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Effect of Repetition Lag on Priming of Unfamiliar Visual Objects in Young and Older Adults

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Abstract

Across three experiments, we examined the effect of repetition lag on priming of unfamiliar visual objects in healthy young and older adults. Multiple levels of lag were examined, ranging from short (one to four intervening stimuli) to long (50+ intervening stimuli). In each experiment, subjects viewed a series of new and repeated line drawings of objects and decided whether they depicted structurally possible or impossible figures. Experiment 1 and 2 found similar levels of priming in young and older adults at short and medium lags. At the longer repetition lags (~20+ intervening stimuli), older adults showed less overall priming, as measured by reaction time facilitation, than young adults. This indicates that older adults can rapidly encode unfamiliar three-dimensional objects to support priming at shorter lags; however, they cannot maintain these representations over longer intervals. In addition to repetition lag, we also explored the relationship between priming and cognitive reserve, as measured by education and verbal intelligence. In the older adults, higher levels of cognitive reserve were associated with greater reaction time priming, suggesting that cognitive reserve may mediate the relationship between aging and priming.

Keywords

aging; perceptual priming; unfamiliar visual objects; implicit memory; object-decision task; cognitive reserve

It is well-established that explicit memory, or the ability to consciously recall or recognize previously encountered information, declines with normal aging (Cabeza, Nyberg, & Park, 2005; Craik, 1994). However, tests used to measure age-related changes in priming, a form of implicit memory, usually reveal smaller or no age differences (Fleischman, 2007; Fleischman & Gabrieli, 1998; Light, Prull, La Voie, & Healy, 2000). Repetition priming refers to a change in the ability to classify, identify, or produce an item resulting from prior exposure to that item. Although it is commonly found that priming of familiar stimuli (i.e., words, familiar faces, or everyday objects) remains intact in healthy older adults

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¹For Experiment 1, only the NART and years of education were available to compute the CR-composite score.

(Fleischman, 2007; Fleischman & Gabrieli, 1998, but see La Voie & Light, 1994), under some conditions, priming of pre-experimentally unfamiliar stimuli (i.e., non-words, unfamiliar objects, or non-sense shapes) declines with aging (Keane, Wong, & Verfaellie, 2004; Soldan, Hilton, Cooper, & Stern, 2009; Wiggs & Martin, 1994). Because priming of unfamiliar stimuli necessarily involves the formation of new memory representations, not just the reactivation of existing traces, these findings suggest that aging may affect encoding, storage, or retrieval processes involving newly formed representations in memory. The current study attempts to further elucidate which cognitive mechanisms contribute to age-related reductions in priming of pre-experimentally unfamiliar information.

Prior studies suggest that when using traditional block-based priming paradigms with encoding and test phases, and unfamiliar stimuli that minimize contributions of pre-existing memory representations, priming in healthy older adults can be reduced or even absent. For example, Keane, et al. (2004) minimized the influence of preexisting semantic, lexical, and sublexical representations by using illegal non-words as stimuli and found priming for younger but not older adults. Similarly, Wiggs & Martin (1994) examined priming for Turkish words in non-Turkish-speaking subjects and observed priming in the young but not older cohort. In addition, Soldan and colleagues (2009) found that older adults demonstrated normal priming for everyday visual objects, but not for unfamiliar objects in three different object-decision tasks in which subjects made judgments about structural possibility, symmetry, or familiarity.

It is important to note that some studies have found age equivalence in priming of novel information (Dew & Giovanello, 2010b; Light, La Voie, & Kennison, 1995; Monti et al., 1997). These studies, however, looked at priming of new associations between familiar stimuli, so the contribution of preexisting memory representations was not fully minimized (but see Light, Kennison, Prull, La Voie, & Zellig, 1996). Schacter, Cooper, and Valdiserri (1992) and Wiggs (1993) did use unfamiliar stimuli and found age equivalence in priming. However, in the Schacter et al. (1992) study the older adults performed at chance so it is unclear exactly on what basis they were responding in the priming task. Further, Wiggs (1993) showed age equivalence in priming of unfamiliar Japanese ideograms only when stimuli were presented three or more times during encoding, but not for stimuli presented once. Thus, more research is needed to resolve these inconsistencies and to determine the conditions that produce age-related differences in priming.

In a typical block-based priming study, subjects are presented with 20-100 stimuli during the encoding phase which are later repeated during the test phase along with an equal number of new stimuli. This means that age-related reductions in priming observed in block-based paradigms (e. g., Keane et al., 2007; Soldan et al., 2009; Wiggs & Martin, 1994) may reflect the inability of older adults to maintain novel memory representations over time (i.e., from the encoding to the test phase) and/or over interference from intervening stimuli. Supporting this view is the finding that when priming is measured over very short delays (i.e., seconds), there is no effect of age on priming in the same structural possibility task (Soldan, et al., 2008) in which older adults showed reduced priming when implemented as a block-based task (Soldan et al., 2009).

Therefore, the primary goal of the present study was to evaluate the hypothesis that older adults can encode unfamiliar objects to support priming over short delays, but are unable to maintain this information over longer periods and/or interfering information. We evaluated this hypothesis by testing two predictions. First, we predicted that at short repetition lags (i. e., seconds) there would be no age difference in priming of unfamiliar stimuli, consistent with the proposal that aging does not affect the ability to encode novel information. Second, at long repetition lags (i. e., minutes or more) older adults will show less priming than young

adults. This would support the view that aging reduces the ability to maintain newly formed memory representations.

Over three experiments, we tested these predictions by examining priming at varying repetition lags in each age group. Experiment 1 examined three lags, ranging from short (on average 2.5 intervening items, or 9 sec) to medium (on average 9.5 intervening items, or 33 sec), and medium-long (on average 28 intervening items, or 98 sec). Experiment 2 included a short lag condition (on average 1.5 intervening items, or 5 sec), a long lag condition (on average 52 intervening items, or 3 min) and a delayed condition, in which a 15 min time delay was added to stimuli repeated after a long lag (on average 52 intervening items, or 18 min). Experiment 3 included only the delayed condition. As in Soldan et al. (2008) and (2009), priming was measured using the possible/impossible object-decision task.

When considering the effects of aging on priming, it is important to note that priming effects in classification tasks like the possible/impossible object-decision test represent the net result of different underlying processes that can reinforce each other or interfere with one another (e.g., Horner & Henson, 2009, 2011; Moutsopoulou & Waszak, 2012). Both perceptual learning of stimulus-specific information (Henson, 2003; Horner & Henson, 2011; Soldan et al., 2012) and learning of stimulus-response and stimulus-decision associations (e.g., Logan, 1990; Horner & Henson, 2009; Soldan et al., 2012) have been shown to contribute to priming in this and other classification tasks. This means that age-related reductions in priming at long repetition lags may reflect a decrease in the maintenance of newly encoded perceptual information and/or a decrease in the maintenance of associations between newly encoded perceptual information and decision or response representations. Because systematic investigations of the effects of aging on the processes that underlie priming are currently lacking, we did not have a-priori hypotheses about which specific process(es) would be affected by aging.

