted as were 1 younger and 1 older adult who were taking selective serotonin reuptake inhibitor medication for dysthymia.

Stimuli, displays, and tasks. In each of the experiments reported here, stimulus presentation, timing, and response collection

Table 1
Participant Characteristics

Age group	*n*	Age (in years)		Education (in years)		Rated health[a]		Visual acuity[b]	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Experiment 1									
Younger adults	24	19.65	0.75	12.52	0.87	8.04	1.72	17.37	3.06
Older adults	24	76.52	6.01	15.81	3.46	8.34	1.21	24.31	7.12
Experiment 2									
Younger adults	21	19.57	1.69	13.86	1.77	8.55	1.38	18.57	3.22
Older adults	21	75.38	6.04	15.38	3.69	8.75	1.03	28.25	12.49
Experiment 3									
Younger adults	24	19.83	1.01	12.42	0.78	8.00	1.94	19.17	6.02
Older adults	24	75.73	5.83	15.88	3.76	8.22	1.47	24.32	6.42
Experiment 4									
Younger adults	24	19.58	1.72	13.71	1.33	8.35	1.29	15.83	4.08
Older adults	30	72.92	14.22	16.41	3.39	8.50	1.27	30.54	9.22

[a] Current state of health self-rated on a 10-point scale (10 = *excellent*). [b] In Snellen units (i.e., "20/20 vision," where the mean acuity value shown in the table would appear after the slash [mean acuity = 20/17.37 for younger adults in Experiment 1]).

were controlled by Microexperiment Laboratory (MEL; Schneider, 1995), running on Intel-486 microcomputers. Viewing distance was not constrained, but measurements made for several participants indicated a typical viewing distance of 46 cm. Visual angles are reported for that distance. In Experiment 1, the stimuli were English letters (MEL font, "MEL") subtending approximately 1.6° by 1.2° presented around the circumference of an imaginary circle on the monitor, 11.75° in diameter. Letters could appear in 1 of 12 locations equally spaced along the circumference. In the phonetically similar set, the letters were *b, d, e, g, p,* and *t;* for the phonetically dissimilar set, the letters were *a, c, f, g, h,* and *i.* The case of the letter, upper or lower, was determined at random on each trial. A letter was presented for 500 ms, then removed. The interstimulus interval was 2,500 ms, and responses were accepted only during this interval. The first two stimuli were presented in red, and the participant was instructed to remember the relevant aspect of the stimulus—identity or location—but not respond. Thereafter stimuli were presented in white, and the participant indicated by a keypress whether the stimulus matched (using the *Z* key) or did not match (using the *X* key) the stimulus two before. Labels were placed above the keys. A sequence consisted of 36 stimuli, 12 of which were matches and 24 of which were not. For name identity conditions in which physical proximity was manipulated but would not be relevant to the task, each stimulus was placed so that it was in the same location as the one two before, was in a nearby location, or was far from the location, with the determination made at random. For both near and far mismatches, the exact placement within each range (15°–30° from the target location for near; 40°–55° for far) was randomly selected. For spatial location conditions in which the name identity of the stimulus was irrelevant, stimuli were chosen to match or not match, randomly, the identity of the stimulus two before, with mismatches chosen at random from the available letters.

Procedure. There were four different conditions: There were two types of instruction, to match stimuli on name identity or to match on spatial location, combined with two different stimulus sets, phonetically similar and phonetically dissimilar. Half the participants completed name identity then spatial location and the other half, the reverse. An ABBA order was used for the similar and dissimilar stimulus sets, with the assignment of sets to A and B alternated for each successive participant in an age group. Each participant completed 3 consecutive sequences in each condition, for a total of 12 sequences. The task was explained to the participant at the outset using a sample sequence printed on cards. A rest break was allowed after each sequence as the participant desired. Personal information was obtained and vision tested at the end of the session.

Results

The dependent variable was the proportion of correct responses on all trials after the third (the first trial for which there was a stimulus two back). Failures to respond were treated as errors. Separate analyses of variance (ANOVAs) were carried out for performance under name identity and spatial location instructions. For each analysis, age group (younger or older) was a between-subjects variable, and stimulus set (phonetically similar and phonetically dissimilar) and physical proximity (match, near miss, and far miss) were within-subjects variables. For all tests reported here and later, alpha was set at .05; the exact significance is reported for information purposes. As appropriate, a Greenhouse–Geiser correction was applied.[1] In those cases, the

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[1] Repeated measures ANOVA assumes sphericity of the variance–covariance matrix. The extent to which the matrix for each repeated measure effect (with more than two levels) meets this assumption is assessed (ranging from 0, not at all, to 1.0, perfectly). The Greenhouse–Geiser correction multiplies the original degrees of freedom for the effect by that fraction, resulting in reduced degrees of freedom and, so, a more stringent criterion to achieve significance.

test was based on the corrected significance level. The mean proportion correct for each condition in Experiment 1 is shown in Figure 1.

Name identity. The only significant effect was a main effect of phonetic similarity, $F(1, 46) = 5.88$, $p = .02$, $MSE = 0.011$. The proportion correct was higher for phonetically dissimilar letters ($M = .68$, $SD = .08$) than for similar letters ($M = .65$, $SD = .07$). Among the nonsignificant results, we note that there was no main effect of age group, $F(1, 46) = 1.69$, *ns*, or physical proximity, $F(2, 92) = 0.38$, *ns*, and no interaction of age group and proximity, $F(2, 92) = 0.70$, *ns*.

