An effect of age on implicit memory that is not due to explicit contamination: Implications for single and multiple-systems theories

Emma V. Ward, David R. Shanks, and Christopher, J. Berry

University College London

Author Note

Emma V. Ward, David R. Shanks, and Christopher, J. Berry, Department of Cognitive, Perceptual and Brain Sciences, University College London, England.

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Correspondence concerning this article should be addressed to Emma V. Ward, Department of Cognitive, Perceptual and Brain Sciences, UCL, 26 Bedford Way, London WC1H 0AP. E-mail: emma.ward@ucl.ac.uk

Abstract

Implicit memory tests often reveal facilitated processing of previously encountered stimuli even when they cannot be explicitly retrieved. For example, despite decrements in recognition memory, priming in healthy older adults is often comparable in magnitude to that in young individuals. Such observations are commonly taken as evidence for independent explicit and implicit memory systems. On a picture version of the continuous identification with recognition task (CID-R), we found a reliable age-related reduction in recognition memory while the effect on priming did not reach statistical significance (Experiment 1). Experiment 2 replicated these observations using separate priming (CID) and recognition (R) phases. However, when data are combined across experiments to increase power, we find that the reduction in priming reaches statistical significance. In Experiments 3, 4 and 5 we provide evidence that priming in this task is unaffected by manipulations of test awareness and explicit processing. We conclude that priming in this task, like recognition memory, is reduced in normal aging and that the effect is not driven by differences between groups in explicit processing ('contamination'). Our results support the view that recognition and priming are driven by a single underlying memory system rather than by multiple systems.

Keywords: aging, priming, implicit memory, recognition, explicit contamination

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Memory can be measured directly or indirectly. Direct or *explicit* tests (e.g., recognition) require deliberate recollection of specific information from a prior study episode, whereas indirect or *implicit* tests measure memory of previously studied information in a seemingly unrelated task (e.g., perceptual identification). Priming is a commonly used index of implicit memory. It refers to a long-term change in behavioural response to an item as a result of prior exposure to it, and usually takes the form of facilitated processing. For example, previously studied words or pictures are usually identified more quickly than new ones.

The question of whether there are distinct memory systems driving explicit and implicit memory has provoked extensive research over the past few decades. Performance on explicit and implicit tests has been shown to dissociate under numerous experimental manipulations (for a review see Roediger & McDermott, 1993) and a common interpretation is that this reflects processing in separate cognitive systems (e.g., Gabrieli, 1998; Squire, 1994, 2004, 2009; Tulving & Schacter, 1990). The dissociation in normal aging has provided particularly compelling evidence for this account – older individuals typically show decrements on explicit tests relative to healthy young individuals despite comparable priming levels (reviewed in Fleischman, 2007; Fleischman & Gabrieli, 1998). The interpretation of this finding is that an explicit (or declarative) system is affected by age whereas an implicit (or nondeclarative) system is not.

Age-invariant priming has been reported on tests of word-stem completion (e.g., Light & Singh, 1987; Park & Shaw, 1992), word identification (e.g., Light, La Voie, Valencia-Laver, Albertson-Owens, & Mead, 1992; Light & Singh, 1987), picture naming (e.g., Mitchell, Brown, & Murphy, 1990; Sullivan, Faust, & Balota, 1995), degraded picture naming (e.g., Russo & Parkin, 1993), and object decision (e.g., Schacter, Cooper & Valdiserri, 1992; Soldan, Hilton, Cooper, & Stern, 2009). However, at variance with the multiple-systems approach, other studies have reported priming deficits for older individuals on some of the same tests (e.g., Abbenhuis, Raaijmakers, Raaijmakers, & Van Woerden, 1990; Chiarello & Hoyer, 1988; Hultsch, Mason, & Small, 1991). These results favor the alternative view that explicit and implicit memory are driven by a single underlying system. It has been suggested that the discrepancies between these studies are largely due to methodological differences (e.g., Fleischman, 2007), but it remains unclear whether priming is truly affected by aging.

It has been argued that it is unnecessary to infer separate systems based on dissociation evidence (e.g., Berry, Shanks, & Henson, 2008a). Many demonstrations of age-invariant priming rest on a null result (a failure to find a statistically significant difference between groups), and it is possible that individual studies lacked statistical power to detect significant priming differences. Indeed, priming was usually numerically lower in older relative to young adults in published studies, and a meta-analysis by La Voie and Light (1994) showed a small but significant effect of age on priming. Another issue is that explicit and implicit memory have traditionally been measured in separate experimental phases, which involves taking two samples of memory on different occasions. Scores may therefore dissociate because there may be a longer study-test delay for one task than the other or because participants adopt different response strategies or levels of motivation in the two tasks when they are presented separately, especially when one may be more cognitively demanding than the other. For samples from explicit and implicit memory to be truly comparable, they need to be taken for the same items at around the same point in time. Dissociations produced under these circumstances constitute more persuasive evidence for multiple memory systems relative to when items are judged on two separate occasions.