In addition to the primary goal of the study, we were also interested in examining whether differences in priming relate to individual differences in cognitive reserve. The concept of cognitive reserve (CR) proposes that differences in the way people process tasks are related to differential rates of cognitive decline in aging. For example, many studies have shown that a set of lifetime experiences, including education, occupational attainment, and engagement in leisure activities, are associated with less memory decline in normal aging and a lower risk of developing dementia (see Stern, 2009 for a review). Although previous studies have examined associations between CR and measures of explicit and/or working memory, the relation between CR and implicit memory has not been examined. This probably stems from the fact that priming and other forms of implicit memory remain relatively intact with aging. However, to the extent that priming of pre-experimentally unfamiliar stimuli shows age-related reductions, the question arises whether differences in priming across subjects are related to differences in CR.

General Method

The Internal Review Boards of Columbia University, the University of Massachusetts, Dartmouth and Tufts University approved this study.

Participants

Young adult subjects were students at Columbia University and UMass Dartmouth. They were compensated \$15 per research hour, or given course credit for participation. Older adults were recruited from the communities surrounding Columbia University, UMass Dartmouth, and Tufts University through ads and existing subject databases.

All participants reported normal or corrected-to-normal vision, and were free from neurological and psychiatric disease as determined via questionnaire. Older participants were screened to ensure the absence of dementia using the Dementia Rating Scale (all scored at or above 135; Mattis, 1988). Subjects' performance on the neuropsychological tests was also reviewed to ensure that they were free of dementia and mild cognitive impairment. All participants were administered the Selective Reminding Test (Buschke & Fuld, 1974), which measures explicit verbal long-term memory, the New Adult Reading Test—North American Version (Grober & Sliwinski, 1991; Nelson, 1982), a measure of verbal IQ, the multiple-choice version of the Benton Visual Retention Test (BVRT), which measures visual perception and recognition memory (Benton, 1955), the Controlled Oral Word Association Test – CFL (Benton & Hamsher, 1976), a measure of verbal fluency, and the Wechsler Adult Intelligence Scale-Vocabulary Subtest (Wechsler, 1981), a measure of verbal intelligence. The latter two tests were administered in Experiments 2 and 3 only. See Table 1 for a list of participant characteristics.

Stimuli—Ninety-six line drawings of three-dimensional structurally possible and 96 structurally impossible objects were used as stimuli across all three experiments (see Figure 1). The possible objects have a globally coherent three-dimensional structure, whereas the impossible objects contain surface and edge violations that make it impossible for them to exist as real three-dimensional objects. Both types of figures were unfamiliar to participants.

Cognitive Reserve Measures—A composite CR score was calculated by averaging the score for NART-IQ, WAIS-vocabulary subtest, and years of education, first converting each value to z-scores¹. Measures of intelligence, particularly verbal intelligence, are commonly included when attempting to model CR (Albert & Teresi, 1999; Alexander et al., 1997). Supporting this approach, a prospective study by Richards and Sacker (2003) found that intelligence at age 53 was uniquely influenced by adult occupation, educational attainment, and childhood cognition. Accordingly, basing a measure of CR on variables such as intelligence means that CR is not inflexible, but rather can change over the course of one's lifetime. Educational attainment, on the other hand, is the most commonly used proxy for CR, and is often combined with other predictors into a composite latent variable as in the present study. As it is long-known that education is a strong determinant of future employment and income level (Beckels & Truman, 2011), educational attainment directly correlates with other CR proxies such as socioeconomic status and occupational attainment. As these secondary variables themselves predict access to healthcare, morbidity, and unhealthy behaviors (Adler & Rehkopf, 2008; Adler & Stewart, 2010), it follows that such variables would be considered in any model attempting to predict individual differences in cognitive decline. See Stern (2009) for further review regarding CR proxies.

Procedure—First, subjects' visual acuity was tested using a Snellen chart. Then, subjects completed the object-decision priming task, which was presented as a visual perception experiment. It was not mentioned that subjects' memory would be assessed. All subjects completed six practice trials at the beginning of the experiment that were excluded from all analyses. The priming task was followed by the DRS. The remaining neuropsychological tests were completed between blocks of the priming task or at the end.

Each trial of the object decision test lasted 3.5 seconds, beginning with a 500 ms central fixation-cross. Fifty ms after fixation offset a stimulus was presented for 1500 ms. Subjects responded any time during stimulus presentation or up to 950 ms after stimulus offset. At the end of the response period (2450 ms) was a 500 ms interstimulus interval. Subjects were instructed to classify each object as possible or impossible. Both speed and accuracy of responding were emphasized. Half of the participants in each age group pressed a key with their left index finger to indicate an object was possible, and another key with their right

index finger to indicate an object was impossible. For the other half of the subjects, the assignment of keys to response categories was switched so that object type would not be confounded with response hand. The stimuli were rotated across conditions and blocks.

General Data Analysis—An α -level of 0.05 was adopted for all analyses. Analyses involving independent variables with more than two levels were corrected for violations of the sphericity assumption using the Huynh-Feldt corrected p values. To first assess the presence of priming within each age group we performed separate repeated measures ANOVAs for the young and older adults using the raw accuracy and reaction time (RT) data, with presentation (new vs. old), object type (possible vs. impossible), and lag (3 levels) as within subject factors. Because this study is concerned with priming, significant interactions and main effects are only reported if they involved the factor of presentation. To follow up effects involving presentation, individual priming scores were calculated for each lag condition and submitted to one-sample t -tests.

To evaluate the effect of age on priming, repeated measures ANOVAs were conducted on the priming scores in each experiment, with age group as a between subjects factor. For RT, proportional priming scores (i.e., percentage decrease in RT for repeated compared to new objects) were used when comparing across age groups because of the large age difference in baseline RT. To assess where age differences in priming are present, independent t -tests, collapsed across object type, were performed at each lag. We collapsed across object type to increase power and because we did not hypothesize differential age effects for possible and impossible objects. Trials with RTs faster than 300 ms ($<0.1\%$ of correct RTs in each experiment and age group) were excluded from all analyses. The RT analyses were based on correct trials only. Unless stated otherwise, p -values are two-tailed.

To determine the relationship between CR, priming, and overall task performance, we correlated the CR composite score with mean proportional RT priming, mean accuracy priming, mean accuracy and mean RT, collapsing across object type and lags in each case. The results were very similar when raw RT priming scores were used instead of proportional scores.

Experiment 1

Design

Subjects completed 6 blocks of 56 trials each of the possible-impossible object-decision priming task. In each block, subjects viewed a different set of 16 possible and 16 impossible objects: 4 possible and 4 impossible objects were repeated after a short lag (1 - 4 items); 4 possible and 4 impossible objects were repeated after a medium lag (8 - 11 items); 4 possible and 4 impossible objects were repeated after a medium-long lag (18 - 41 items, mean lag = 28 items for both possible and impossible objects); and 4 possible and 4 impossible objects were presented only once during the last 16 trials of a block. These objects served as comparison stimuli (i.e., new objects) for objects in the medium-long lag condition. Thus, across all six blocks, there were 24 possible and 24 impossible objects in each condition (i.e., short lag, medium lag, medium-long lag, and new).