Spatial location. There were significant main effects of proximity, $F(2, 92) = 76.58$, $p < .001$, $MSE = 0.016$, and phonetic similarity, $F(1, 46) = 4.90$, $p = .03$, $MSE = 0.009$. There was a significant interaction of age group and proximity, $F(2, 92) = 4.03$, $p = .02$, $MSE = 0.009$. Separate follow-up analyses were carried out for younger adults and for older adults. For the younger adults, only the main effect of proximity was significant, $F(2, 46) = 82.41$, $p < .001$, $MSE = 0.006$. Bonferroni post hoc tests showed that performance was best in the far miss condition ($M = .62$), worst in the match condition ($M = .43$), and intermediate in the near miss condition ($M = .54$). The effect of phonetic similarity did not approach significance, $F(1, 23) = 0.25$, *ns*. For the older adults, there were significant main effects of proximity, $F(2, 46) = 18.07$, $p < .001$, $MSE = 0.011$, and of phonetic similarity, $F(1, 23) = 6.04$, $p = .02$, $MSE = 0.010$. Bonferroni post hoc tests showed that performance was best in the far miss condition ($M = .58$), worst in the match condition ($M = .45$), and intermediate in the near miss condition ($M = .50$). Phonetically dissimilar letters resulted in better performance ($M = .53$) than phonetically similar letters ($M = .49$).

Discussion

Younger adults showed a perfect double dissociation. Phonetic similarity had a small but significant effect on memory for name identity and no effect whatsoever on memory for spatial location. Conversely, physical proximity of probe to target had a strong effect on memory for spatial location and no effect on memory for name identity. The results are consistent with separable and distinct memory systems in young adults.

Older adults failed to show the double dissociation. Performance was better with phonetically dissimilar letters not only on memory for name identity, where they would be expected to help, but also on memory for spatial location, where phonetic similarity was irrelevant to the task. How might the two systems interact?

One possibility that can be rejected is that older adults occasionally forgot that the instructions were to match on spatial location and, instead, matched on identity. Similar sounding foils would be more likely to be erroneously seen as a match than dissimilar sounding foils. First, this explanation requires the assumption that forgetting the instructions was asymmetrical; older adults mistakenly matched on name identity in the spatial location task but did not match on spatial location in the name identity task. It is certainly plausible, though, that being asked to match letters is a more familiar task than being asked to match spatial locations. Second, an identity match would occur in the location task on only one trial in six. This would produce a bias toward a mismatch response, which would elevate performance for near and far misses but depress performance for matches. Further, there should be a bias toward match responses for similar-sounding letters, resulting in a greater difference between similar and dissimilar letters for location matches than for near or far misses, a pattern that was not seen. The possibility of differences in decision criterion was explored by calculating the signal-detection measure, β. At the point where the criterion is set to discriminate between matching and nonmatching stimuli, β is the ratio of the likelihood of a matching stimulus to a nonmatching stimulus. An ideal decision maker would set the criterion such that β was 1.0; that is, the stimulus was equally likely to be a match or a mismatch. ANOVA on the βs resulted in significant main effects of the task, name and location, $F(1, 46) = 49.08$, $p <$

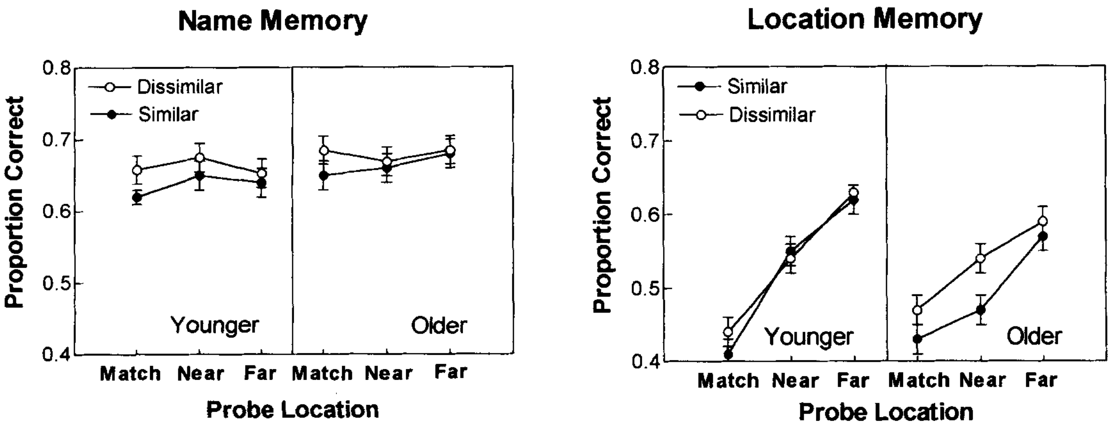

Figure 1. Mean proportion correct in Experiment 1 as a function of acoustic similarity of letters in the stimulus set and spatial proximity of target and probe. Error bars represent the standard error of the mean.

.001, $MSE = 2.40$, and of age group, $F(1, 46) = 6.31$, $p = .016$, $MSE = 2.90$. βs were higher—that is, shifted more in favor of a mismatch response—for name identity ($M = 2.92$, $SD = 1.18$) than for location ($M = 1.30$, $SD = 0.15$). Younger adults adopted a criterion shifted more toward mismatch ($M = 2.43$, $SD = 0.87$) than did older adults ($M = 1.80$, $SD = 0.89$). The main effects were qualified by a significant interaction of task and age group, $F(1, 46) = 4.37$, $p = .043$, $MSE = 2.40$, such that β for younger and older adults was equivalent for location (Ms = 1.38 and 1.23, respectively) whereas β for name identity was higher for younger adults ($M = 3.48$) than for older adults ($M = 2.36$). In sum, both age groups adopted fairly neutral decision criteria, as measured by β, in the location task. The decision criterion was unaffected by either the phonetic similarity of the letters or the physical proximity of the target and probe. Moreover, to the extent there was an age difference in decision bias, it was in the name identity task, and it was the younger adults who adopted the stricter criterion for a match.

There are two other possibilities. One is that older adults use the letter identity as a mnemonic aid, an elaboration of the stimulus that can later be used to recover the associated location. Similar-sounding letters may have resulted in mnemonic confusions, depressing performance. A second explanation is that the ability to inhibit irrelevant material from entering working memory is impaired in older adults as Hasher and Zacks (1988) argued (but see Burke, 1997, and McDowd, 1997, for contrary views). Older adults are unable to inhibit processing of the letter names even though the task calls for location memory. The processing interferes with encoding of location, and it does so more for similar letter names than for dissimilar letter names. Whatever the explanation, artifacts aside, it does appear that memory for name identity and spatial location was distinct in younger adults but not in older adults.

