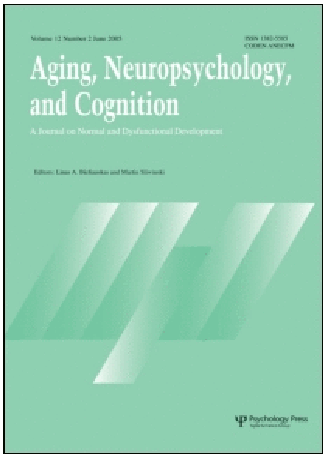

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Repetition Priming Across the Adult Lifespan - The Long and Short of It

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Repetition Priming Across the Adult Lifespan—The Long and Short of It

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ABSTRACT

Previous reports suggest that repetition priming (i.e., enhanced processing of a stimulus after experience with that stimulus) is long lasting and impervious to the effects of age, in contrast to the pattern found with explicit memory. However, the nature of repetition priming in aged individuals remains unclear, as conflicting findings have also been reported. We used a longitudinal design to examine how repetition priming is affected by multiple stimulus repetitions (three presentations) and different delay intervals (no delay, 1 day, 1 week, and 1 month) in young adults, as well as in two groups of aging adults (young-elderly and old-elderly). Our findings extend previous reports that priming is long lasting, even when 1 month intervenes between the initial experience with an item and the subsequent priming test of that item (Cave, 1997), and is relatively impervious to the effects of age (Mitchell, et al., 1990). In addition, a more detailed characterization of priming and the effects of aging was revealed. Although priming is long lasting, remaining significant even at the month delay for all groups, it did decline over time and the rate of that decline differed with age. Both young-elderly and old-elderly groups showed a marked drop-off at 1 day, whereas young adults did not show a decline until 1 week. All groups benefited from multiple repetitions; however, this benefit disappeared at the month delay (in contrast to recognition memory, where the benefit remained significant). These findings support the assertion that repetition priming and explicit memory reflect the operation of distinct systems, and that these systems may undergo different rates of change in aging.

Previous exposure to a stimulus can enhance subsequent processing of that stimulus. For instance, a repeated presentation of an object facilitates naming that object (Brown et al., 1991; Durso & Johnson, 1979; Park & Gabrieli, 1995). It is now commonly accepted that this phenomenon, known as repetition

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priming, is preserved under conditions that cause tremendous decrements to explicit memory (i.e., conscious recollection of context-related information) (Richardson-Klavehn & Bjork, 1988; Tulving & Schacter, 1990). For example, although it is well established that explicit memory performance decreases over time (Ebbinghaus, 1913), there are reports that priming persists, even after long time intervals (e.g., 48 weeks, Cave (1997); 52 weeks, Beatty et al., (1998)). Furthermore, repetition priming has been found to be intact in people who experience difficulties with explicit memory, such as amnesic patients (Cave & Squire, 1992; Verfaellie et al., 1996) and elderly subjects (Mitchell, 1989; Mitchell et al., 1990) (although see Ostergaard (1999) and La Voie and Light (1994), respectively, for conflicting findings).

These different characteristics of repetition priming and explicit memory suggest they may reflect distinct systems (for a review, see Roediger & McDermott, 1993), although these claims remain debated (e.g., McKoon & Ratcliff, 1996; Rouder et al., 2000). The current study aims to clarify the unique qualities of repetition priming—in particular, the longevity and imperviousness to aging noted above.

It is not clear to what degree priming remains intact with advancing age. Although the literature overall suggests that repetition priming remains stable, Light and colleague's (La Voie & Light, 1994; Light et al., 2000) meta-analyses have revealed a slight but consistent priming reduction in elderly subjects across studies. It is possible that this reduction reflects a mild effect that is generally undetected in individual studies, yet exists and may be exacerbated as people enter advanced old age (i.e., over 75 years old). Since age-related memory decline appears to accelerate after the early 70's (Backman et al., 2000; Small et al., 1999), it may be that priming is likewise affected. However, if priming and explicit memory reflect distinct systems, one would expect their course of decline to be different. As few repetition priming studies to date include "old-elderly" participants (see Davis, Trussell, and Klebe (2001) for an exception), it is not clear to what degree priming remains intact across the spectrum of late life.

It is also not clear how robust repetition priming is as people age. While some studies report that both young and elderly persons show no changes over long intervals (Mitchell et al., 1990), other studies report that elderly subjects no longer show repetition priming over long retention intervals (Maylor, 1998). Most inferences about the effects of age on priming are largely drawn from cross-sectional studies. It remains to be seen whether the same subjects (i.e., in a within-subjects design) will show stable priming over long delays (1 month). A longitudinal design allows us to examine this question.