Computational models can offer considerable theoretical insights regarding empirical dissociations. Formal single-system models have successfully reproduced several dissociations that have previously been taken as support for multiple memory systems (e.g., Berry, Shanks, & Henson, 2006; Berry et al., 2008a; Berry, Shanks, & Henson 2008b; Berry, Shanks, Li, Rains, & Henson, 2010; Berry, Shanks, Speekenbrink, & Henson, 2011; Kinder & Shanks 2001; 2003; Shanks & Perruchet, 2002; Shanks, Wilkinson, & Channon, 2003). The model by Berry and colleagues assumes that a single memory signal drives performance on explicit and implicit tasks, but that there are independent sources of random noise, the variance of which is greater in the implicit task (an assumption which is fortified by the generally lower reliability found in implicit relative to explicit tests; Buchner & Wippich, 2000). The model has been shown to reproduce dissociations between recognition and priming such as those generated by manipulating attention at study (e.g., Butler & Klein, 2009), as well as neuropsychological dissociations such as that seen in individuals with amnesia due to damage to the hippocampus or medial temporal lobe (e.g., Conroy, Hopkins, & Squire, 2005; see Berry et al., 2008b, 2010, 2012).

Until recently there have been few attempts to test formal multiple-systems models. Berry et al. (2012) developed two such models in which two independent signals either make unique contributions to explicit and implicit memory or are assumed to have some degree of correlation. Not only did the single-system model reproduce the qualitative dissociation observed in amnesia in the Conroy et al. (2005) study, but model selection on the basis of the Akaike Information Criterion indicated that it fit the data better than the multiple-systems models. Thus, many empirical observations which on the surface appear to be indicative of multiple systems are not incompatible with the single-system view.

No strict conclusion regarding whether explicit and implicit forms of memory operate from a single or multiple memory systems has yet been reached, and robust empirical evidence on which inferences can be drawn is limited. A particularly diagnostic case would be to demonstrate evidence of completely preserved priming in the face of compromised recognition memory when the two are measured consecutively on each test trial, so in the present study we attempted to establish whether such a pattern can be produced. The present study is the first to compare recognition and priming in young and older individuals using the continuous identification with recognition (CID-R) paradigm (e.g., Conroy et al., 2005) in which the two are measured concurrently on each trial. Each test trial comprised a speeded masked picture identification (priming measure) followed immediately by an old (studied)/new (nonstudied) recognition judgement for the item. Recognition memory is typically affected by age, thus the study allows us to test the multiple-systems prediction that priming will be unaffected. On the other hand, the single-system prediction is that there will be an effect of age on priming, although this is likely to be smaller than that on recognition memory.

Experiment 1

In Experiment 1 we compared the performance of young and older adults on the CID-R task. Participants studied pictures of everyday objects both immediately and 60 minutes prior to the test. The delay was included in an attempt to reduce the strength of memory for a subset of items as much as possible. We anticipated reductions in recognition memory as a function of age and delay, and the question of whether priming would be similarly affected was of primary interest.

Method

Participants

Twenty young (seven male) and 20 older (two male) adults participated for a small payment. The young adults were students from University College London (UCL), recruited through an advertisement on an internal website. The older adults were members of the University of the Third Age (U3A) organisation. All were native English speakers who reported good health. Participant demographic information is summarised in Table 1.[1]

Materials

The stimuli were pictures of everyday objects from ten categories: animals, clothing, fruit and vegetables, electrical appliances, musical instruments, transportation vehicles, kitchen utensils, insects, tools, and furniture. Items within these categories were selected based on the category norms collected by Van Overschelde, Rawson, and Dunlosky (2004). There were 120 critical items, each depicting a colour photograph of a single object on a 400 x 400 pixel white background (Figure 1A). Sixty pictures, six from each object-category, appeared in the study phases (30 in each phase) and were also presented at test to serve as old items. The other 60 pictures served as new items and were only presented at test. The assignment of pictures to old/new status and initial/second study phase was counterbalanced across participants by rotating four sets of 30 pictures. The mask used in the identification task was a 400 x 400 pixel grid randomly filled with fragments of non-critical item pictures.

Design and procedure

The experiment used a mixed factorial design with the between-subjects factor Age-group (young/older) and the within-subjects factor Delay (60 min/no delay).

The experimental procedure, identical for both groups, consisted of four parts: an initial study phase, a 60 minute interval, a second study phase, and finally the CID-R test. Participants were tested individually, and the duration of the experiment was approximately 90 minutes per participant. In this and subsequent experiments, the task was programmed in Matlab 6 and administered on a PC with a screen resolution of 1024 x 768 pixels. Viewing distance was approximately 50 cm.

Initial study. Participants performed an incidental encoding task which involved matching briefly presented pictures to object-categories. Each trial was presented as follows: (1) a fixation point (‘+’) was presented in centre screen for 500 ms, (2) a picture (e.g., a dog) was presented for 250 ms, (3) The instruction “Which category was the object from?” appeared at the top centre of the screen, and two category options were displayed (e.g., F = animal / J = musical instrument). Participants were instructed to use the ‘F’ and ‘J’ keyboard keys to select the correct option. No time limit was imposed on participants to respond, and the choice categories remained on the screen until a keypress was made. (4) Finally, there was a 1000 ms blank screen prior to the start of the next trial. There were 30 randomised trials in total, plus 5 practice trials.

Interval testing. The interval between the initial and second study phases was 60 minutes. The following battery of tests was administered: (1) Demographic and health questionnaire, (2) Near Vision Test, (3) Wechsler Test of Adult Reading, (4) WAIS-III subtests: Vocabulary and Digit-symbol Coding, (5) Mini Mental-state Exam (older adults only). Breaks were provided where needed.

Second study. Next, participants performed the second study phase which was identical in procedure to the initial study task, but comprised a different set of 30 critical items.