Experiment 2

The second experiment tested memory for object identity and for spatial location. The objects were characters from the Arabic alphabet. We ascertained that the participants were unfamiliar with the Arabic characters and their names, so this should have discouraged verbal encoding. Two sets of stimuli were formed. One consisted of visually similar characters; the other consisted of visually dissimilar characters. Physical proximity was manipulated as it was in Experiment 1. In pilot testing we found that error rates were unacceptably high using the 2-back task, so we used a 1-back task instead, in which the task was to determine whether each stimulus matched the one before, either in object identity or spatial location, as appropriate.

Method

Other than the substitution of Arabic characters (MEL font, "Arabic-36") and the use of a 1-back task instead of 2-back, the design and procedures of Experiment 2 were identical to those of Experiment 1. The visually similar and visually dissimilar stimulus sets are shown in Figure 2.

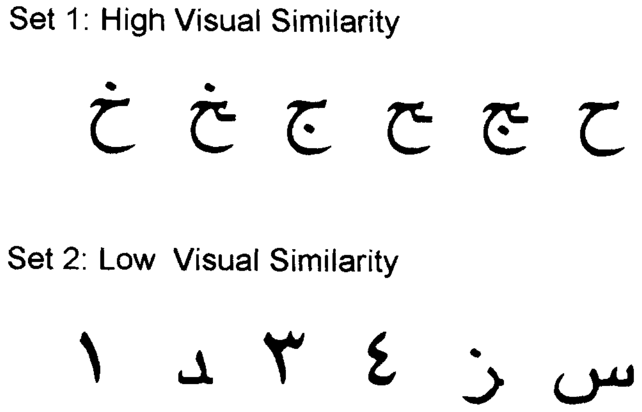

Figure 2. Visually similar and visually dissimilar Arabic character sets used in Experiment 2.

Results

Separate ANOVAs were carried out on the proportion of correct responses under object identity and spatial location instructions. Age group (younger or older) was a between-subjects variable, and visual similarity (high and low) and physical proximity (match, near miss, and far miss) were within-subjects variables. The mean proportion correct for each condition in Experiment 2 is shown in Figure 3.

Object identity. There were significant main effects of age group, $F(1, 38) = 6.10$, $p = .02$, $MSE = 0.006$, and of visual similarity, $F(1, 38) = 98.41$, $p < .001$, $MSE = 0.009$. Younger adults ($M = .88$, $SD = .11$) were more accurate than older adults ($M = .80$, $SD = .10$). Performance was better with visually dissimilar characters ($M = .90$, $SD = .10$) than with visually similar characters ($M = .78$, $SD = .11$). Among the nonsignificant effects, the interaction of age group and similarity was clearly nonsignificant, $F(1, 38) = 0.60$.

Spatial location. There was a significant main effect of proximity, $F(2, 76) = 32.39$, $p < .001$, $MSE = 0.030$, and a significant interaction of age group and proximity, $F(2, 76) = 3.90$, $p = .02$, $MSE = 0.030$. Bonferroni post hoc tests showed, for younger adults, that performance was better in the far miss condition ($M = .93$) than the near miss condition ($M = .81$), which was, in turn, better than the match condition ($M = .67$). For older adults, performance was better in the far miss condition ($M = .88$) than in the near miss condition ($M = .69$) and the match condition ($M = .73$), which did not differ.

β. As in Experiment 1, the measure of the decision criterion, β, was calculated and subjected to ANOVA. There was no significant main effect of age, nor was there any interaction of experimental variables with age. There was a main effect of task, $F(1, 38) = 7.69$, $p = .009$, $MSE = 9.43$, with the criterion shifted more toward mismatch for location memory ($M = 2.65$, $SD = 1.90$) than for object identity memory ($M = 1.30$, $SD = 1.28$). There was also a significant main effect of similarity, with the criterion shifted more toward mismatch for visually dissimilar ob-

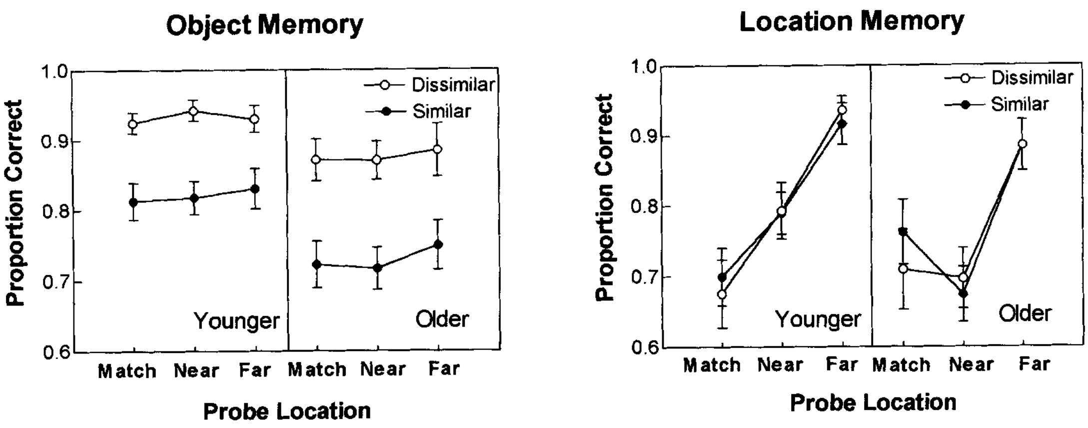

Figure 3. Mean proportion correct in Experiment 2 as a function of visual similarity of Arabic characters in the stimulus set and spatial proximity of target and probe. Error bars represent the standard error of the mean.

jects ($M = 2.51$, $SD = 1.94$) than for visually similar objects ($M = 1.44$, $SD = 1.02$).

Discussion

Both younger and older adults showed a double dissociation of memory for object identity and for spatial location. In each age group, visual similarity affected only memory for object identity, and physical proximity affected only memory for spatial location. Object identity and spatial location remain distinct systems in old age.