One issue that may contribute to the discrepancies in the literature may be the type of test used to measure repetition priming. Priming has been measured in elderly subjects with text and pictures (for a review, see Fleischman and Gabrieli (1998)) and various methods have been used that differ in the extent to which they are susceptible to explicit memory contamination. For instance, the picture-fragment completion task (Gollin, 1960) requires subjects to identify fragmented pictures of objects. Gradually, more complete versions of the pictures are presented until subjects are able to identify the objects. The procedure is repeated after a set delay, and repetition priming is measured as the savings in identifying repeated fragments. Whereas some studies suggest that priming on fragment completion tasks is intact in elderly subjects (Beatty et al., 1998), other reports suggest that it is somewhat diminished compared with young control subjects (Cherry & St. Pierre, 1998; Maki et al., 1999). Concerns have been raised, however, that the fragment picture completion task lends itself to influence from explicit memory processes (Schacter, 1990; Snodgrass, 1989; Verfaellie et al, 1996), as recalling the identity of the picture can aid performance in young control subjects.

The picture-naming paradigm, on the other hand, appears to be less susceptible to explicit memory influence. The task simply requires people to name a line drawing—some of which have been previously presented, and some of which have not. The measure of priming is the difference in naming time between the repeated objects and newly presented objects. Naming is generally accomplished in under 1 second, too quickly for strategies or conscious recollections to be employed. In fact, such strategies would only serve to impair performance on a naming task, as such processes would take additional time. Evidence suggests that aging does not affect priming on this task (Mitchell & Brown, 1988), even after long delays (e.g., 1 month) (Mitchell et al., 1990). Moreover, meta analyses suggest that, although age differences have been found on a variety of priming response measures, tasks involving latency measures (such as picture naming) yield no age differences in priming (Light et al., 2000; Mitchell, 1993).

Previous reports have not examined, however, whether priming remains intact in very old age (i.e., over 75 years), nor have subjects been observed longitudinally (as their own control) over several delay periods (from immediate tests up to 1 month after initial presentation). Here we examine three adult age groups (young, young-elderly, old-elderly) on tests of repetition priming (picture naming) and explicit memory (recognition) after four different delay conditions (immediate, 1 day, 1 week, 1 month). The combination of these variables in a single experiment should provide a strong test of whether repetition priming is indeed resistant to the effects of time and age.

Our experimental design includes multiple repetitions of items as well. Repetition enhances explicit memory performance after short and long delays (Ebbinghaus, 1913) for both young and elderly subjects (Wiggs, 1993)—as a result, we may avoid having subjects performing at floor in the more difficult memory sessions (i.e., at 1 month, particularly for elderly participants). Although multiple exposures of an item have been shown to increase the magnitude of priming after short delays in both young and elderly subjects (Wiggs et al., 1994), little is known regarding whether this effect remains after long delays. If enhanced priming due to multiple repetitions is not reflected in the long delay conditions (e.g., 1 week, 1 month), then our data would lend further support to the assertion that priming and explicit memory are subserved by different systems and are differentially affected by aging.

METHOD

Participants

Seventy-two subjects were volunteers from the community. All subjects gave informed consent under an approved National Institute of Mental Health (NIMH) protocol and were paid to participate. All subjects were native speakers of English, had good vision (including those corrected to 20/20), no history of major psychiatric or neurological illness, and no tremors. Subjects were asked to rate their general physical health (on a scale from 1 [poor] to 5 [excellent]), and all scored in the upper range.

Subjects were divided into three groups: young, young-elderly, and old-elderly (see Table 1). The three groups had similar levels of education ($p > .10$). Their verbal abilities were similar, as measured by the Wechsler Adult Intelligence Scale-Revised (WAIS-R) (Wechsler, 1981) Vocabulary subtest; however, the young participants scored slightly lower on this test than young-elderly (F [2, 68] = 4.9, $p = .03$) and old-elderly ($p = .07$). The groups did not differ on the Mini Mental Status Exam (Folstein et al., 1975) ($p > .10$). However, as expected, the young participants performed significantly better on the WAIS Digit Symbol subtest than the young-elderly

TABLE 1. Subject Characteristics

	Young Adults (n = 24)		Young Elderly (n = 24)		Old Elderly (n = 24)	
	M	(*SD*)	*M*	(*SD*)	*M*	(*SD*)
Age (years)	27.1	(5.1)	70.0	(2.9)	78.3	(2.8)
	(range 20–38)		(range 65–74)		(range 75–84)	
Education (years)	16.6	(2.2)	17.0	(3.6)	16.2	(2.6)
WAIS vocabulary	50.1	(6.4)	54.2	(5.6)	53.6	(7.3)
MMSE	29.5	(0.6)	29.4	(2.0)	29.3	(0.9)
WAIS Digit Symbol	69.5	(7.5)	52.4	(9.9)	41.8	(9.5)

WAIS = Wechsler Adult Intelligence Scale
MMSE = Mini Mental Status Exam

($F[2,68] = 42.7$, $p < .0001$) and the young-elderly performed better than the old-elderly ($F[2, 68] = 16.1$, $p < .001$).