CID-R test. Immediately following the second study phase, participants were given instructions for the CID-R task. Participants were not informed of this task in advance. Each trial consisted of a speeded masked-picture identification in which response times (RT) were measured, and a recognition judgement. Each trial was self-initiated by the participant, and began with the identification task as follows: A mask was initially presented in centre screen for 500 ms. A picture (old or new) was then presented for 17 ms, followed immediately by the mask for 233 ms (making a 250 ms block). These block presentations were repeated, with the duration of picture presentations increasing by 17 ms on every alternate block while the total block duration remained constant, thus making the picture gradually more visible (Figure 1B). Participants were required to identify the picture as quickly and accurately as possible, pressing the ‘Enter’ key when they knew the identity of the object. RTs were captured on the keypress, at which point the picture disappeared and participants were prompted to type the object name into a box. The block presentations ceased at 7 sec (30 blocks) after initiation if identification had not taken place, and any such trials were discarded.

The recognition segment of the trial immediately followed each identification. The picture was presented once more and participants were required to make a judgement as to whether they thought it was shown in either of the study phases using a 6-point scale where 1 = *very sure no*; 2 = *fairly sure no*; 3 = *guess no*; 4 = *guess yes*; 5 = *fairly sure yes*; 6 = *very sure yes*. No time limit was imposed in making recognition judgements, and no feedback was provided. There were 120 randomised trials in total – 60 old (30 items from each study phase) and 60 new.

Results

In this and subsequent experiments, an alpha level of .05 was used for all statistical tests, and all *t*-tests were two-tailed unless otherwise stated.

Study phases

Mean categorization accuracy was at 98.3% (SD = 2.29) for young and 96.5% (SD = 4.77) for older adults on the initial study phase, and 97.7% (SD = 3.26) for young adults and 98.5% (SD = 2.53) for older adults on the second study phase. Performance was not statistically different between groups in either phase: $t(38) = 1.55$, $p = .13$, and $t < 1$, $p = .37$, for the initial and second study phases, respectively. In this and subsequent experiments, items associated with incorrect study phase responses were removed from all further analyses.

Recognition

Ratings 4-6 (‘*yes’* – old) and 1-3 (‘*no’* – new) on the 6-point scale were collapsed. For each participant, the proportion of hits (old pictures judged old) and false alarms (new pictures judged old) were used to calculate d' (Figure 2A).

Discrimination was significantly greater than chance (i.e., $d' > 0$) for both young and older adults, for items studied immediately prior to testing and those studied 60 min prior to testing (all t’s(19) > 7, all p’s < .001). There was a significant main effect of Age-group, F(1,

38) = 5.04, $p = .03$, and Delay, $F(1, 38)$, = 6.58, $p = .01$, and no significant interaction between the factors, $F < 1$, $p > .05$. Young adults' recognition performance was superior to that of older adults for items studied immediately prior to testing, $t(38) = 2.12$, $p < .05$, and items studied 60 min prior to testing, $t(38) = 2.03$, $p < .05$. Recognition was significantly reduced for items studied 60 min prior to testing relative to those studied immediately before for young adults, $t(19) = 1.73$, $p = .05$, and older adults, $t(19) = 1.99$, $p = .03$ (both one-tailed).

Priming

The following steps were performed on each participant's raw RT data (Table 2) to obtain a priming score: (1) trials associated with incorrect identifications were removed; (2) RTs for old and new items were averaged separately and trials with identification latencies faster than 100 ms or greater than 2.5 SD from the mean were removed; (3) Priming was then calculated as the difference in the median RT between new and old items, expressed in proportion to the individual's baseline (new item) RT[2]. Priming scores were averaged within each group (Figure 3A).

Priming was strong and significantly greater than chance (i.e., > 0 ms) for items studied immediately prior to testing ($t(19) = 3.68$, $p < .005$, and $t(19) = 2.80$, $p < .05$, for young and older adults, respectively), and items studied 60 min prior to testing ($t(19) = 4.60$, $p < .001$, and $t(19) = 2.80$, $p < .05$, for young and older adults, respectively). However, a repeated measures ANOVA with the between-subjects factor Age-group revealed no significant main effects or interaction (all F's < 2, p's > .05).

Discussion

Recognition memory was reduced by age and delayed testing, while priming was not significantly affected. There was however a clear numerical trend towards lower priming in the older adult group, and an important question is whether this is due to contamination of the priming task with explicit memory. It has been suggested that age-effects in priming may reflect the use of explicit processing strategies which could be more beneficial to young individuals due to their superior explicit memory (see MacLeod, 2008, for a review). Participants may use explicit processing in an implicit test if they become aware that some test items were previously studied. In the CID-R paradigm, participants are made aware that some items were previously studied, so it is possible that the age-group trend in priming reflects the use of a recollective strategy which amplified priming in the young group. In Experiment 2 we attempted to replicate Experiment 1 while reducing the level of test awareness experienced by participants in the priming task.

Experiment 2

In an effort to reduce awareness in the priming task, we separated the priming (CID) and recognition phases. All other aspects of the design and procedure were the same as in Experiment 1, except that we introduced a post-test awareness questionnaire. We assumed that participants would be less likely to become aware in the CID task when no reference is made to the prior study episode and when they are not required to make a recognition judgement after every identification. Test-unaware participants are not likely to adopt a voluntary explicit strategy in the priming task, so replicating the age-group trend in priming in Experiment 1 would minimise the likelihood that the effect is due to differences between groups in explicit processing.

Method

Participants

Eighteen young (seven male) and 18 older (two male) adults participated for payment of £5. The young adults were again recruited through the UCL participant database, and the older adults through the U3A. All were native English speakers who reported good health. Participant demographic information is summarised in Table 3.