The effect of physical proximity was different for younger and older adults. Unlike the younger adults, older adults were equally accurate for matches and for near misses, performing better than younger adults for matches and less well for near misses. This would have resulted if older adults adopted a response bias in favor of responding match if a stimulus was in the near vicinity of the target location. They would give correct responses more frequently than would be expected for matches, and they would give incorrect responses more frequently for near misses. The decision criterion was biased toward mismatch in the location task, but that was equally true for younger and older adults. An alternative explanation is that older adults encoded the spatial location less precisely. The correlation between visual acuity and proportion correct on the match and near miss conditions for older adults was only −.12, so the problem should not be due to impairment in the sensory registration of the stimulus. (The correlation was −.19 for younger adults.) It is possible that older adults used a coarser grain for encoding but that was independent of sensory acuity.

It should also be noted that the equivalent performance of older adults in the match and near miss conditions of the location memory task is not due to a floor effect. Although the floor determined by chance is dependent on the response strategy, the proportion of correct responses in the match and mismatch (near or far miss) conditions would range from .00 and 1.00, respectively (always guessing mismatch), to .50 and .50 (guessing at random), to .67 and .33 (probability matching), to 1.00 and .00 (always guessing match). The observed data are not well fit by any of these pairs.

Whichever explanation is accepted, no such pattern was observed in Experiment 1 with English letters, so the effect must have been elicited by the Arabic characters used in Experiment 2. The range of sizes among the Arabic characters was considerably larger than among the English letters, so this could have prompted a coarser grain of encoding for location. Why it would do so only among older adults is not clear.

Experiment 3

The third experiment tested memory for object identity and name identity. As in Experiment 2, Arabic characters were used as the objects. Four sets of characters were chosen. Two comprised characters that were visually similar to one another; two comprised visually dissimilar characters. Testing was carried out over 2 days. On the 1st day, all four sets were tested on the 1-back task under object identity instructions only. On the 2nd day, artificial names were assigned to the characters. One set of similar characters and one set of dissimilar characters were assigned acoustically similar names. Likewise, one set of similar characters and one set of dissimilar characters were assigned acoustically dissimilar names. The participants then learned the assigned names using a paired-associates learning procedure. They were then tested again on each of the four stimulus sets—formed by the combination of visual similarity and dissimilarity and acoustic similarity and dissimilarity—in the 1-back task. With a unique verbal label learned for each character, this should now have become, at least potentially, a name identity task.

We could have adopted, but did not adopt, a research strategy using pictures of real objects. We chose the present approach instead for several reasons. First, by using artificial names it could be ensured that the names for the different objects were equally well learned. Second, the use of unfamiliar objects and artificial names allowed strong manipulations of similarity. Third, the use of unfamiliar objects ensured that they would not fall into preexisting, well-learned categories. The final reason was practical. Although it was relatively easy to identify visually dissimilar objects with phonetically similar names (e.g., bear, chair, hare), visually similar objects with dissimilar names (e.g., tiger, lion, cougar), and dissimilar objects with dissimilar names (e.g., lamp, tree, frog), we found it nearly impossible to find a set of visually similar objects with other than trivially similar names (e.g., rocking chair, dining chair, desk chair).

Method

The two sets of visually similar Arabic characters included those used in Experiment 2 as well as two additional sets. All four sets are shown in Figure 4. The presentation of the stimuli was similar to that in Experiments 1 and 2 except that all stimuli were centered on the monitor display. Three sequences were completed with each stimulus set on Day 1. The instructions were to press the match key if the object was the same as the one that had appeared just before and to press the mismatch key if the object was different.

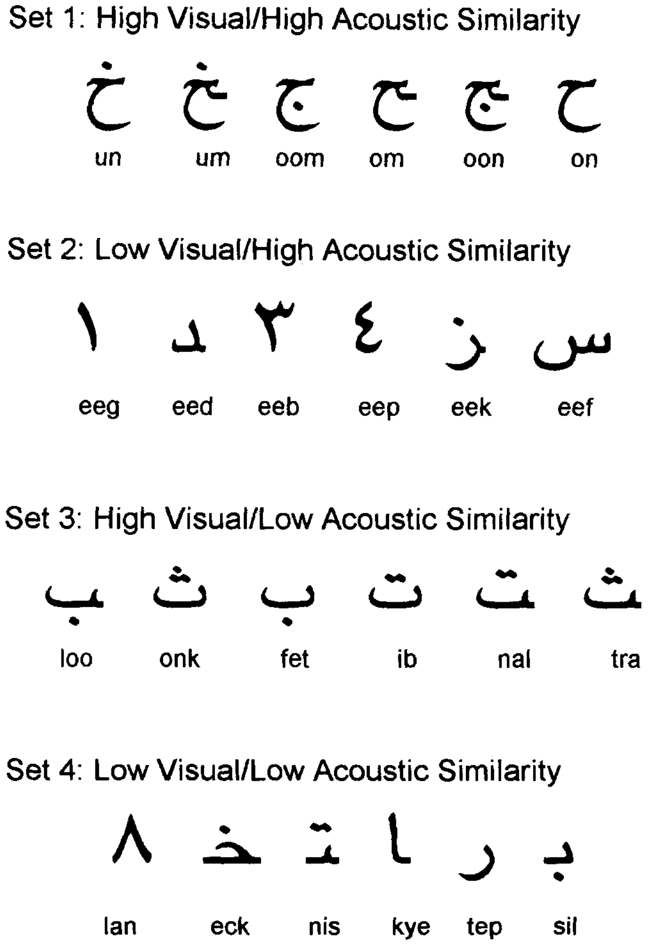

Figure 4. Arabic character sets used in Experiment 3, varying in both visual similarity and in acoustic similarity of the arbitrarily assigned names.

The second testing session was scheduled no sooner than 48 hr and no later than 7 days after the first session. Before each set was tested, names were provided for the characters, and the participant learned the names to criterion. On the first 12 trials, the character appeared, centered on the computer display, with the assigned name in lowercase English characters just below. This was followed without pause by a paired-associates task in which the computer presented one character at a time with no name. The character remained on the screen until the participant responded, at which time the correct name was displayed along with the character. The characters were repeatedly permuted and the set presented until the participant completed three successful runs through the stimulus set without error. Once this criterion was met, the participant completed three sequences of 36 stimuli under 1-back instructions.