Materials

Line drawings of objects (n = 480) were used as stimuli (including materials from Berman et al., 1989; Cycowicz et al., 1997; Snodgrass & Vanderwart, 1980). The objects were divided into 48 lists of 10 objects, which were all equated for number and type of category (e.g., furniture, vegetable, clothing) and word frequency (Kucera and Francis (1967) and Cobuild Frequency from the CELEX database) for each object name. The lists were counterbalanced across all variables of interest: delay (immediate, 1 day, 1 week, 1 month), repetition (0, 1, 3), and test type (priming, recognition). An additional list of 16 line drawings was included as fillers (see below).

These lists were combined to create encoding lists, priming tests, and recognition tests for each testing session. Each encoding list included 124 different objects in which the first two and last two were fillers to counteract any primacy or recency effects. The remaining 120 stimuli consisted of 30 objects presented once and 30 presented three times. These were presented in a random order, with the following constraints: The same object never followed itself and the objects presented only once and the third presentation of objects occurred equally often in the first, second, and final third of the list.

Each priming test included 80 objects—half were new objects that had not been seen before, and the other half were 20 objects presented once during the encoding list and 20 that had been seen three times. Each recognition test included 40 objects that were different than those presented in the priming test—20 were new objects, 10 were presented once in the encoding list, and 10 were presented three times in the encoding list.

Procedures

All subjects came in for four sessions of testing (see Table 2). After Session 1, subjects returned the next day for Session 2, then 1 week after Session 2 for Session 3, and 1 month after Session 3 for Session 4. The first session consisted of the following procedures: First, subjects were given the standardized tests described in the participants section. Before the initial object naming task (Session 1 encoding task), subjects were given an orientation session with nonsense objects presented on a computer screen to familiarize them with the task (in terms of presentation rate and response interval). They were asked to say “yes” as each stimulus appeared.

Once they were comfortable with the experimental situation, the encoding object naming task began. Line drawings were presented on the screen, one at a time. Each item was presented for 1500 ms then followed by a fixation cross (500 ms). Subjects were instructed to name each object

TABLE 2. Testing Procedure for Subjects

SESSION 1 (Immediate)	SESSION 2 (1 Day)	SESSION 3 (1 Week)	SESSION 4 (1 Month)
Standardized testing Encode Priming/ Recognition test Recognition/ Priming test Encode	Priming/ Recognition test Recognition/ Priming test Encode	Priming/ Recognition test Recognition/ Priming test Encode	Priming/ Recognition test Recognition/ Priming test

Encode: 64 different items (*30 seen 1 time, 30 seen 3 times, 4 fillers*).
Priming Test: 80 different items (*20 seen 1 time, 20 seen 3 times, 40 new*).
Recognition Test: 40 different items (*10 seen 1 time, 10 seen 3 times, 20 new*).

as quickly and accurately as possible (within a 2-second window) and voice-onset time was recorded by voice key. Each object was presented either one or three times in the series. Subjects were also instructed that they would later be given a memory test for the items presented.

Since type of test was counterbalanced across subjects, half of the subjects were then given a second object-naming task (immediate priming task), in which half of the objects presented were from the initial task and half were new. Subjects were again instructed to name the objects as quickly and accurately as possible. Next, subjects were given a recognition task, in which some objects shown in the encoding task, but not in the priming task, were presented along with novel pictures, and subjects were instructed to indicate whether they had seen them before. The other half of the subjects received the recognition test first, followed by the priming task. Finally, all subjects were given another object-naming task (encoding task for Session 2), and again named objects presented either one or three times.

Each subsequent session was similar; however the sessions began with the priming task (for half of the subjects) or the recognition test (for the other half), in which some of the items from the last encoding task were presented. The experiments were run on a Macintosh G3 computer (Apple, Cupertino, CA) using SuperLab software (Cedrus, San Pedro, CA) to present the pictures and record voice onset times.

RESULTS

The priming results are discussed first, followed by those of the recognition tests. Unless stated otherwise, the significance level was set at .05 for all statistical tests. All figures display standard error bars and asterisks indicate significant differences.

Priming

For all of the naming tasks, subjects had the full 2 seconds to name the object. Items that were misidentified or not named were recorded as errors and removed from analysis. Overall, the number of errors increased with age, F (2, 69) = 13.09, MSE = 69.68. In particular, old-elderly subjects made more errors than young-elderly (F [1, 69] = 17.29, MSE = 1205) and young (F [2, 69] = 21.72, MSE = 1513) subjects (means of 11.0, 6.0, and 5.4 errors, respectively). Items that were not named within the allotted time and items named differently on the encoding and priming tasks were also removed from analyses. These responses also increased with age, F (2, 69) = 18.08, MSE = 87.11 (means were old-elderly = 17; young-elderly = 11, and young = 9.6). The remaining data were submitted to the analyses described below.