Materials and procedure

The picture stimuli, categories and priming masks were the same as those used in Experiment 1, and the experimental procedure was the same, except that the CID and recognition tasks were separated. Different critical items were presented in the CID and recognition phases as we found ceiling recognition performance in a pilot study that used the same items in both phases. Thirty pictures from each study phase later served as old items in the CID task, and an additional 30 pictures which were included in the initial study phase served as old items in the recognition task, but were not presented in the CID task. An additional 60 pictures served as new items in the CID task, and 30 in the recognition task. Six sets of 30 items were rotated.

At the end of the experiment participants completed a post-test questionnaire to gauge the level of awareness experienced during the CID phase. The questionnaire was similar to that introduced by Bowers and Schacter (1990), and included the following items: (1) *What do you think was the purpose of the identification task you performed?* (2) *Do you think that any of the pictures you identified were previously presented in the first parts of the experiment?* If participants failed to notice that any of the pictures were previously studied, they were classified as unaware and were not required to complete the rest of the questionnaire. If they realised that some pictures were previously studied they were classified as aware and asked to complete the following questions: (3) *Were you aware that some of the pictures had been shown before as you were performing the task, or did you become aware of this afterwards/in hindsight?* (4) *Did you suspect prior to the start of the identification task that you would be tested on your memory of the pictures?* (5) *Did you try to use your memory of the pictures to help you in this task?* (6) *If yes, do you think this strategy helped you, and how so?*

Results and Discussion

Study phases

Categorization accuracy was at 98.4% correct for both young and older adults on the initial study phase (young *SD* = 1.93; older *SD* = 2.25), and at 98.7% (*SD* = 2.60) for young, and 99.1% (*SD* = 1.92) for older adults on the second study phase. Performance was not statistically different between groups in either study phase (all *t*'s(34) < 1, *p*'s > .05).

Recognition

Recognition (Figure 2B) was significantly greater than chance for young, $t(17) = 7.52$, $p < .001$, and older adults, $t(17) = 7.32$, $p < .001$. Discrimination (d') was significantly greater for young relative to older adults, $t(34) = 3.41$, $p < .005$.

Priming

Priming (Figure 3A; See Table 2 for RTs) was significantly greater than chance for items studied immediately prior to testing for young and older adults (both *t*'s > 2, *p*'s < .05), and items studied 60 min prior to testing for young adults, $t(17) = 2.20$, $p < .05$. Priming for items studied 60 min before testing fell short of significance in the older adult group, $t(17) = 1.58$, $p = .06$ (one-tailed). The ANOVA revealed no significant main effect of Age-group or Delay, and no significant interaction (all *F*'s < 2, *p*'s > .05).

Post-test awareness

Ten out of 18 young participants (55.5%), and 9/18 older participants (50%), were rated as test-aware during the CID phase. Collapsed across immediate and delayed items, priming did not significantly differ between aware versus unaware young participants (aware $M = .12$; unaware $M = .13$), or aware versus unaware older participants (aware $M = .08$; unaware $M = .08$), both *t*'s < 1, $p > .05$. There was also no significant difference between aware young versus older participants, or unaware young versus older participants (both *t*'s < 1, *p*'s > .05). It should be noted that, because participants completed the questionnaire after the task was completed in its entirety, their recollection of the awareness experienced during the CID phase may have been inaccurate, and more participants may have actually been test-unaware during this phase than is reflected here.

In sum, we replicated the results of Experiment 1 – recognition was reliably reduced by aging, and priming numerically lowered. To test the possibility that the age-difference in priming is genuine but failed to reach significance because of low power, we increased power by pooling the data from the individual experiments.

Re-analysis of pooled priming data

In this analysis we included data from Experiments 1 and 2 as well as that of an additional experiment. The latter was of a similar design to Experiment 1 – examining the effects of aging and delayed testing on recognition and priming using the CID-R task. The experiment was based on 20 young adults (*M* age = 23.4 years, *SD* = 3.2) and 20 older adults without cognitive impairment (*M* age = 65.8 years, *SD* = 5.5), but the procedure involved two 60 min separated CID-R tasks following a single study phase rather than a single CID-R task as in Experiment 1. The statistical outcomes were very similar to those of Experiment 1 (Table 4).

Data analysis and results

Across experiments, we pooled the priming scores for young and older individuals for immediate and delayed items ($n = 58$ per group). Figure 3C illustrates the age-difference in priming for immediate items. Priming was significantly above chance for young adults ($t(57) = 7.29$, $p < .001$, $t(57) = 6.44$, $p < .001$, for immediate and delayed items, respectively), and older adults ($t(57) = 5.64$, $p < .001$, $t(57) = 5.87$, $p < .001$, for immediate and delayed items, respectively). A 3 (Experiment) x 2 (Age-group) x 2 (Delay) ANOVA revealed significant main effects of Experiment, $F(2, 110) = 7.17$, $p < .005$, and Age-group, $F(1, 110) = 4.10$, $p < .05$, but no effect of Delay, $F < 1$, $p = .45$, and no interactions (all F's < 2, p's > .05).

Discussion

Critically, this analysis confirms a reliable reduction in priming as a function of age, and the effect is of a substantial magnitude (47% reduction collapsed across immediate and delayed items). This effect is of considerable theoretical significance, as noted in the

Introduction. If levels of priming in young and older individuals were equivalent, this would strongly suggest that they are driven by distinct memory systems. In contrast, the single-system view predicts that the same age effect on priming will be observed as occurs in recognition, although this trend may be weaker because of the lower reliability of priming measures. The results therefore favor the single-system view.