All of the short and medium lag repetitions occurred within the first 40 trials of a block. The second presentation of objects in the medium-long lag condition occurred in the last 16 trials during which the new objects were also presented. For each block, a different repetition sequence was used, with the order of blocks counterbalanced across subjects in a double-diagonal Latin square. See Figure 2 for a sample trial sequence of a block.

Data Analysis

To facilitate comparisons of priming across lags, priming for all conditions was calculated as the difference in accuracy or RT between repeated items and “new” items. For the short lag condition, new items comprised the first presentation of items in the medium-long lag condition; for medium-lag items, new item consisted of the first presentation of short-lag stimuli; and for the medium-long lag condition, new items referred to the comparison stimuli presented at the end of the block. This way, the number of items per condition was the same for all three lags and priming is not confounded by general task practice effects occurring within blocks. The overall pattern of results was the same when priming for the short and medium-lags was calculated by directly comparing the first and second presentation of the same item.

Results

Young Adults

Accuracy: A main effect was found for presentation, $F(1, 23) = 12.51, p = .002$, partial $\eta^2 = 0.35$, establishing the presence of overall priming. There was no interaction between presentation and lag ($F < 1$), indicating similar levels of priming across lags. Collapsing across lags, priming was significant for possible objects, $t(23) = 3.65, p = 0.001$, but not for impossible objects, $t(23) = 1.03, p = .3$. See Table 2 for mean accuracy and accuracy priming scores.

Reaction Time: There was a main effect of presentation, $F(1, 23) = 175.33, p < 0.001$, partial $\eta^2 = 0.88$, indicating the presence of overall RT priming. The presentation by object type interaction was significant, $F(1, 23) = 5.07, p = 0.03$, partial $\eta^2 = 0.18$, reflecting greater priming for possible than impossible objects. Priming was significant for both types of objects at each lag (all $p < 0.0001$). See Table 3 for mean reaction times and RT priming scores.

Older adults

Accuracy: A main effect of presentation was detected, $F(1, 23) = 22.61, p < .001$, partial $\eta^2 = 0.50$, establishing the presence of overall priming, but priming did not differ as a function of lag ($F = 1$). Averaging across lags, significant priming was observed for possible objects, $t(23) = 4.68, p = .0001$, but not for impossible objects, $t(23) = 1.47, p = .16$. See Table 2 for means.

Reaction Time: Older adults showed significant priming, as indicated by a main effect of presentation, $F(1, 23) = 72.37, p < 0.001$, partial $\eta^2 = 0.76$. The presentation by object type interaction was significant, $F(1, 23) = 6.60, p = 0.02$, partial $\eta^2 = 0.22$, indicating more priming for possible than impossible objects. *T*-tests found significant priming for both object types at each lag (all $p < 0.03$).

Comparison across age groups—An ANOVA on accuracy priming scores showed no effect of age or interaction between age and lag, indicating similar levels of accuracy-based priming in both age groups at all lags. For proportional RT-priming, there was a main effect of age, $F(1, 23) = 4.03, p = .05$, partial $\eta^2 = .08$, revealing less RT-priming in the older than the young adults. Although the interaction between age group and lag did not reach significance, planned comparisons were performed comparing proportional RT-priming at the short and longest lag conditions. As predicted, there was no age difference in at the short lag, $t < 1$, but at the longest lag, older adults showed significantly less priming, $t(46) = 1.85, p = .03$ (one-tailed). See Figure 3 for priming scores at each lag.

Cognitive Reserve: For the older subjects, a positive relationship was found between the CR composite score and overall accuracy on the object-decision task, $r = 0.52$, $p = 0.009$. The CR composite score also positively correlated with overall proportional RT priming, $r = 0.57$, $p = 0.003$. There was no relation between CR and priming, mean accuracy, or mean RT in the young adults.

Discussion

The main findings from Experiment 1 can be summarized as follows. First, there was no age difference in overall priming when the repetition lag was short, replicating previous behavioral results from an imaging study (Soldan et al., 2008). This finding suggests that the observed lack of an age difference in priming at short lags in the possible/impossible object decision task is reliable and not specific to older subjects who are able and willing to participate in imaging studies. Second, the older adults showed less RT priming at the longest lag than the young adults. However, because the decrease in RT-priming in the older adults did not reach significance, this finding needs to be interpreted carefully and requires replication. The third major finding was that CR, defined by the composite score of individual CR proxies, predicted both accuracy on the object-decision task, and overall priming measured by RT in the older adults. Finally, there was more priming for possible than impossible objects in both age groups. This finding is consistent with many prior studies of priming using the possible/impossible object-decision task, where priming is typically smaller or absent for impossible objects (Schacter, Cooper, & Delaney, 1990; Schacter et al., 1992; Soldan et al., 2008, 2009).

As experiment 1 only provided limited support for the hypothesis that normal aging is associated with a decrease in the ability to maintain priming of unfamiliar stimuli over long intervals, the aim of Experiment 2 was to replicate and extend the findings of Experiment 1. That is, the trend in decreased priming for older adults in the first experiment suggests that if the time between study and test were increased further, a greater age difference would be revealed. Thus, in Experiment 2 we increased the number of stimuli intervening between object presentations and added a 15 min delay prior to the test phase. In addition, we sought to replicate the demonstrated relationship between CR and priming.

Experiment 2

Methods

Stimuli and Design—Subjects viewed 64 objects that were repeated after a short lag (1- 2 intervening items), 64 objects that were repeated after a long lag (48 - 58 intervening items, mean lag = 52 items for both object types), and 64 objects that were repeated after a 15 min delay (48 - 58 intervening items, mean lag = 52 items for both object types). Half of the objects in each condition were possible and half were impossible.

Subjects completed 4 blocks of trials, separated by 15 min delay periods during which subjects were administered neuropsychological tests. In each block, subjects viewed 8 possible and 8 impossible objects that were repeated after a short lag and 8 possible and 8 impossible objects that were repeated after a long lag. The short lag repetitions were distributed roughly equally throughout each block. By necessity, the first presentation of objects in the long-lag condition occurred in the first half of the block, while the second presentation of long-lag items occurred in the second half of the block. Additionally, in blocks 1 and 3 subjects saw 11 possible and 11 impossible objects that were repeated in blocks 2 and 4, respectively. These items constituted the delayed condition. In block 2, subjects saw 10 new possible and 10 new impossible objects that were repeated in block 3. The number of delayed items differed slightly across blocks so that the total number of

stimuli per condition would equal 32 for all lags. The first presentation of objects in the delayed condition occurred in the second half of a block, whereas their second presentation occurred in the first half of the next block. Using this stimulus arrangement, the number of items intervening between repetitions in the long lag and in the delayed conditions was the same, keeping item-specific interference constant across conditions. Each block used a different repetition sequence.

Procedure—Trials were administered in the same manner as in Experiment 1.