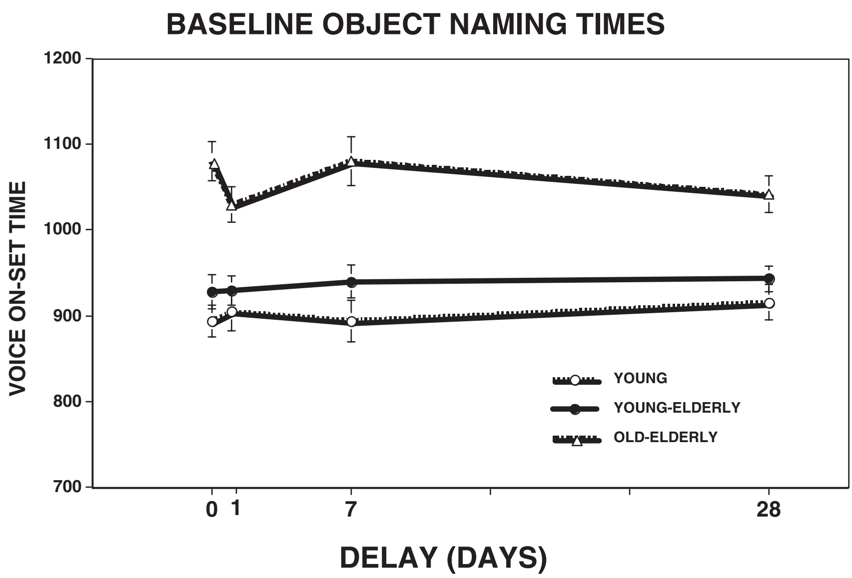
Voice onset times for the three age groups are presented in Table 3. These times were submitted to a 3 (Age: young, young-elderly, or old-elderly) × 3 (Repetition: 0, 1, or 3) × 4 (Delay: immediate, 1-day, 1-week, or 1-month) analysis of variance (ANOVA), with age as a between-subjects factor and repetition and delay as within-subjects factors. In general, elderly subjects named items more slowly than did young subjects, F(2, 69) = 19.79, MSE = 76,650, with young taking 845 ms to name items, young-elderly taking 889 ms, and old-elderly taking 987 ms. Contrasts demonstrated that the slowing was significant for the old-elderly (F = 18.10, MSE = 1,387,538 for young-elderly vs. old-elderly) and approached significance for the young-elderly (F = 3.55, MSE = 272,594, p = .06 for young vs. young-elderly).

TABLE 3. Voice Onset Times for Picture Naming as a Function of Repetition, Delay, and Age

	Delay							
	Immediate		1 Day		1 Week		1 Month	
Repetition	*M*	(*SD*)	*M*	(*SD*)	*M*	(*SD*)	*M*	(*SD*)
Young								
New	894	(91)	907	(109)	897	(120)	916	(99)
1 Rep.	804	(115)	812	(94)	855	(115)	848	(101)
3 Reps.	768	(93)	788	(107)	804	(86)	860	(101)
Young Elderly								
New	928	(96)	929	(85)	940	(96)	943	(72)
1 Rep.	825	(70)	895	(89)	908	(118)	914	(80)
3 Reps.	798	(86)	840	(77)	839	(99)	906	(93)
Old Elderly								
New	1037	(237)	988	(233)	1038	(251)	991	(233)
1 Rep.	876	(208)	926	(216)	970	(214)	930	(214)
3 Reps.	860	(195)	914	(224)	887	(198)	950	(222)

Times are in mean milliseconds based on medians.

FIGURE 1. Mean baseline object naming times for each age group across delays.



This effect did not vary with delay ($F < 1$), suggesting that the baseline naming times were stable across repeated measures (see Figure 1).

This analysis also revealed significant main effects for repetition and delay, as well as Age × Repetition, Repetition × Delay, and Age × Delay × Repetition interactions. Interpreting these interactions was problematic due to the significant age-related difference in naming times. Thus, to provide a measure independent of the different baselines among subjects, voice onset data were converted into percentage priming scores (i.e., the change in naming speed [baseline minus primed] as a proportion of baseline naming speed; see Moscovitch et al., (1986) and Verfaellie et al., (1991)) and submitted to a 3 × 2 × 4 ANOVA.