This inference, however, rests crucially on eliminating the possibility that our priming measures were contaminated by greater explicit processing in the young participants. In Experiment 2 priming was lower in unaware older versus unaware young participants, and because such participants would not have used explicit processing, this suggests that the age-difference is unlikely to be due to explicit contamination. Nevertheless, we conducted further experiments to clarify whether orientation to explicit memory affects the magnitude of priming in the CID task.

Experiment 3

We compared priming in young individuals on the concurrent CID-R task – which we assume induces awareness – to the purer CID task in which participants are less likely to become aware. A within-subjects design was used and test-order was rotated between participants – half performed the low-awareness condition (CID) first and the high-awareness condition (CID-R) second, and vice versa for the other half. If awareness enhances priming then we expect to find greater priming in the CID-R relative to the CID task and we expect this to interact with test-order. That is, the condition in which the CID task is presented first is the only true ‘unaware’ condition, and thus the only instance in which we might expect priming to be reduced in comparison to CID-R. We would not expect priming to be reduced in the CID task when it is presented second because participants will have become test-aware by this point.

Method

Participants

Forty students from UCL took part in the experiment for course credit or payment of £4. There were 24 females and 16 males with a mean age of 22.6 (*SD* = 3.2). All were native English speakers with normal or corrected vision. Participants were split equally between the test-order conditions.

Materials

The same stimuli were used once more. Eighty pictures were presented at study, and 80 in each test (40 old and 40 new). Four 40-item sets of pictures were rotated among old/new item type. The post-test questionnaire was used to assess the level of awareness experienced by participants in the condition in which the CID task was performed first. Participants who performed the CID-R task first were all deemed test-aware.

Procedure

The procedure for the study phase, CID and recognition tasks was identical to that described previously. The test phase began with the CID task for half of the participants, and with the CID-R task for the other half. After the first test, participants were immediately given instructions for the second.

Results and Discussion

Study phase

Categorization accuracy was at 95.4% (*SD*= 2.1) and 96.8% (*SD*= 2.0) in the CID task first and CID-R task first conditions, respectively. Although the study task was identical in the two groups, performance was statistically superior in the latter group, $t(38) = 2.12$, $p = .04$. Incorrect study phase trials were removed from all further analyses, meaning that slightly more data were lost in the condition in which the CID task was presented first, but the total loss was very low in both cases.

Recognition

Recognition (d', Figure 2C) was significantly greater than chance in both conditions (CID-R task first: $t(19) = 10.13$, $p < .001$; CID-R task second: $t(19) = 11.30$, $p < .001$).

Performance was reliably greater when the CID-R task was presented first as opposed to second, $t(38) = 2.57$, $p = .01$, presumably reflecting normal memory decay over time.

Priming

Priming (Figure 4; See Table 5 for RTs) was significantly greater than chance in both tests in both conditions (all t's(19) > 1, p's < .05). There was no main effect of test-type, $F(1, 38) < 1$, $p = .82$, or test-order, $F(1, 38) = 1.83$, $p = .13$, and no interaction, $F(1, 38) = 2.65$, $p = .11$, thus there is no evidence that awareness affects priming. Priming was identical in the CID and CID-R tests when they were each presented first ($M = .10$), and although awareness would have been greater in the CID task when it followed CID-R relative to when it was presented first, priming was actually lower in the former case (.06 versus .10). In the second tests, the magnitude of priming was numerically (but not statistically, $t(38) = 1.50$. $p = .14$) greater in the CID-R relative to the CID task, but it is unlikely that the trend is related to test-awareness as all participants would have become aware by the time they performed the second test.

Post-test awareness

Of the participants who performed the CID task first, 9/20 (45%) were rated as test-aware. Priming in this subset of individuals was actually elevated in comparison to that of participants classed as unaware, but not significantly so (unaware $M = .11$; aware $M = .09$, $t(16) < 1$, $p = .65$).

To summarise, the critical observation is that priming did not reliably differ between the CID and CID-R tasks, or between aware and unaware participants in the first CID task. This suggests either that awareness does not promote explicit processing in this task, or explicit processing does not alter the magnitude of priming. Taking things a step further, in Experiment 4 we directly examined whether explicit processing affects priming in the CID task. We attempted to create optimal conditions for the use of an explicit strategy – namely, providing participants with relevant explicit information ahead of each CID trial.

Experiment 4

We compared priming in the CID task in Informed versus Uninformed participants. In Experiment 4a, Informed participants were told before each CID trial whether the next item to be identified was previously studied or new, while Uninformed participants received no such information. If explicit processing enhances priming we expect to see greater priming in the former group because these participants are provided with sufficient information to enable them to explicitly search memory of the previously studied items on appropriate trials and make more rapid identifications. We also varied the proportion of previously studied trials in the CID task – half the participants in both groups were exposed to a high proportion of old trials (80% old) and half to a low proportion (20% old) with the assumption that this would create further differences in test awareness in the Uninformed group (e.g., see Jacoby, 1983). With regards to this manipulation, the critical observation that would constitute evidence for an influence of awareness on priming is an interaction between the factors. We do not expect to see an effect of the different proportions in the Informed group, because all participants in this group – whether exposed to a high or low number of old trials – are made test aware. In contrast, an effect of proportion in the Uninformed group would suggest that awareness affects priming.