Results

Separate ANOVAs were conducted on the proportion correct for Day 1 and Day 2. For each day, age group (younger or older) was a between-subjects variable, and visual similarity (similar and dissimilar) and acoustic similarity (similar and dissimilar) were within-subjects variables. It is important to note that for Day 1, acoustic similarity did not yet have any meaning. The two levels refer to sets of items that on Day 2 would have acoustically similar or dissimilar names. Of course, no names had yet been assigned on Day 1. The mean proportion correct for each condition on each day in Experiment 3 is shown in Figure 5.

Day 1. There was a significant main effect of visual similarity, $F(1, 45) = 79.03, p < .001, MSE = 0.004$, with poorer performance on visually similar items ($M = .87$, $SD = .05$) than on visually dissimilar items ($M = .95, SD = .02$). In addition there was a significant main effect of age group, $F(1, 45) = 17.45, p < .001, MSE = 0.009$, and an interaction of age group and visual similarity, $F(1, 45) = 15.59, p < .001, MSE = 0.009$. Older adults showed a greater difference between visually similar ($M = .82$, $SD = .07$) and visually dissimilar ($M = .94$, $SD = .03$) items than did younger adults ($M = .92, SD = .07; M = .96, SD = .03$). There was a significant interaction of the acoustic similarity of the (not-yet-assigned) names and visual similarity, $F(1, 45) = 12.14, p = .001, MSE = 0.002$. There was a larger effect of acoustic similarity for visually similar items (mean difference, 0.034) than for visually dissimilar items (mean difference, 0.016). The three-way interaction of age group with acoustic and visual similarity approached significance, $F(1, 45) = 2.57, p = .12$.

Day 2. Because there were significant differences among the acoustically similar and acoustically dissimilar stimulus sets on Day 1, even though names had not yet been given, proportions correct on Day 2 were adjusted to compensate for those differences. The adjustment for each participant in each condition was the value that would have removed the difference between high- and low-acoustic-similarity stimuli on Day 1 for each age group, for high- and low-visual-similarity stimuli separately. That is, the assumption was made that the high- and low-acoustic-simi-

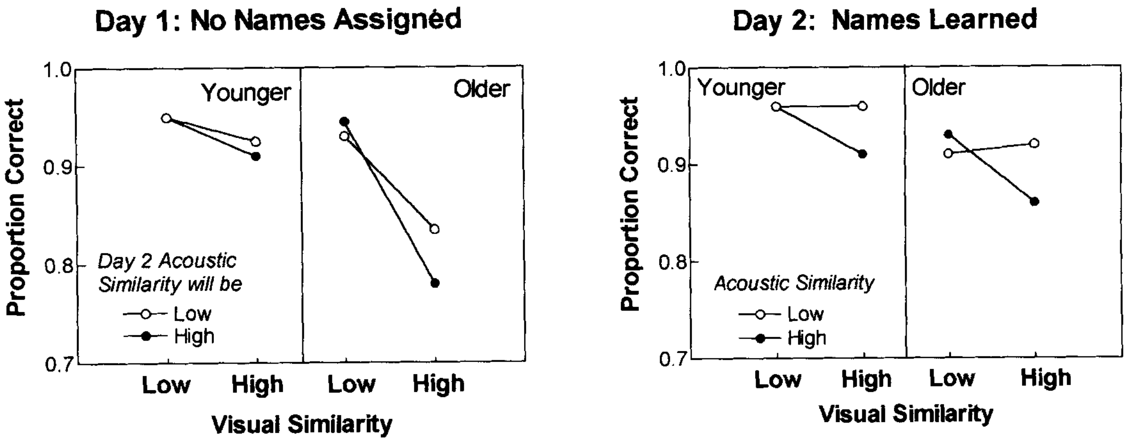

Figure 5. Left: Mean proportion correct in Experiment 3 on Day 1 as a function of visual similarity of the characters in each stimulus set and the acoustic similarity of the names that would be assigned to the characters on Day 2. Right: Mean proportion correct in Experiment 3 on Day 2 as a function of visual similarity and acoustic similarity of the assigned names. Day 2 means are adjusted for Day 1 differences in acoustic similarity.

larity sets should have produced identical results on Day 1 for a particular level of visual similarity and for a particular age group. ANOVA was carried out on the adjusted proportions correct on Day 2. There were significant main effects of visual similarity, $F(1, 45) = 26.27$, $p < .001$, $MSE = 0.084$, and acoustic similarity, $F(1, 45) = 23.84$, $p < .001$, $MSE = 0.090$. Performance was better with visually dissimilar characters ($M = .94$, $SD = .03$) than with visually similar characters ($M = .91$, $SD = .04$), and it was better with acoustically dissimilar names ($M = .95$, $SD = .03$) than with acoustically similar names ($M = .90$, $SD = .04$). The main effects were qualified by a significant interaction of visual and acoustic similarity, $F(1, 45) = 19.53$, $p < .001$, $MSE = 0.082$. Tests of simple main effects showed that visual similarity had no effect when the assigned names were dissimilar, whereas performance was lower with high visual similarity when the assigned names were similar. There were two significant effects involving age: a main effect of age group, $F(1, 45) = 14.05$ $p = .001$, $MSE = 0.007$, and an interaction of age group with acoustic similarity, $F(1, 45) = 24.92$, $p < .001$, $MSE = 0.004$. The interactions of age group with visual similarity and with both acoustic and visual similarity approached significance, $F(1, 45) = 3.19$, $p = .081$, and $F(1, 45) = 3.96$, $p = .053$, respectively. Paired comparisons showed that there was no effect of visual similarity when acoustic similarity was low, either for younger adults, $t(23) = 0.62$, *ns,* or for older adults, $t(23) = 0.29$, *ns*. There was a significant effect of visual similarity when acoustic similarity was high, and that effect was stronger for older adults, $t(23) = 5.55$, $p < .001$, than for younger adults, $t(23) = 3.06$, $p = .006$.