Data Analysis—For the long lag condition, priming was calculated as the difference in performance between repeated long-lag objects (occurring in the second half of each block) and new items presented in the second half of each block. New items in this case consisted of the first presentation of objects in the short lag and delayed lag conditions. For the delayed lag condition, priming was calculated as the difference in performance between repeated delayed-lag objects (which occurred in first half of blocks 2, 3, and 4) and new objects that were presented in the first half of blocks 2, 3, and 4. These consisted of the first presentation of objects in the long lag and short lag conditions. Calculating priming in this manner accounts for practice and fatigue effects that might occur throughout a block. For objects in the short lag condition, priming was calculated as the difference between presentations 1 and 2 and by comparing presentation 2 to new items. New items consisted of the first presentation of objects in the long-lag or delayed-lag conditions that were closest in the trial sequence to the repeated short-lag item. The same pattern of results was obtained using both approaches. Only the results using new items as the baseline are presented below so that priming at all lags represents a contrast between repeated and new items.

Results

Young Adults

Accuracy: A main effect was found for presentation, $F(1, 23) = 11.02$, $p = 0.003$, partial $\eta^2 = 0.32$, establishing the presence of overall priming. No interactions were significant (all $p > 0.2$). Priming was reliable for possible objects at the short lag, $t(23) = 2.46$, $p = 0.02$, and the long lag, $t(23) = 3.27$, $p = 0.003$, and approached significance in the delayed lag, $t(23) = 1.81$, $p = 0.08$. Priming was not observed for impossible objects at any lag (all $p > 0.05$). See Table 4 for means.

Reaction Time: There was a main effect of presentation, indicating significant overall priming of response times, $F(1, 23) = 25.71$, $p < 0.001$, partial $\eta^2 = 0.53$. The object type by presentation interaction reflects greater priming for possible than impossible objects, $F(1, 23) = 18.00$, $p < 0.0005$, partial $\eta^2 = 0.44$. Significant interactions were also found between lag and presentation, $F(2, 46) = 12.72$, $p < 0.0001$, partial $\eta^2 = 0.36$, and between lag, presentation, and object type, indicating a greater decrease in priming with increasing lags for impossible than possible objects, $F(2, 46) = 5.16$, $p = 0.01$, partial $\eta^2 = 0.18$. Reliable priming was observed for possible objects at the short, $t(23) = 5.26$, $p < 0.0001$, long, $t(23) = 5.45$, $p < 0.0001$, and delayed lags, $t(23) = 3.47$, $p = 0.002$. For impossible objects priming was only significant at the short lag, $t(23) = 4.64$, $p = 0.0001$. See Table 5 for means.

Older Adults

Accuracy: The main effect of presentation only approached significance, $F(1, 23) = 3.28$, $p = 0.08$. There was, however, an interaction between object type and presentation, $F(1, 23) = 11.89$, $p = 0.002$, partial $\eta^2 = .34$, indicating more priming for possible than impossible objects. Significant positive priming was observed for possible objects at the short, $t(23) = 3.49$, $p = 0.002$ and delayed lags, $t(23) = 2.26$, $p = 0.03$, but not at the long lag, $t(23) = 1.04$,

$p = 0.3$. Significant negative priming was evident for impossible objects at the delayed lag, $t(23) = 3.59$, $p < 0.005$. See Table 4 for means.

Reaction Time: There was a main effect for presentation, $F(1, 23) = 14.54$, $p < 0.001$, partial $\eta^2 = 0.39$, revealing overall priming of response latencies. The interaction between object type and presentation approached significance, indicating more priming for possible than impossible objects, $F(1, 23) = 3.87$, $p = 0.06$, partial $\eta^2 = 0.14$. The interaction between presentation and lag was also reliable, $F(2, 46) = 6.71$, $p = 0.003$, partial $\eta^2 = 0.23$, and provides evidence for a decrease in priming with increasing lags. Priming was significant for possible objects at the short, $t(23) = 6.75$, $p = 0.001$ and long lags, $t(23) = 2.75$, $p = 0.01$, and approached significance at the delayed lag, $t(23) = 1.83$, $p = 0.08$. Priming of impossible objects approached significance at the short lag, $t(23) = 2.00$, $p = 0.06$, but was not reliable at the long lag. At the delayed lag, there was a trend for slower responses to repeated impossible objects, $p = 0.09$. See Table 5 for means.

Comparison across age groups—For proportional RT priming a three-way interaction between lag, object type, and age group was significant, $F(2, 92) = 3.14$, $p < 0.05$, and the main effect of age approached significance, $F(1, 46) = 2.94$, $p = 0.09$, partial $\eta^2 = 0.06$. For accuracy priming, there were interactions between object type and age group, $F(1, 46) = 6.42$, $p = 0.01$, partial $\eta^2 = 0.12$, and between lag, object type, and age group, $F(2, 92) = 3.28$, $p = 0.04$, partial $\eta^2 = 0.16$. Follow up analyses found that for both accuracy and RT, there was no age difference in the magnitude of priming at short lags (both $p > 0.3$). To assess the age difference in long-lag priming, we collapsed across the long and delayed lags because there was no difference between them for both accuracy and proportional RT priming (all $p > 0.19$). The older adults showed less proportional RT priming at the long lags $t(46) = 1.83$, $p = 0.037$ (one tailed), but similar levels of accuracy-based priming, $t(46) = 1.26$, $p > 0.1$ (one tailed). The priming scores for each age group are shown in Figure 4.

Cognitive reserve: For the older adults, CR positively correlated with overall accuracy, $r = 0.49$, $p = 0.02$, while the correlation with proportional RT-priming only approached significance, $r = 0.36$, $p = 0.08$. No significant correlations were found for the young adults.

Discussion

Consistent with the results from Experiment 1, young and older adults showed similar levels of priming of unfamiliar objects when tested after a short repetition lag. However, the older individuals showed less RT-priming in the long lag conditions, where many stimuli intervened between the first and second presentation of repeated stimuli. This provides further evidence that the ability to maintain priming of novel stimuli over time and interfering information declines with normal aging. As in Experiment 1, CR mediated the effect of age on priming and task performance, such that older adults with higher levels of CR had greater accuracy in the object-decision task and showed more priming, as measured by RT-facilitation.

The lack of a difference in priming at the long and delayed lag conditions is of interest, as it suggests that the added delay had little effect on priming. It might also suggest that the age-related decrease in priming at long lags largely reflects increased susceptibility to interference from intervening stimuli among the older adults, rather than greater memory decay. Consistent with this interpretation, there is evidence from word fragment priming tasks that older adults show greater interference effects in implicit memory than young adults (Ikier & Hasher, 2006; Ikier, Yang, & Hasher, 2008). We speculate that the increased interference among the older adults is less due to proactive mechanisms because this might predict an age difference in short-lag priming toward the end of the experiment, following

exposure to many interfering stimuli. However, when we averaged across the short-lag conditions of Experiments 1 and 2, there was no age difference in short-lag priming in the second half the experiment (i.e., blocks 4-6 for Experiment 1 and blocks 3 and 4 for Experiment 2), $p > 0.38$ for both accuracy and proportional RT priming. Rather, newly encountered stimuli might interfere retroactively with the retrieval or storage of previously encoded stimuli and their associated responses.