In Experiment 4b Informed and Uninformed groups performed a CID task with an equal number of old and new trials, and Informed participants were given an item-status plus category cue prompt in advance of each old trial (e.g., 'OLD – ANIMAL'; on new trials participants were just prompted with the word 'NEW'). Thus, on these trials, participants were guided to explicitly search memory of a particular (small) set of previously studied items, which arguably provides the best possible opportunity for them to produce a rapid identification time.

General Method

Participants and design

107 first year undergraduate students from UCL took part in Experiment 4a as part of a course requirement. There were 24 males and 83 females with an overall mean age of 18.7 (*SD* =

0.8). The experiment used a 2 (Informed vs. Uninformed) x 2 (High vs. Low proportion old trials) between-subjects design, and participants were randomly allocated to one of four conditions – Informed-High (*n* = 26), Informed-Low (*n* = 27), Uninformed-High (*n* = 27), Uninformed-Low (*n* = 27). Thirty-two UCL students (16 in each the Informed and Uninformed groups) participated in Experiment 4b. There were 11 males and 25 females with an overall mean age of 22.7 (*SD* = 3.3).

Materials and procedure

In Experiment 4a 120 critical pictures were presented at study and 150 in the CID phase. In the High conditions, all the pictures presented at study were shown again at test (old items), along with an additional 30 new items. In the Low conditions, only 30 old items were presented at test, along with 120 new items. Five sets of 30 items were rotated among old/new status. In Experiment 4b there were 60 critical study trials and 120 CID trials (60 old and 60 new). There were six object categories in total (animals, clothing, electrical appliances, fruit and vegetables, kitchen utensils and furniture), thus in both conditions, ten items within each category were previously studied and ten were new. Two sets of items were rotated.

The study phase, identical for all groups, was the same as described previously. The procedure for the CID phase was also as outlined earlier, with the exception that, for participants in the Informed groups, the word ‘OLD’ or ‘NEW’ was presented in centre screen for 2000 ms prior to the start of each trial to correspond to the next item to be identified. Informed participants in Experiment 4b were also given a category cue prompt on old trials (e.g., ‘OLD – ANIMAL’). Informed participants were instructed to try to use the information provided to help them identify the objects. Participants in the Uninformed groups witnessed a fixation cross for 2000 ms prior to the start of each trial, and were not informed that some items were previously studied. They were given the awareness questionnaire at the end of the experiment.

Results and Discussion

Experiment 4a

Study phase

Categorization accuracy ranged from 97.7% (*SD*= 2.7) to 98.3% (*SD*= 1.8), and performance did not significantly differ between conditions (all $t < 1$, $p > .05$).

Priming

Priming (Figure 5A; See Table 5 for RTs) was significantly greater than chance in all groups (all *t*'s > 2, *p*'s < .05). A two-way ANOVA indicated no main effect of informing participants, $F(1, 103) < 1$, $p = .74$. This provides compelling evidence that explicit processing does not affect priming, as informing participants which items were previously studied provides excellent conditions for the successful use of an explicit strategy. Although the main effect of varying the proportion of studied trials was significant, $F(1, 103) = 4.02$, $p < .05$, there was no interaction between the factors, $F(1, 103) < 1$, $p = .92$. It seems likely that the effect of the different proportions of studied trials was driven by something other than awareness. Both the Informed-High and Informed-Low groups were test-aware, so an interaction between the factors whereby the High and Low conditions only differed in the Uninformed group is required to conclude that the effect is mediated by awareness. A comparison of priming in the Uninformed-High and Uninformed-Low conditions revealed no significant difference, $t(52) = 1.25$, $p = .22$.

Post-test awareness

Of the participants in the Uninformed groups, 25/27 (92.6%) in the High condition, and 14/27 (51.9%) in the Low condition reported being aware that some pictures were previously studied at the time of testing. Priming in these participants did not significantly differ to that in unaware participants (High: aware $M = .09$, unaware $M = .11$, $t < 1$, $p > .05$; Low: aware $M = .06$, unaware $M = .05$, $t < 1$, $p > .05$).

The results suggest that explicit orientation does not affect the magnitude of priming in the CID task. Identification times were very similar in the Informed and Uninformed groups, suggesting that providing participants with information that would enable them to use an explicit strategy in identifying the objects did not affect response speed.

Experiment 4b

Study phase

Categorization accuracy was at 95.7% (*SD*= 4.8) in the Informed group and 97.7% (*SD*= 2.1) in the Uninformed group. Performance did not significantly differ between groups, $t < 1$, $p > .05$.

Priming and post-test awareness

Priming (Figure 5B; See Table 5 for RTs) was significantly greater than chance in both groups (both *t*'s > 3, *p*'s < .01), but did not differ between groups, $t(30) < 1$, $p = .79$. Of the participants in the Uninformed group, 8/16 (50%) were classed as test-aware, but priming did not significantly differ between aware and unaware participants (aware $M = .10$, unaware $M = .11$, $t < 1$, $p = .64$).

The results suggest that explicit processing during the CID task does not affect the speed of identification of previously studied items or the magnitude of priming. Even with a cue that should have created a small search set in explicit memory, no benefit to identification speed was observed.