Percent priming did not vary with age, but did vary with repetition and delay. A main effect of repetition revealed that, overall, subjects showed greater priming for objects presented three times than for objects presented only once, F (1, 69) = 58.20, MSE = 23.25, $\eta^2 = .46$, and this did not vary with age, $F = 2.13$, MSE = 49.63, $p > .10$, $\eta^2 = .06$, (see Figure 2). This priming effect was qualified by a significant Repetition × Delay interaction, F (3, 207) = 12.40, MSE = 26.96, $\eta^2 = .15$, which revealed that this enhanced priming for items with multiple repetitions occurred at all time points except at 1 month. This was true for all age groups (Age × Repetition × Delay, $F < 1$, MSE = 25.88, $\eta^2 = .03$) (see Figure 3).

Priming also decreased over time, as revealed by a significant main effect of delay, F (3, 207) = 24.31, MSE = 70.57, $\eta^2 = .26$. A significant

FIGURE 2. Priming repetition effect (enhanced priming for three items vs. one item) for each age group.

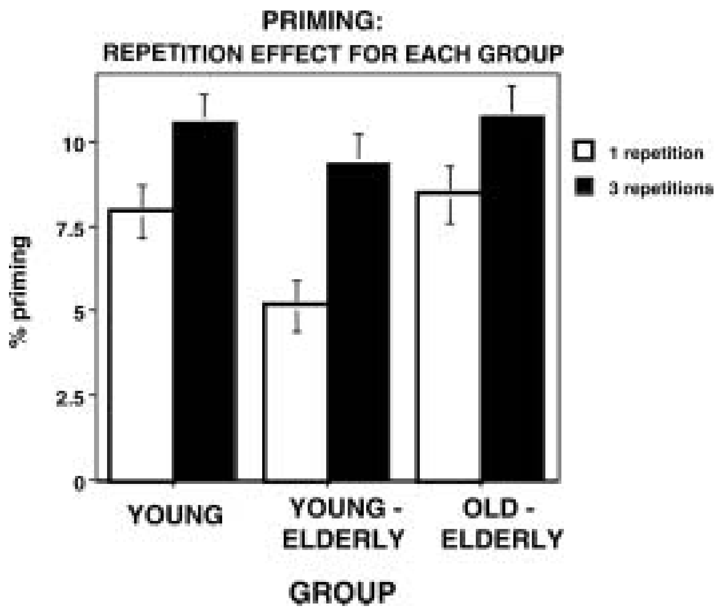
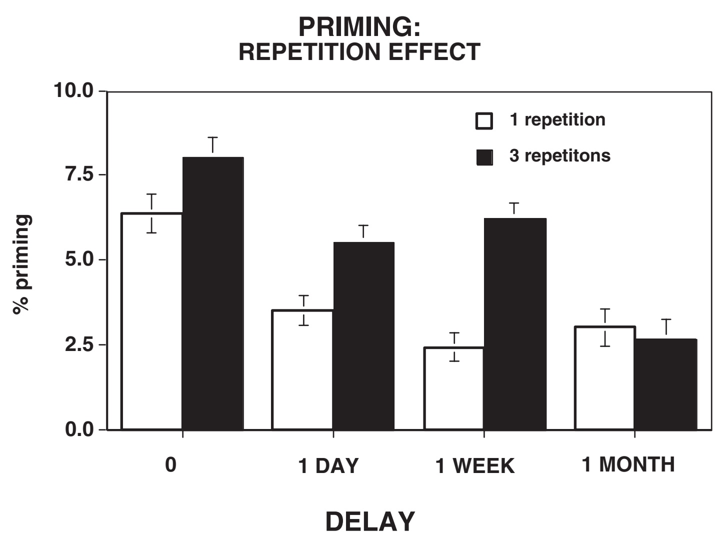
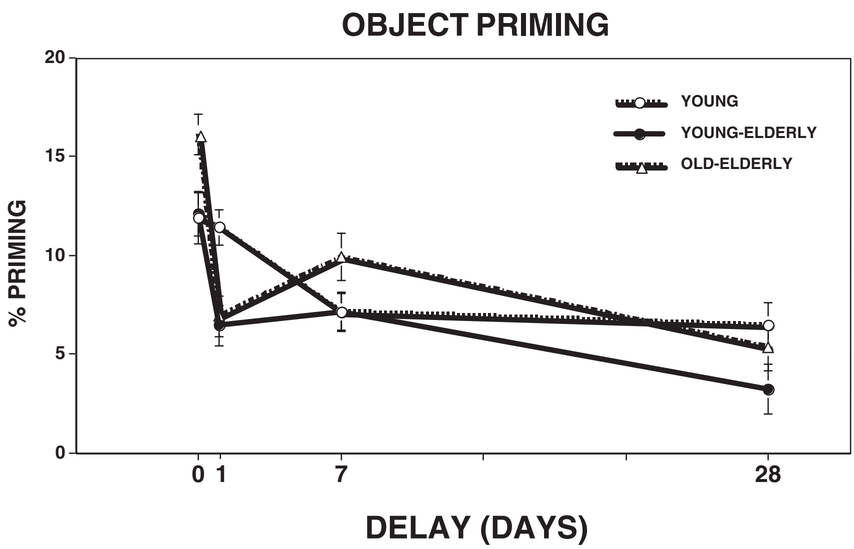