Experiment 3 was designed to replicate the age-associated reduction in priming at long repetition lags using a “standard” study-test design, with single study and test phases, which is more common than the interleaved stimulus presentations and multiple blocks used in Experiments 1 and 2. Because the first two experiments, as well as in Soldan et al. (2008), were consistent in showing no effect of age on overall priming at short repetition lags, Experiment 3 only included a delayed lag condition. This also allowed us to increase the number of stimuli to increase statistical power.

Experiment 3

Methods

Stimuli and Design—The same stimuli and trial structure were used as in the first two experiments. The stimuli were randomly divided into 3 lists of 64 stimuli (32 possible, 32 impossible). Each subject saw one of these lists at encoding and the same list plus one new list at test. Thus, 64 items were presented at encoding (32 possible and 32 Impossible), and 128 items (64 old and 64 new) were presented during the test phase. The lists were rotated across conditions and subjects. For example, some subjects saw list 1 at encoding and lists 1 and 2 at test, some saw list 1 at encoding and lists 1 and 3 at test, and so forth. Within each list, the items were randomized during encoding and test for each subject. As in the delayed condition in Experiment 2, the encoding and test phases were spaced by a 15-minute interval, in which neuropsychological tests were administered.

Data Analysis—Because there was only one repetition lag, we conducted 2 (presentation) by 2 (object type) ANOVAs, separately for reaction time and accuracy scores, for each of the age groups. Priming scores were calculated by comparing repeated items to new items presented in the test phase.

Results

Young Adults

Accuracy: A main effect of presentation was found, $F(1, 35) = 6.43$, $p = 0.016$, partial $\eta^2 = 0.16$. This indicates the presence of overall priming in young adults. No other effects were significant.

Reaction time: The main effect of presentation was significant, $F(1, 35) = 12.00$, $p = 0.001$, partial $\eta^2 = 0.26$, indicating an overall presence of priming. The two-way interaction was not significant ($p > 0.3$). See Table 6 for means.

Older Adults

Accuracy: The main effect of presentation and the presentation by object type interaction were not significant (all $p > 0.1$), indicating a lack of priming.

Reaction time: The effect of presentation was not significant ($p > 0.7$) indicating that overall, older adults were not priming. An interaction, however, was observed between object type and presentation, $F(1, 23) = 5.39$, $p = 0.03$, partial $\eta^2 = 0.19$. Whereas RTs to repeated possible objects tended to be faster, $t(23) = 1.86$, $p = 0.08$ than to new possible

objects, RTs to repeated impossible objects were slower than to new impossible objects, $t(23) = 2.17, p = 0.04$. See Table 6 for mean accuracy, reaction time, and priming scores.

Comparison Across Age Groups—The magnitude of proportional RT priming was smaller in the older than in the young participants, $t(58) = 2.51, p = 0.015$. The age difference in priming in the accuracy measure was not reliable, $t(58) = 1.38, p = 0.17$. See Figure 5.

Cognitive Reserve—In the older adults, the CR composite score was positively correlated with proportional RT-priming, $r(23) = 0.40, p = 0.05$, while the correlation with task accuracy was not reliable, $r(23) = 0.29, p = 0.17$. No significant correlations were observed for the young adults.

Discussion

In Experiment 3, which examined long-lag repetition priming after a 15-minute delay, significant priming was observed in the young but not older adults and the age difference in priming was significant for the RT measure. The results are consistent with and extend the findings by Soldan et al. (2009) by showing that age-related decreases in priming of unfamiliar objects can be observed in block-based priming tasks, both when subjects perform the same task during the encoding and test blocks (i.e., Experiment 3), and when there is a task switch across blocks (i.e., Soldan et al., 2009, a left/right orientation judgment during encoding and a possible/impossible classification at test). These data provide additional support for the view that the ability to maintain priming of unfamiliar objects over long repetition lags decreases with normal aging. Replicating the results from Experiments 1 and 2, individual differences in CR were associated with the magnitude of RT-priming in the older subjects.

Although priming was not significant in older adults in Experiment 3 when averaging across object types, the older adults tended to show performance improvements for repeated possible objects (i.e., faster RTs and higher accuracy) and performance decrements for repeated impossible objects (i.e., slower RTs and lower accuracy). The same pattern was found for the delayed condition of Experiment 2. This finding is important for two reasons. First, it indicates that older adults are retaining some information in memory about the repeated objects at the delayed lag, leading them to respond differently to new and repeated items. Second, the slowing of response times to repeated impossible figures provides evidence for the presence of two or more interfering memory processes that form the basis for observed priming effects. Although the present study was not designed to disentangle the contributions of different underlying processes to priming, it is useful to consider this issue as it might provide clues about the specific processes affected by aging.

The pattern of results observed here is consistent with the view that priming in the possible/impossible object-decision test and in classification tasks more generally represents the net results of two processes: SR-learning and perceptual facilitation (Horner & Henson, 2009, 2011; Soldan et al., 2012). S-R learning occurs when subjects associate stimuli with responses (e.g., 'left button press') and decisions (e.g., 'possible object') they make the first time they encounter the stimuli. When a repeated item is presented, this integrated S-R episode is retrieved and provides a faster route of responding because many of the perceptual processes that were initially required to perform the classification can be bypassed. In addition, the perceptual processes themselves operate more efficiently on repeated stimuli, reflecting perceptual priming.

With regard to the possible/impossible task, it has been shown that facilitated perceptual processing of repeated figures leads to an increase in the proportion of 'possible' responses

and faster RTs to repeated possible objects, as well as to those repeated impossible objects that contain sufficient local three-dimensional information (Soldan, et al., 2009b; Williams & Tarr, 1997). When the perceptual and S-R learning mechanisms are combined, they positively reinforce each other for possible objects because they are associated with the same response, giving rise to robust priming. For impossible objects, the two processes are associated with opposite responses because the perceptual process increases the tendency to make a 'possible' response, whereas the S-R association leads to an 'impossible' response. Resolution of this response conflict slows down RTs to repeated impossible objects. The relative contributions of S-R learning and perceptual facilitation to a response are likely determined by their strength in memory.

When considered within this framework, the present results might be consistent with the following scenario. At short repetition lags, S-R learning makes relatively strong contributions to priming in both age groups, leading to robust positive priming for possible and impossible objects, as was observed in the short and medium lag conditions. Perceptual facilitation also likely contributes to priming, resulting in smaller priming effects for impossible than possible figures (because the perceptual and S-R learning effects interfere with one another for impossible objects and because impossible figures contain less valid structural information that can be primed, see Soldan et al., 2009b and Williams & Tarr, 1997). Both S-R learning and perceptual facilitation likely decrease with increasing repetition lags, resulting in less overall priming at long than at short lags for both object types in both age groups, as was found in this study. The observed age-difference in RT-priming at long lags might be attributable to a greater lag-related decrease in S-R learning in the old than the young adults. In support of this idea, older adults were biased to respond 'possible' to repeated objects at the delayed lags, indicating that perceptual processes were contributing to priming. At the same time, S-R learning contributions to priming were not completely eliminated in older adults, as indicated by the slowing of RTs to repeated impossible objects, which likely arose from the response conflict generated by the S-R and perceptual mechanisms. Please note that this is a tentative, post-hoc interpretation that needs to be tested empirically.