Experiment 5

In a final experiment we investigated whether receiving incorrect explicit information about test items affects identification speed. In Experiment 4 we found that providing old/new status and category information about items yielded no speeding of RTs or enhancement of priming relative to uninformed conditions. But a stronger test is to compare a correctly informed condition with a misinformed condition. If explicit orientation can affect priming (and is responsible for the age effect obtained here) then we would expect that providing a cue (such as 'old' before an old picture) should induce particularly faster identification when compared to a misinformed condition (such as 'new' before an old picture) in which the participant would be positively discouraged from engaging in search of explicit memory. To achieve this comparison, we therefore compared identification times in the CID task in two groups who were correctly informed about the majority of items but misinformed about the status of a subset of items. It is important that the majority of items were correctly cued as this ensures the overall validity of the cue. Participants were given an ‘OLD/NEW’ prompt before each trial, but one group was falsely informed that 30 (out of 60 total) new items were old (Misinformed-New group), and the other that 30 (out of 60 total) old items were new (Misinformed-Old group). If explicit processing affects the rate of identification of previously studied items, then we expect RTs for items correctly cued to differ from those incorrectly cued in both conditions (e.g., slower identification speeds for old items that participants in the Misinformed-Old group are led to believe are new, in comparison to correctly cued old items).

Method

Participants

There were 32 participants equally divided into the Misinformed-New and Misinformed-Old groups. All were students from UCL who participated for a small payment. There were 15 males and 21 females with an overall mean age of 22.9 (*SD* = 3.6).

Materials and procedure

In total there were 60 study trials and 120 CID trials (60 old and 60 new). The stimuli and object categories were the same as in Experiment 4b. In the CID phase, participants were prompted before each trial with the word ‘OLD’ or ‘NEW’ as described previously, but both groups received incorrect information about 30 of the 120 test trials. Participants in the Misinformed-New group were informed that 30 new items were old, and participants in the Misinformed-Old group were informed that 30 old items were new.

Results and Discussion

Study phase

Categorization accuracy did not significantly differ between the Misinformed-New (M = 95.8%; SD= 3.9) and Misinformed-Old (M = 97.9%; SD= 4.7) groups, $t < 1$, $p > .05$.

RTs and priming

RTs were recorded for items for which participants received correct information (correctly-cued old and correctly-cued new) and those for which they received incorrect information (incorrectly-cued new items in the Misinformed-New group and incorrectly-cued old items in the Misinformed-Old group; see Figures 6A and B). One-way repeated measured ANOVAs indicated a significant main effect of item-type in the Misinformed-New group, $F(2, 30) = 29.3$, $p < .001$, and the Misinformed-Old group, $F(2, 30) = 5.67$, $p < .05$. In the Misinformed-New group, RTs for incorrectly-cued new items (new items that were cued 'old') did not significantly differ to correctly-cued new items, $t(15) < 1$, $p = .43$, and in the Misinformed-Old group, RTs for incorrectly-cued old items (old items that were cued 'new') did not significantly differ to correctly-cued old items, $t(15) < 1$, $p = .78$. In the Misinformed-New group, correctly-cued old items were identified significantly faster than correctly-cued new items, $t(15) = 7.66$, $p < .001$, and incorrectly-cued new items, $t(15) = 4.53$, $p < .001$, and in the Misinformed-Old group, correctly-cued new items were identified significantly slower than correctly-cued old items, $t(15) = 2.47$, $p < .05$, and incorrectly-cued old items, $t(15) = 2.44$, $p < .05$ (a significant priming effect in both groups). In other words, identification speed only varied in each group as a function of the actual status of the items (old/new) and not the information provided to participants about the items. Collapsed across true item status, priming (Figure 6C) did not significantly differ between groups, $t(30) = 1.06$, $p = .30$.

These results add further weight to the general observation that providing participants with explicit information (correct or incorrect) does not affect the speed of identification of previously studied items in the CID task, nor the amount of priming.

General Discussion

We investigated whether implicit memory is preserved in normal aging despite reduced explicit memory. To overcome the problems associated with measuring these memory phenomena in separate experimental phases, each test item was appraised for a recognition and priming judgement in a single trial (Experiment 1). Recognition memory was significantly lower in older relative to young adults, and priming was numerically reduced. These observations were replicated in Experiment 2 in which the priming and recognition tasks were presented separately to reduce test awareness, and the age difference in priming reached significance when data from the individual studies was pooled to increase power. This result is consistent with several other studies that have shown an effect of age on priming (e.g., Abbenhuis et al., 1990; Hultsch et al., 1991), and the meta-analysis by La Voie and Light (1994).

It is often argued that age differences in priming are due to explicit contamination. The use of explicit processing in implicit tests, which may be driven by test-awareness (the realisation that previously studied items are present in the test), could contribute to age effects in priming because young and older adults may differ in their ability to use an explicit strategy. Russo and Parkin (1993) found an age difference in priming on a fragmented picture completion task, but showed that the effect disappeared when explicit memory was equated between groups (young participants performed a dual study task). They suggested that older individuals are less able to facilitate priming with explicit processing. Geraci and Barnhardt (2010) found greater levels of test-awareness and priming in young relative to older adults on word-stem completion and category production tasks, and a greater relationship between the two, which was taken as evidence that awareness mediates age effects in priming. Park and Shaw (1992) demonstrated a small, nonsignificant age difference in priming on a word-stem completion task, but means were identical for unaware young and unaware older participants (.08). In contrast, in Experiment 2 of the present study the numerical age difference in priming persisted when the data from aware participants was removed.