Discussion

The results from Day 1 showed an age-related dissociation. Younger and older adults performed equivalently on the 1-back task with visually dissimilar stimuli, whereas older adults performed significantly worse with visually similar stimuli. Performance for the younger group with visually dissimilar stimuli was close to ceiling, so interpreting the interaction as showing that older adults show a greater deficit with increased similarity is probably unwarranted. The results on Day 2 showed a trade-off between memory for name identity and object identity in both age groups. When the stimuli had acoustically distinct names, there was no effect of visual similarity: Visually similar items were recalled as well as visually dissimilar items. When, however, the items had similar names and were not easily discriminated acoustically, visually similar stimuli resulted in substantially lower performance than visually dissimilar stimuli. There was no sign in either age group that the effects of visual similarity and acoustic similarity were additive, although overall performance was quite high and ceiling effects cannot be ruled out. The benefit of acoustically distinct items was the same for younger and older adults. In fact, performance was equivalent, indicating that acoustic dissimilarity allowed older adults mostly to overcome their greater disadvantage with visually similar items when no names had been assigned or when the assigned names were not readily discriminated.

One interpretation of these results is that subvocal rehearsal is a powerful tool for refreshing the contents of memory, and when it can be used, it is. When the items to be rehearsed are acoustically distinct, both younger and older adults can and do use rehearsal. When distinct names are not available, older adults are substantially more disadvantaged, consistent with an age-related impairment in memory for object identity unaided by subvocal rehearsal. An alternative interpretation is that younger adults can capitalize on the names if they are helpful, that is, when they are dissimilar, and inhibit processing of the names when they are not helpful, that is, when they are phonetically similar. By contrast, older adults are unable to inhibit processing of the names. This works to their benefit when the names are dissimilar but to their detriment when they are similar. The fact that performance in the older adults with low visual similarity but high acoustic similarity fell below their performance in either condition with low acoustic similarity argues in favor of the failure-of-inhibition explanation.

Discussion of Experiments 1–3

There was a clear finding of a lack of dissociation between memory systems in both older and younger adults in Experiment 3. We prefer the explanation that, once acoustically dissimilar names for the unfamiliar Arabic characters were introduced, a task that had tapped memory for object identity became one that tapped memory for name identity. Subvocal rehearsal could then be used effectively to maintain the stimuli in verbal working memory, and visual similarity among the characters no longer had an effect. If the names were acoustically similar, however, there was no such benefit. Although the value of subvocal rehearsal would be reduced as the confusibility of the items was increased, rehearsal should still have been of some value. It seems likely, then, that falling back on the visual features—the object identity—is a strategic choice, whether conscious or not. The one clear finding of a lack of dissociation unique to older adults was an effect of acoustic similarity on memory for spatial location in Experiment 1. This was interpreted as the result of an attempt to use the name of the stimulus as a mnemonic aid, an elaboration. However, an alternative and equally good explanation for the results both of Experiment 1 and Experiment 3 is that older adults are unable to inhibit activation of verbal working memory, even when the names of items are irrelevant or unhelpful for the task. This explanation proposes a passive, reactive response rather than an active, strategic response.

In summary, although working memory for name identity, object identity, and spatial location generally remains separable in old age as it is in youth, there are clear signs of activation of working memory for name identity in tasks that do not require it. This finding is consistent with the evidence from neuroimaging for activation of specialized as well as nonspecialized cortical regions in older adults (e.g., Grady et al., 1992, 1994; Reuter-Lorenz et al., 2000) and from the bilateral presentation study of Reuter-Lorenz et al. (1999). Those age-related differences have been characterized either as dedifferentiation of cognitive function or as recruitment of compensatory processes that younger adults do not require to perform the task. The findings of Experiment 1 are more consistent with recruitment, because the result was improved performance when the stimulus names allowed them to be discriminated more easily. Most important, the interactions of the memory systems are not general. The name identity system is recruited to aid in memory for object identity and spatial location, both of which showed some signs of age-related impairment. This may be due to the powerful and highly practiced tool of subvocal rehearsal associated with the name identity system, or it may be due to an age-related impairment in the ability to inhibit the activation of the name identity system by extraneous verbal material. There was no evidence that object identity or spatial location memory systems were recruited to aid other types of working memory.

Experiment 4

The fourth study used a quasi-experimental design in which younger and older adults each completed 2-back tasks for name identity, object identity, and spatial location. In addition, measures were obtained for simple reaction time (RT) and for match–mismatch RTs using each of the three types of stimuli. This design allowed structural equation modeling of the structure of working memory and speed measures and their relation to age.

Method

There were three 2-back memory tasks, one using English letters (*a, b, d, e, f, g, h, p, q, r, t,* and *y*), one using Arabic characters (Sets 1 and 2 from Experiment 3), and the third using locations of dots. The English letters and Arabic characters were the same size as those used in Experiments 1–3 but were presented at fixation. The dots subtended approximately 0.60° and appeared on the circumference of an imaginary circle, 11.75° in diameter. The timing of displays and the collection of responses were as in the previous experiments. Simple RT was measured by a keypress (period key) to the onset of an asterisk at the center of the display. This was preceded by a warning stimulus (a carat) that appeared just below the location of the asterisk. The stimulus-onset asynchrony was randomly chosen as either 300, 500, 700, or 900 ms. Twenty percent of the trials were catch trials, with no asterisk presented. The warning stimulus was presented for 500 ms and remained present when the imperative stimulus appeared (which remained for 1,500 ms or until a response was given). The intertrial interval was 1,000 ms. There were also three match–mismatch tasks: English letters, Arabic characters, and dot locations. Match–mismatch RTs were obtained by presenting pairs of stimuli; the participant gave one keypress response (period) if the two stimuli matched and another (slash) if they did not. For English letters and Arabic characters, the two stimuli were preceded by a fixation cross at the center of the display and were located with the nearest contour of the letter or character 1.4° above or below fixation. The fixation cross appeared for 500 ms and the letters or characters for 2,000 ms or until a response was given. For spatial location, the onset of the fixation cross was followed 500 ms later by the appearance of two outline boxes, each subtending 9.5° vertically by 11.0° horizontally. Horizontally, the boxes were equidistant from fixation, with the inner contour 1.0° to the left or right of fixation. The left-hand box was displaced upward from the center of the screen by 2.0° and the right-hand box downward by a similar amount. Within each box appeared a small dot, subtending 0.40°. The participant's task was to indicate whether or not the dot was located at the same relative location in both boxes. The boxes and spots remained on for 2,000 ms or until a response was given. In each of the match–mismatch tasks, the intertrial interval was 1,000 ms.