Analysis Across Experiments

In order to confirm that the differential effect of repetition lag on priming in the two age groups was not mediated by differences in explicit memory or overall task performance, mean accuracy and proportional RT priming scores were averaged across the short-lag conditions of Experiments 1 and 2 as an index of short-lag priming ($N=48$ young subjects and $N=48$ older subjects) and the long-lag and delayed lag conditions of Experiments 1, 2, and 3 as an index of long-lag priming ($N=84$ young subjects and $N=72$ older subjects, leaving out the medium condition of Experiment 1). *T*-tests confirmed that there was no age difference in priming at the short lag for both accuracy and RT ($p > 0.25$). For the accuracy measure of priming, there was also no age difference at the long lag ($t < 1$). For the RT-measure, by comparison, less proportional priming was observed in the older group than in the young group, $t(154)=2.36$, $p=0.02$. Multiple regression analyses indicated that this age difference in proportional RT-priming at the long lags was significant even after accounting for individual differences in mean RT, mean accuracy, CR-composite, and performance on neuropsychological tests of explicit memory (SRT-total learning and delayed recall, as well as BVRT-recognition), $t(1, 142) = 2.20$, $p=0.03$, see Table 7.

To confirm that the effect of CR on priming was not mediated by subjects' ability to perform the task, multiple regression analyses were conducted on the mean priming scores (averaging across lags and object type), using the CR-composite score, mean RT, mean accuracy, and indicators for experiment as predictors, separately for the young ($N=84$) and

older subjects ($N=72$). All predictors were entered into the models. Cognitive reserve emerged as a significant predictor of proportional RT-priming in the older subjects, $t(1, 66) = 3.49$, $p=0.0009$, but not the young subjects ($p=0.96$). Thus, even after accounting for participants' speed and accuracy in the task, CR predicts RT-priming in older adults, see Figure 6. CR was not related to priming as measured by accuracy in both age groups, both $p > 0.5$.

Finally, in order to test if CR protects against the observed age-related decrease in long-lag priming, we split the older adults into three CR groups (high vs. medium, vs. low). High CR-subjects were defined as those with a CR composite score more than 0.5 SDs above the mean ($N=26$), whereas low CR subjects were defined as those with a CR-composite score of more than 0.5 SDs below the mean ($N=22$), with the remaining subjects constituting the medium CR group ($N=24$). Post-hoc t-test showed that although there was no difference in long-lag proportional RT-priming between the medium and high CR groups ($t < 1$), the high CR group showed more proportional RT-priming than the low CR group, $t(46) = 2.04$, $p < 0.05$.

General Discussion

The present study supports the view that at least under some conditions, normal aging is associated with reduced priming of unfamiliar stimuli at long repetition lags (Keane et al., 2004; Wiggs & Martin, 1994; Soldan et al., 2009). Moreover, we provided evidence that this age-related decrease in priming does not represent an encoding deficit among the older adults, but, at least in part, a reduced ability to maintain newly encoded memory representations. Future research is needed to determine the mechanisms that form the basis of this age-related change, particularly the role of interference. We found preliminary evidence that greater vulnerability to interference among older adults may reduce S-R learning contributions to priming at long lags, but this finding needs to be replicated using tasks that disentangle S-R learning and perceptual facilitation effects.

To our knowledge only two prior studies have examined age effects on S-R learning in priming tasks. While Dew and Giovanello (2010) reported no age difference, Schnyer et al. (2006) reported smaller S-R contributions to priming in older adults and no S-R learning in amnesic patients, suggesting that at least under some conditions, S-R learning deficits may underlie age-related differences in priming. Additional support for this view comes from the associative deficit hypothesis of aging (Old & Naveh-Benjamin, 2008), whereby older adults are particularly impaired on associative memory tasks that require them to bind together information in memory within or across items or between items and responses, as in this study. However, the associative deficit hypothesis was originally proposed for episodic memory tests and the degree to which it applies to implicit associative memory is still unclear, as studies of aging and implicit associative memory have produced mixed results (e.g., Ergis, Van der Linden, & Deweer, 1998; Spieler & Balota, 1996; Monti et al., 1997; Dew & Giovanello, 2010b).

Because this study used unfamiliar objects, the stimulus-level representations that form part of the S-R bindings must involve some novel perceptual information. As such, age-related changes in S-R contributions to priming may also be related to changes in the maintenance of stimulus-level perceptual information that is linked to decision and response codes. For example, young and older adults may associate different kinds of stimulus-level information (global structural descriptions, contour information, etc.) with decisions and responses and this perceptual information may be differentially sensitive to interference and decay, and to aging.

When interpreting the present results within the context of prior research, it is important to consider those studies not finding age-effects on long-lag priming of unfamiliar stimuli. Specifically, Schacter et al. (1992) reported age-equivalence in priming on a block-based version of the possible/impossible object-decision test, but baseline accuracy of the older adult sample did not differ from chance. Given that in both this study and in Soldan et al. (2008) all older adults were reliably above chance, it is possible that above chance performance is necessary to observe an age difference in this task. Wiggs (1993) also found age-equivalence in priming, as measured by the mere exposure effect (i.e., increased liking) when the stimuli were repeated three or nine times at encoding. This may suggest that repeated stimulus exposures strengthen the memory traces supporting priming, allowing older adults to maintain priming over long delays. It is also possible that priming, as measured by the mere-exposure effect is mediated by different memory processes than priming measured in object-decision tests, as suggested by Willems and Van der Linden (2009), with the latter being less susceptible to the effects of aging.

A second major finding of this study is that the composite CR scores of older subjects correlated with overall priming, suggesting that higher levels of reserve may protect against the loss of repetition priming over increased delays. Consistent with this view, older adults with high CR showed more RT-priming at the long lags than older adults with low CR. As this relationship, to our knowledge, has never been examined, these findings add to existing literature regarding CR as a mediating factor between brain aging/pathology and the clinical and behavioral outcomes of such pathology (Stern, 2009). Furthermore, these findings may be relevant to some inconsistencies found in the literature on the effects of age on priming by drawing attention to the potentially important mediating role of CR on priming. For example, relatively small effects of aging on priming may be masked in studies using older adults with very high CR, or they may be exaggerated in studies using older adults with lower CR.

The finding that CR was not associated with priming in young subjects could reflect differences in how CR is expressed across age groups. Cognitive reserve is thought to encompass both neural reserve, or differences in the capacity and efficiency of neural networks, and neural compensation, or differences in the ability to recruit different brain networks to cope with pathology (Stern, 2009). Neural compensation is particularly important when task demands are high, as it allows individuals to cope with inefficient or low-capacity networks by activating additional, compensatory regions. As the possible/impossible object decision task is fairly demanding for older but not younger subjects (as indexed by slower RTs and lower accuracy), the relationship observed between priming and CR in older adults could reflect individual differences in neural compensation. Because younger adults generally find the task less demanding and have more efficient networks in operation, compensation mechanisms may not be a factor for them, thus a relationship between CR and priming in young adults does not emerge. Supporting this interpretation, Soldan et al. (2008) showed that baseline levels of fMRI activation are greater and more widespread in old than in young adults when performing the possible/impossible object-decision task, consistent with a compensatory role during processing.