FIGURE 3. Priming repetition effect for all subjects at each delay.



interaction revealed that this change over time differed for the three age groups, F (6, 207) = 2.74, MSE = 70.57, η^2 = .07 (see Figure 4). Separate 2 (Repetition) × 4 (Delay) ANOVAs for each age group demonstrated that

FIGURE 4. Effect of age and delay on priming performance.



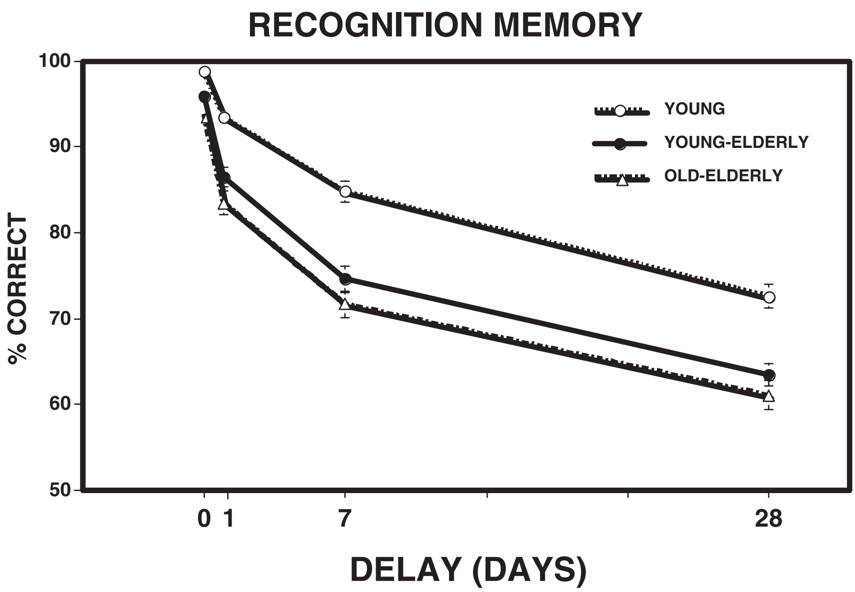
priming for young participants showed a slight, nonsignificant decline between the immediate and 1-day delays ($F < 1$), but dropped dramatically at 1-week ($F = 5.44$, MSE = 441.20) and remained at that level at 1-month. In contrast, the decline in priming occurred earlier in both elderly groups. Priming was significantly different from the immediate priming test at the 1-day delay (young-elderly, $F = 10.91$, MSE = 761.42; old-elderly, $F = 33.36$, MSE = 2027.35). Separate 3 (Age) × 2 (Repetition) ANOVAs for each time-point confirmed this pattern: there was a significant age difference at the 1-day delay, F (2, 69) = 5.47, MSE = 66.39, but not at the immediate ($F = 2.58$, p = .08), 1-week ($F = 2.05$, p > .10), or 1-month ($F = 1.30$, p > .10) delay time points.

Recognition

A 3 (Age) × 2 (Repetition) × 4 (Delay) ANOVA revealed that all subjects were better able to recognize items that were presented three times than presented once, F (1, 69) = 249.72, MSE = 33.19, $\eta^2 = .78$. Overall, the recognition performance varied according to age (F [2, 69] = 39.26, MSE = 128.75, $\eta^2 = .53$). Contrasts showed that young participants were more accurate than both older groups (young-elderly $F = 33.78$, MSE = 4,571.94; old-elderly $F = 63.74$, MSE = 8,626.04), and young-elderly were more accurate than old-elderly ($F = 4.72$, MSE = 638.09). In addition, performance declined over time, F (3, 207) = 370.59, MSE = 67.83, $\eta^2 = .84$ (see Figure 5).