Half of the participants completed all the RT tasks followed by the working memory tasks; for the other half, the order was reversed. Within the RT tasks, the simple RT task was administered first; the order of the match–mismatch tasks was counterbal-

Table 2
Age Comparisons for Tasks in Experiment 4

Task	Age group				
	Younger		Older		
	M	*SD*	*M*	*SD*	*F*(1, 52)
Speed (reaction time)					
Simple reaction	262	34	380	81	44.55**
English letter comparison	721	97	906	98	46.80**
Arabic character comparison	652	87	784	98	26.26**
Dot location comparison	1,221	177	1,323	153	5.09*
Working memory (proportion correct)					
Name identity	.88	.10	.82	.11	4.39*
Object identity	.76	.14	.63	.20	6.89*
Spatial location	.81	.12	.75	.16	2.30

$* p < .05$. $** p < .001$.

anced across participants. Similarly, the order of the three working memory tasks was counterbalanced across participants. Each of the RT tasks had 25 practice trials, followed by 100 experimental trials; data from the practice trials were discarded. There were three runs of 36 stimuli for each of the 2-back tasks.

Results and Discussion

The measures used were mean RT on correct trials for RT tasks and proportion correct for 2-back tasks. As can be seen in Table 2, performance was significantly poorer for older adults than for younger adults—RT was longer and proportion correct was lower—for every task except the 2-back location task.

Models generating the variance–covariance matrix were explored using analysis of moment structures (Arbuckle & Wothke, 1999). The first step in the analysis was to fit a measurement model (shown in Figure 6) to the covariance matrix. (A measurement model has no structural—that is, causal—links. It is equivalent to confirmatory factor analysis.) The three 2-back tasks were modeled as loading on a single working memory factor and the four RT tasks as loading on a single speed factor. This model accounted for 90.8% of the difference between a fully saturated model and a fully independent model, $\chi^2(15, N = 54) = 16.39$, $p = .23$.[2] All of the factor loadings were significantly greater than zero, and examination of modification indices showed no changes that would result in a significant improvement, so the measurement model was deemed to adequately represent the observed data. The first structural model was patterned on that used by Salthouse (1995) and is shown in Figure 7. Age was modeled as affecting working memory only indirectly, through its direct effect on speed; there was no direct causal link from age to working memory. Following Salthouse, working memory was viewed as dependent on speed, which arguably is a relatively basic measure of the intactness of the central nervous system. This model accounted for 86.0% of the variance explained by a fully saturated model, $\chi^2(19, N = 54) = 30.67$, $p = .04$. The coefficients were all significantly greater than zero. Modification indices showed that the fit of the model could be improved somewhat by allowing a direct connection from age to simple RT. Setting the loadings for the match–mismatch tasks on the speed factor to zero so that age affected only simple RT, however, resulted in a significant worsening of the model, $\chi^2(2, N = 54) = 65.10, p < .001$. A second, nonnested structural model was tested, incorporating independent factors for simple RT and for match–mismatch RT, both affected by age and both affecting working memory. This model also provided an adequate fit, $\chi^2(18, N = 54) = 21.60, p = .25$, but the coefficients for the links from simple RT and from match–mismatch RT to working memory were nonsignificant. Finally, we also tested a much-simplified, nonnested model in which the match–mismatch RT tasks were completely dropped, leaving only simple RT. This model, shown in Figure 8, accounted for 94.2% of the variance explained by a fully saturated model, $\chi^2(5, N = 54) = 7.04, p = .22$. All coefficients were significant, and no changes were indicated.

The results are similar to those reported by Salthouse (1995). The three working memory tasks were adequately modeled as manifestations of a single latent variable. There were no indications that the fit of the models would be improved by allowing direct connections from age to any of the memory measures. Further, there was no indication in any of the models of a direct connection between age and the working memory latent variable. Rather, speed accounted for a modest proportion of the variance in working memory (.18 in the first structural model), and age, in turn, accounted for a substantial proportion of the variance in speed (.83 in the first model).

General Discussion

We return now to the paradox that motivated this research. The first three experiments showed that working memory for name identity, for object identity, and for

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[2] In structural equation modeling, chi-square measures the lack of fit between the actual variance–covariance matrix and the best fitting matrix generated from the structural model. Contrary to most statistical analyses, a nonsignificant chi-square value is indicative of an adequate fit of model to data.

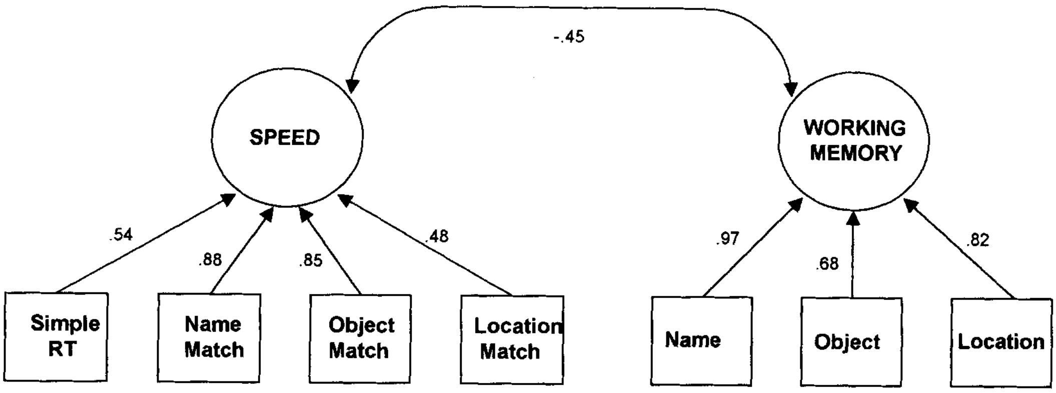

Figure 6. Measurement model for speed and working memory measures. RT = reaction time.