It is important to note that the observed age differences in priming were found with reaction time measures, but not with accuracy. Although RT and accuracy priming tend to trend in the same direction, prior studies using unfamiliar stimuli have shown similar results where age, group, or experimental differences emerge relative to only one measure (e.g., Fleischman, Gabrieli, Reminger, Vaidya, & Bennett, 1998; Laver, 2000; Smith & Oscar-Berman, 1990; Soldan et al., 2012; Orfanidou, et al., 2011). A possible reason for why age differences were not observed for accuracy priming in this study may be the relatively

smaller magnitude of accuracy priming even at the short lags, making it difficult to detect differences at the long lags.

Lastly, it is important to consider the observed relationship between explicit and implicit memory as measured in the present study. If explicit memory influenced our measures of priming, then age differences in priming observed at the longer lags could be explained by an advantage younger adults have in explicitly remembering stimulus-specific information during the test phase. It is important to note, however, that no significant correlations were found between the priming variables and the neuropsychological measures of explicit memory in either age group, supporting the view that age differences in explicit memory do not account for the age difference in priming.

In sum, we provide further evidence that normal aging can be associated with reduced priming of unfamiliar objects at long repetition lags and that the magnitude of this reduction is related to individual differences in cognitive reserve.

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Figure 1.
Examples of structurally possible and impossible figures used in each experiment.

Figure 2. Example of a trial sequence for one block in Experiment 1. Short 1, Medium 1, and Long 1 refer to the first presentation of an item in the short, medium, and medium-long lag conditions, respectively; Short 2, Medium 2, and Long 2 indicate the second presentation of an item in the respective lag condition. The first and second presentation of all short and medium lag objects occurred in the first 40 trials of a block. For medium-long lag items, the first presentation was in the first 40 trials of a block and the second presentation in trials 41 to 56. New items refer to the first presentation of a stimulus in trials 41 to 56 and served as comparison stimuli for repeated medium-long lag items.

Figure 3.

Experiment 1 results: Mean accuracy priming (top panel) and RT proportional priming (bottom panel) for each lag condition. Error bars represent the standard error of the mean. * Indicates significant difference between age groups, $p = 0.03$, one-tailed.

Figure 4.

Experiment 2 results: Mean accuracy priming (top panel) and RT proportional priming (bottom panel) for the short lag condition and the average of the long and delayed lag conditions (i.e., long/delayed). Error bars represent the standard error of the mean. * Indicates significant difference between age groups, $p = 0.04$, one-tailed.

Figure 5. Experiment 3 results: Mean accuracy priming and RT proportional priming. Error bars represent the standard error of the mean. * Indicates significant difference between age groups, $p = 0.015$.

Figure 6.

Scatterplot depicting the correlation between the cognitive reserve composite score and mean standardized RT priming, partialing out the effects of mean accuracy, for older participants from all three experiments (partial $r(69) = 0.39$, $p = 0.0006$). The priming scores were standardized by converting them to z-scores, separately for each experiment, to account for differences in priming across experiments. Mean accuracy was partialled out because it was correlated with both cognitive reserve and priming.

Table 1
Demographic and neuropsychological variables for subjects in Experiment 1, 2, and 3

	Experiment 1		Experiment 2		Experiment 3	
	Young	Old	Young	Old	Young	Old
Female/Male	14/10	14/10	11/13	20/4	15/21	19/5
Age	23.5 (2.5) *	68.2 (4.6)	19.6 (1.2) *	67.9 (6.5)	18.8 (0.8) *	68.6 (7.5)
Education (yrs)	16.5 (1.2)	16.9 (2.2)	13.8 (0.9) *	16.7 (2.7)	12.8 (0.7) *	16.8 (2.7)
DRS-2	n/a	143.6 (0.7)	n/a	140.8 (2.3)	n/a	142.0 (3.4)
NART-IQ	120.0 (5.5)	121.3 (6.0)	112.0 (4.4) *	120.8 (7.8)	111.7 (5.8) *	121.2 (7.2)
SRT total	63.5 (4.8) *	54.0 (8.9)	53.3 (7.8) *	48.3 (5.2)	50.1 (6.8) **	45.0 (10.3)
BVRT-Mat	9.9 (0.3)	10.0 (0.2)	9.8 (0.4)	9.8 (0.5)	9.6 (0.6) **	9.9 (.3)
BVRT-Rec	9.8 (0.7) *	9.0 (1.1)	9.5 (0.9) **	8.6 (1.6)	9.0 (1.0)	9.2 (.9)
WAIS-Vocab	—	—	10.0 (0.3) *	12.0 (0.5)	11.0 (2.6)	12.1 (2.1)
CFL	—	—	39.7 (16.5)	47.4 (12.1)	42.7 (12.0)	48.4 (16.5)

Note: means and standard deviations (in parentheses) for demographic variables and neuropsychological test scores. DRS-2, Dementia Rating Scale-2; NART-IQ, North American Adult Reading Test estimated IQ; SRT, Selective Reminding Test; BVRT, Benton Visual Retention Test, Mat = matching, Rec = recognition; WAIS, Wechsler Adult Intelligence Scale, Vocabularly Subtest, age-scaled scores; CFL-Controlled Oral Word Association Test.

* denotes significant difference between age groups at the $p=.05$ level,

** $p=.01$.

Table 2
Experiment 1. Mean object-decision accuracy (standard errors), and accuracy priming scores for new and repeated objects for young and older adults

Stimulus	Young		Old	
	Possible	Impossible	Possible	Impossible
Short				
New	91.0 (2.1)	81.4 (2.9)	85.4 (2.6)	74.3 (2.9)
Repeated	92.5 (1.5)	85.1 (2.8)	87.0 (2.6)	74.3 (3.3)
Priming	1.6 (1.5)	3.6 (2.3)	1.6 (1.9)	0.0 (2.8)
Medium				
New	89.9 (1.9)	84.5 (2.2)	81.4 (2.7)	73.8 (2.5)
Repeated	93.7 (1.4)	84.4 (2.9)	87.3 (2.9)	75.9 (2.8)
Priming	3.8 (1.1) **	-0.2 (2.2)	5.9 (1.8) **	-2.1 (2.2)
Medium-Long				
New	90.8 (2.1)	83.0 (2.7)	83.3 (3.1)	75.0 (3.1)
Repeated	93.7 (1.1)	82.8 (2.8)	87.5 (2.2)	78.0 (2.7)
Priming	3.0 (1.9)	-0.2 (2.2)	3.8 (2.0) *	2.5 (2.2)

Note:

** indicates significant priming at $p < 0.005$;

* $p < 0.05$.

Table 3

Experiment 1. Mean object-decision RT (standard errors) in milliseconds, and difference and proportional RT priming scores for novel and repeated objects for young and older adults.