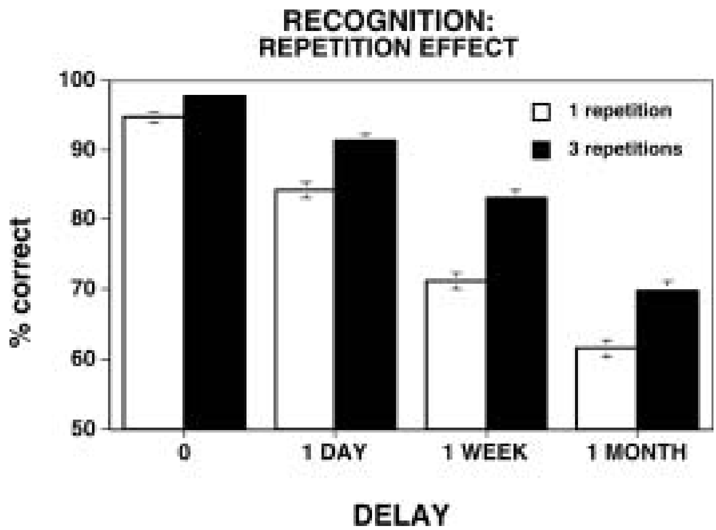
These main effects were qualified by significant interactions. Specifically, the older groups' performance appeared to decline faster than did the

FIGURE 5. Effect of age and delay on recognition performance.



young (Age × Delay interaction, F (6, 207) = 2.76, MSE = 67.83, η^2 = .07). The disparate performance on items that were presented three times compared with those presented once increased over time (Repetition × Delay interaction, F (3, 207) = 15.62, MSE = 31.09, η^2 = .19) (see Figure 6), but more so for young than for elderly (Age × Repetition × Delay interaction, F (6, 207) = 2.67, MSE = 31.09, η^2 = .07). These interactions are difficult to interpret, however, due to ceiling effects at the immediate delay, particularly for young subjects. (One sample *t*-tests were used to check for floor effects in the elderly subjects, and even their memory for single repetition items at the 1-month mark was significantly above chance.) Although the disparate decrements in performance between items presented once or three times appears to become greater with time for young subjects in particular, this effect is exaggerated because their performance was identical at the immediate delay. To address this problem, analyses were also run after removing the immediate delay data. The 3 (Age) × 2 (Repetition) × 3 (Delay) ANOVA revealed that indeed the Age × Delay interaction was no longer significant, $F < 1$; however, the Age × Repetition × Delay interaction remained significant, F (4, 138) = 2.89, MSE = 32.31, η^2 = .08. Separate ANOVAs for the different age groups showed significant Repetition × Delay interactions for young (F [2, 46] = 4.47, MSE = 25.33) and young-elderly (F [2, 46] = 5.97, MSE = 33.08), but the interaction only approached significance in the old-elderly (F [2, 46] = 2.52, MSE = 38.53, p = .09). This suggests that the

FIGURE 6. Recognition repetition effect for all subjects at each delay.



benefits of repetition on explicit memory may begin to break down at long delays (1 month) in advancing age.

Priming and Recognition

The relationship between priming and recognition memory was investigated in two ways. First, we selected old-elderly subjects whose recognition performance was near or at chance (range = 40–60% correct) for items presented once at the 1-month testing session (n = 10) and analyzed their priming data. These subjects showed significant priming (2.85 percent priming; $t = 2.46$, $p < .05$).

Second, we computed correlations between the percent priming and percent correct recognition for each delay and repetition condition. None of these correlations approached significance when all of the data were collapsed across groups (n = 72), nor for each group separately (n = 24). For example, at 1-month, the correlations were .171 and .066 between priming and recognition for items seen once and three times, respectively (n = 72).

DISCUSSION

These findings extend previous reports that priming is long-lasting, even when 1-month intervenes between the initial experience and the subsequent priming test of an item (Cave, 1997; Mitchell, et al., 1990). Moreover, these findings lend some support to previous reports that priming remains stable in later life, despite impaired explicit memory (for reviews, see Craik, 2000; Fleischman & Gabrieli, 1998; Howard & Wiggs, 1993; Light & La Voie, 1993; Wiggs &

Martin, 1998). Our results not only replicate these findings, but also provide a more detailed characterization of priming and the effects of aging.

Delay

Although priming lasts, it does, indeed, decline over time. The decline is relatively steep initially, and then appears to plateau at the longer delays. Moreover, the time course for these decline and plateau functions differs between age groups. Specifically, whereas the initial decrease in priming occurred at the 1-week mark for young subjects, it declined earlier—at the 1-day mark—for elderly subjects (both young- and old-elderly). This is in contrast to Mitchell, et al. (1990), who found that priming decreased for both young and elderly subjects after a 1-day delay. It is not clear why the two studies would have such different drop-off rates for young subjects, since both implemented a picture-naming task with similar delay intervals between initial presentation and tests. However, it is important to note that Mitchell and colleagues report naming time difference scores rather than percent priming. In addition, other aspects of the study designs differed (e.g., Mitchell et al (1990) used a between-subjects design rather than within-subjects and included single repetitions rather than multiple repetitions).