spatial location are separable systems in young adults. Experiments 2 and 3 evidenced age-related differences in memory for spatial locations and visual objects. Myerson, Hale, Rhee, and Jenkins (1999) also reported a greater age deficit in spatial working memory than in verbal working memory. The differences we observed were consistent with less effective encoding of the stimuli by older adults, although poorer performance was not correlated with lower visual acuity in either age group in Experiment 2. The experiments did show evidence of interactions between the name identity system and the other two working memory systems. The evidence admits two rather different interpretations. One interpretation is that the name identity system is recruited in service of the other systems. In this interpretation, both younger and older adults recruited the name identity system in Experiment 3 when acoustically dissimilar names made subvocal rehearsal effective. Older adults appeared to recruit the name identity system in a location memory task in Experiment 1. Attaching the name of the stimulus to the memorial representation of the location apparently aided in retrieval, because the locations of acoustically distinct stimuli were remembered better than those of acoustically confusible stimuli. Thus, we did find evidence for age-related recruitment of one memory system on tasks that targeted other memory systems. The recruitment was quite limited and by no means general. The alternative explanation is that older adults are unable to inhibit the activation of verbal working memory, even when it is inappropriate or inefficient. In Experiment 3 with acoustically similar names, activation of the verbal working memory system is inefficient. In this interpretation, the younger adults are able to inhibit activation of verbal working memory, but older adults are not. Similarly, in the location task in Experiment 1, older adults are unable to inhibit activation of verbal working memory even though the task does not call for it.

Most important, we did not find evidence in the first three experiments for a general dedifferentiation of working memory systems. On the whole, the three working memory systems remained mostly distinct in old age. By contrast, Experiment 4 showed an age-related decline in memory performance that was mediated by reduced speed of cogni-

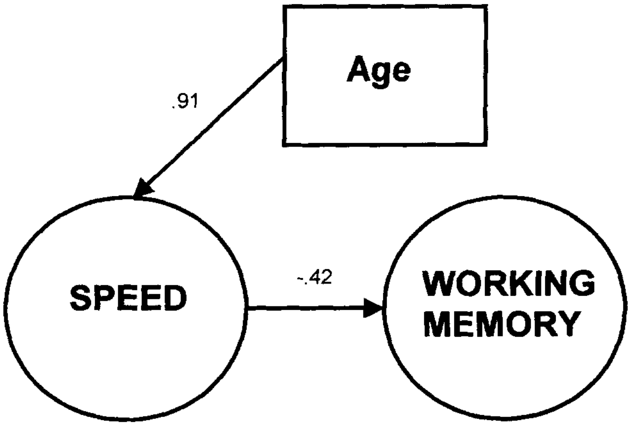

Figure 7. Structural model with age affecting working memory only indirectly, through speed.

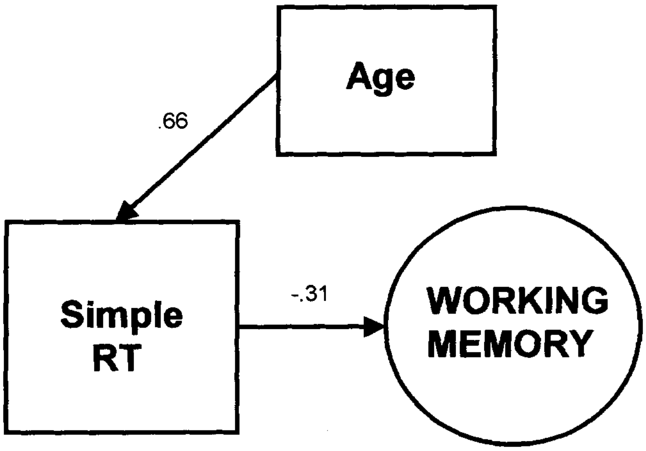

Figure 8. Simplified structural model with simple reaction time (RT) as the sole indicator for speed.

tive processing. The decline was general; there was no evidence for greater decline in some memory systems as opposed to others.

How can these findings be reconciled? Our contention is that they do not have to be reconciled, that there are two phenomena at work. Our speculations are as follows. There are three distinct memory systems. They remain mostly distinct in old age, although there is either some strategic recruitment of the name identity system or some failure to inhibit its activation. Superimposed on this preserved structure is a broad, pervasive change in some underlying neural substrate. This might be a change in some brain structure that plays a critical role in virtually all cognitive activity. For example, this could be an area such as DLPFC that appears to be concerned with a range of executive operations (Cohen, 2000; D'Esposito et al., 1995), or it might be a subcortical structure such as the basal ganglia, which are involved in maintaining a coherent flow of processing by suppressing extraneous activity (Alexander, DeLong, & Strick, 1986; Cummings, 1993; Shallice & Burgess, 1991). More likely, candidates would be impaired in the production or operation of a ubiquitous neurotransmitter (Li & Lindenberger, 1999) or a widespread, nonselective loss of neurons or neural-support cells. The entire system would be degraded by such changes. Measures of basic cognitive function would serve as markers for the level of degradation, accounting for much of the variance in higher level tasks. Although it is circular, we can speculate that RT is an indirect and imperfect marker and therefore accounted for only a modest proportion of the variance in memory performance in Experiment 4. At moderate levels of degradation, the original structure, in this case the different working memory systems, would be mostly preserved. At high levels of degradation, we might expect the structure to break down (Baltes & Lindenberger, 1997). Our contention, then, is that the activation of previously separate systems reported by Reuter-Lorenz et al. (1999) and the undifferentiated decline argued for by Salthouse (1995) need not be mutually exclusive possibilities.

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