Stimulus	Young		Old	
	Possible	Impossible	Possible	Impossible
Short				
New	863 (28)	968 (39)	1221 (39)	1334 (40)
Repeated	771 (25)	890 (33)	1101 (42)	1259 (45)
Priming-Diff.	92 (14) ***	78 (15) ***	119 (25) ***	75 (21) **
Priming-Prop.	10.4 (1.4) ***	7.5 (1.4) ***	9.6 (1.8) ***	5.6 (1.6) **
Medium				
New	872 (30)	985 (40)	1201 (39)	1346 (46)
Repeated	771 (30)	911 (36)	1097 (37)	1254 (43)
Priming-Diff.	101 (18) ***	74 (16) ***	104 (19) ***	92 (21) **
Priming-Prop.	11.4 (1.9) ***	7.1 (1.4) ***	8.4 (1.5) ***	6.5 (1.6) **
Medium-Long				
New	883 (33)	1003 (39)	1221 (42)	1323 (50)
Repeated	775 (27)	914 (36)	1094 (40)	1264 (42)
Priming-Diff.	108 (12) ***	89 (15) ***	126 (19) ***	58 (25) *
Priming-Prop.	11.9 (1.1) ***	8.4 (1.3) ***	10.1 (1.5) ***	3.6 (1.9)

Note:

*** indicates significant priming at $p < 0.0001$;

** $p < 0.005$;

* $p < 0.05$.

Table 4

Experiment 2. Mean object-decision accuracy (standard errors), and accuracy priming scores for novel and repeated objects for young and older adults.

Stimulus	Young		Old	
	Possible	Impossible	Possible	Impossible
Short				
New	91.6 (1.4)	81.5 (2.6)	81.1 (4.1)	76.0 (4.0)
Repeated	94.5 (4.6)	85.2 (2.2)	86.1 (3.3)	76.4 (4.2)
Priming	2.9 (1.2) *	3.7 (1.8)	5.0 (1.4) **	0.4 (2.1)
Long				
New	92.0 (1.7)	85.2 (2.5)	82.5 (4.2)	74.4 (3.8)
Repeated	95.1 (6.9)	84.9 (2.3)	84.5 (4.0)	75.5 (3.4)
Priming	3.1 (0.9) **	-0.2 (1.6)	2.0 (1.9)	1.2 (1.6)
Delayed				
New	92.2 (1.2)	84.7 (2.8)	80.9 (4.3)	79.5 (3.8)
Repeated	93.8 (6.0)	87.1 (2.2)	84.9 (4.0)	73.8 (4.1)
Priming	1.5 (.85)	2.4 (2.3)	4.0 (1.8) *	-5.8 (1.6) **

Note:

** indicates significant priming at $p < 0.005$;

* $p < 0.05$

Table 5

Experiment 2. Mean object-decision RT (standard errors) in milliseconds, and difference and proportional RT priming scores for novel and repeated objects for young and older adults.

Stimulus	Young		Old	
	Possible	Impossible	Possible	Impossible
Short				
New	939 (30)	1048 (36)	1123 (29)	1221 (48)
Repeated	885 (28)	974 (30)	1055 (33)	1171 (44)
Priming Diff.	53 (11) ***	74 (16) **	68 (17) ***	43 (21)
Priming Prop.	5.5 (1.1) ***	6.5 (1.4) ***	6.1 (1.6) **	3.4 (2.0)
Long				
New	932 (31)	1011 (35)	1088 (30)	1170 (43)
Repeated	872 (28)	1027 (33)	1064 (30)	1160 (46)
Priming Diff.	60 (11) ***	-16 (15)	27 (10) *	12 (15)
Priming Prop.	6.3 (1.1) ***	-2.1 (1.5)	2.1 (1.0)	1.0 (1.4)
Delayed				
New	944 (30)	1022 (36)	1116 (30)	1164 (47)
Repeated	892 (24)	1024 (36)	1088 (30)	1184 (46)
Priming Diff.	51 (15) **	-1.8 (1.3)	29 (16)	-35 (20)
Priming Prop.	4.9 (1.4) **	-0.4 (1.5)	2.4 (1.4)	-3.0 (1.6)

Note:

*** indicates significant priming at $p < 0.0001$;

** $p < 0.005$;

* $p < 0.05$

Table 6

Experiment 3. Mean object-decision accuracy, RT, priming, and proportional priming scores for novel and repeated objects for young and older adults. Standard errors are given in parenthesis.

Stimulus	Young		Old	
	Possible	Impossible	Possible	Impossible
Accuracy				
New	87.1 (2.1)	84.4 (2.1)	78.8 (3.2)	74.1 (2.4)
Repeated	91.7 (1.9)	85.2 (2.4)	81.6 (3.3)	71.6 (3.1)
Priming	4.6 (1.6) *	0.8 (1.5)	2.9 (2.2)	-2.5 (2.3)
Reaction Time				
New	947 (32)	1021 (31)	1112 (41)	1201 (44)
Repeated	919 (37)	1004 (31)	1083 (39)	1226 (42)
Priming Diff.	28 (9) **	17 (9)	30 (16)	-24 (11) *
Priming Prop.	3.4 (0.9) **	1.5 (0.9)	2.4 (1.4)	-2.3 (1.0) *

Note:

** indicates significant priming at $p < 0.005$;

* $p < 0.05$

Table 7

Analysis Across Experiments: Multiple regression of age group (young vs. old), explicit memory test scores and overall task performance measures on long-lag reaction-time priming.

Variable	B	SE (B)	t-value	p
Age Group	-1.88	0.92	-2.04	0.04
Cognitive Reserve	0.64	0.46	1.39	0.17
SRT – Total Learning	0.04	0.06	0.68	0.50
SRT – Delayed Recall	0.10	0.21	0.46	0.64
BVRT – Recognition	0.30	0.34	0.88	0.38
Mean Accuracy	0.006	0.04	0.16	0.88
Mean RT	0.001	0.002	0.46	0.64
Experiment 1	6.67	0.98	6.82	0.0001
Experiment 2	0.12	0.86	0.14	0.89

Note: All variables listed in the table were forced into a multiple regression model. B indicates unstandardized regression coefficient. SE indicates standard error. SRT=Selective Reminding Test, BVRT = Benton Visual Recognition Test, Mean Accuracy = mean percent correct in priming task, Mean RT = mean reaction time in priming task, Experiment 1 and 2 are indicators (coded 0 or 1) for the respective experiments.

Table 8

Analysis Across Experiments: Multiple regression of cognitive reserve and overall task performance measures on total reaction-time priming in older adults.

Variable	B	SE (B)	t-value	p
Cognitive Reserve	1.69	0.48	3.49	0.0009
Mean Accuracy	0.02	0.04	0.59	0.56
Mean RT	0.0004	0.002	0.18	0.86
Experiment 1	6.83	0.95	7.16	0.0001
Experiment 2	2.49	0.93	2.69	0.009

Note: All variables listed in the table were forced into a multiple regression model. B indicates unstandardized regression coefficient. SE indicates standard error. Mean Accuracy = mean percent correct in priming task, Mean RT = mean reaction time in priming task, Experiment 1 and 2 are indicators (coded 0 or 1) for the respective experiments.