Why aged individuals showed this earlier decline is difficult to interpret. It may be that young and elderly subjects engage the same object-naming systems, but with different time courses. Neuroimaging data for priming tasks have mirrored behavioral data, where repeated stimuli are associated with reduced cortical responses relative to novel items (Buckner et al., 1998; Koutstaal et al., 2001), and young and older adults show similar reductions in neural responses during immediate priming tasks (Backman et al., 1997; Lustig & Buckner, 2004). The effect of repetition delay on the neural correlates of priming, however, shows a more complex picture. Recent neuroimaging findings indicate that repetition priming, as measured by object naming may be mediated by two neural mechanisms. One is a change in posterior cortical regions that may reflect a form of perceptual learning (Wiggs & Martin, 1998). This change is present at very short delays (30 seconds), and is long lasting (up to 3 days, the longest delay tested). The second mechanism occurs in left inferior frontal and insular cortices and is presumed to reflect a progression from effortful to more automatic lexical retrieval. This change develops slowly over the course of 6 hours or more in young adults (van Turennout et al., 2003, 2000). Thus, consistent with reports of age-related anatomical and functional changes in frontal cortices (Cabeza, 2002; Prull et al., 2000; Raz, 2000; although see Mueller et al., 1998), one could speculate that the progression from effortful to automatic lexical retrieval develops more slowly in elderly individuals than in young individuals, resulting in a decrement in priming at one day relative to the immediate testing session. Neuroimaging data on the time course of priming in young and elderly individuals may help to clarify this issue.

In the current study, percent priming did not differ for the three age groups when observed after the 1-day mark. That is, at 1-week and 1-month, all age groups showed equivalent priming. Thus, magnitude of priming was no different for advanced old age than for young-elderly subjects, and these two groups did not differ from young subjects.

Our recognition data replicate decades of work (e.g., Ebbinghaus, 1913) showing that memory accuracy declines linearly with delay. Although priming data also showed a decrease, that decrease was not linear—on the contrary, it stabilized.

Repetition

For both recognition and priming, additional repetitions resulted in better performance. For items presented three times, recognition was more accurate and the magnitude of priming was greater compared to items presented once, and this advantage was observed in young and old participants (also see Wiggs, 1993; Wiggs et al., 1994). However, the effect of time on this enhancement was different for each task. For recognition memory, the advantage of three presentations versus a single repetition was as great after 1 month (8%) as after 1 day (7%), although this enhancement may break down with advancing age. In contrast, the repetition enhancement observed for priming decreased over time: the advantage for items presented three times after 1 day (6%) is all but eliminated by 1 month (0.8%). Again, these results are consistent with the idea that explicit recognition and repetition priming are subserved by distinct memory systems.

Aging

Our recognition data replicated several reports of memory deficits in elderly subjects (for reviews, see Craik, 2000; Light, 1996; Zacks et al., 2000), including old elderly groups (Backman et al., 2000; Small et al., 1999; Zelinski & Burnight, 1997). Age-related deficits were apparent in recognition memory at all time points (with the exception of the immediate test, when ceiling effects confounded any conclusions that could be drawn). The overall magnitude of priming, on the other hand, did not differ between the three age groups. Instead, the effects of age on priming appear to be related to its time course. That is, all subjects showed comparable levels of priming immediately after learning and a comparable decline in priming after a 1 month delay. However, the timing of this decline differed with age, occurring with a day for the elderly but not until a week for the young subjects.

OVERALL CONCLUSIONS

Overall, the results are consistent with the idea that recognition memory and repetition priming are subserved by distinct memory systems, and these systems are differentially affected in aging. Two general threads are particularly compelling. First, whereas aging was associated with significant impairment in recognition memory over time, priming remained intact—even at long delays for elderly subjects. In fact, the group that showed the worst recognition memory (old elderly) showed normal priming; moreover, a group of subjects who performed no better than chance on the recognition test also showed significant priming. Second, both priming and recognition performance were enhanced by repeated exposures to the objects later tested; however, at longer delays, only recognition tests showed this differential enhancement. The enhancement for priming decreased over longer delays.

Our data also provide a more detailed characterization of priming than previous reports, as well as some caveats. First, although priming lasts, it does indeed decline over time. Second, the effect of repetition on priming differs across time. The number of presentations of an item clearly affects the degree of priming for both young and old; however, this differential priming effect decays at 1 month. Interestingly, this did not occur with recognition—the enhanced performance for items presented multiple times actually increased with time, although it is possible that this may begin to break down in the old elderly subjects.

Finally, aging does appear to effect priming. However, the effect is on the time course of decline (i.e., when it occurs) rather than the amount of decline (i.e., magnitude of priming). Questions do remain—is it possible that reduced priming would be found in much older subjects (90 year olds and older)? In a similar vein, is it possible that age effects might be found at greater delay intervals (e.g., 1 year)? Further research may reveal that priming does, indeed, remain intact even in centenarians after a year's delay.

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