In Experiments 3, 4 and 5 of the present study we shed further light on the issue by showing that priming in the CID task is generally unaffected by explicit orientation. Thus, we suggest that the age difference in priming is unlikely to have been driven by differences in explicit processing between the young and older participants. Several other studies have examined the effects of awareness and explicit processing on priming in young individuals, but results have been mixed. Bowers and Schacter (1990) found that priming on a word-stem completion task did not differ between informed and uninformed participants and did not interact with a levels-of-processing manipulation, however priming was enhanced in uninformed participants who spontaneously became test-aware relative to those who did not (Experiment 1). In contrast, Mace (2003) reported enhanced priming on a word-stem completion task for informed relative to uninformed participants for items studied under semantic conditions, but not nonsemantic conditions. Similarly to the present Experiment 3, Brown, Jones, and Mitchell (1996) found that priming did not differ when identification and recognition judgements were presented concurrently on every trial relative to separate experimental phases, suggesting that the presence of the recognition task alongside priming, which arguably induces greater test awareness than when the tasks are separated, does not affect priming (see also Stark and McClelland, 2000). Moreover, Brown, Nesblett, Jones, and Mitchell (1991) found no difference in priming when old and new test trials were presented in separate blocks (and participants were informed which block contained which type of item) versus interleaved. Similarly to our informed versus uninformed groups manipulation, this would have provided good conditions for the use of explicit processing, yet priming was unaffected. In sum, although it appears that some priming tasks may be more susceptible to the effects of explicit contamination, we suggest that explicit processing does not affect priming in the CID paradigm employed here.

The current study revealed an effect of varying the number of old trials in the priming task (Experiment 4a). A high proportion of old trials resulted in stronger priming relative to a low proportion of old trials. A handful of other studies have also varied the ratio of old/new trials in the priming task, but because this has typically been done to bolster an instructional manipulation (i.e., informed participants are exposed to a high proportion of old trials and uninformed participants to a low proportion of old trials), it is impossible to unravel the differential contributions of the factors to the results. Jacoby (1983) reported enhanced priming on a word naming task in informed participants who witnessed 90% old trials at test relative to uninformed participants who were exposed to 10% old trials at test (see also Richardson-Klavehn, Lee, Joubran, & Bjork, 1994). For the reasons noted in the discussion of Experiment 4a we are confident that the present differences in priming as result of varying the proportion of old trials is not an effect of test awareness. Rather, it could be the case that a disproportionate number of old and new trials created a motivational imbalance which affected the speed of responding. Identification times were faster overall in the High conditions, suggesting that participants' general ability to identify objects was boosted in these conditions. Overall, the influence on priming of varying the number of old trials in the test is not well understood and merits further investigation.

While the present results favor the single-system account of the organisation of memory, there are several observations in the literature that remain a challenge. First, demonstrations of 'pure' implicit memory, that is, priming in the absence of recognition, pose a problem because single-system models cannot predict this pattern. If priming and recognition depend on a common underlying memory trace, then that trace should yield recognition whenever it yields priming. A handful of studies have reported robust priming for items despite recognition of those items being at chance (e.g., Butler & Klein, 2009; Vuilleumier, Schwartz, Duhoux, Dolan, & Driver, 2005), but the replicability of such observations has been questioned (e.g., Berry et al., 2010). Second, conversely to amnesic individuals with damage to the hippocampus and medial temporal lobe, Gabrieli, Fleischman, Keane, Reminger, and Morrell (1995) reported a case in which damage to the right occipital lobe produced impairment to priming while leaving explicit memory unaffected. This double dissociation suggests a neural distinction between systems (but see Yonelinas et al., 2001). Lastly, imaging studies have shown that recognition and priming are associated with distinct functional neural pathways (e.g., Wollams, Taylor, Karayanidis, & Henson, 2008). Despite this, as outlined in the Introduction, because many observations which appear to be indicative of multiple-systems can be accommodated by single-system models, the idea that a single memory signal drives performance on both explicit and implicit tests is a feasible alternative to the view that there are distinct systems for explicit and implicit memory.

To conclude, we provide evidence that both priming and recognition memory are reduced by normal aging and suggest that the effect on priming is not due to explicit contamination. The findings are consistent with the single-system account of memory.

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Footnotes

[1] In Experiments 1 and 2 Young and Older adults differed in visual acuity, vocabulary, and processing speed scores (Tables 1 and 3). None of these variables were reliably correlated with priming (the largest correlation was between priming for items studied immediately before testing and processing speed scores in Experiment 1, $r = .22$, $p = .17$), thus it is unlikely that differences between groups in these factors underlie the age-difference in priming.

[2] Priming = (RTnew – RTold) / RTnew. A proportional priming score was used as baseline (new item) identification times were slower in older relative to young adults in Experiments 1 and 2 (both t's > 3, p's < .005). Furthermore, a pure difference priming score was correlated with baseline RTs in Experiment 1 (Immediate items: $r = .44$, $p = .005$; Delayed items: $r = .57$, $p < .001$), whereas the proportional score largely overcame this (Immediate items: $r = .20$, $p = .22$; Delayed items: $r = .35$, $p = .03$). For all experiments except 4a priming was calculated using median identification RTs, but the qualitative pattern of results was identical when means were used. In Experiment 4a analyses were based on mean identification RTs due to unequal numbers of old and new items in the test phase.

Table 1

Participant characteristics for Experiment 1

	Young (n = 20)	Older (n = 20)
	M (SD)	*M (SD)*
Age (years)	24.3 (3.8)	69.1 (5.5)
Education (years)	16.5 (1.2)	15.9 (2.5)
Visual acuity *	27.0 (5.5)	32.6 (6.1)
WAIS-III Vocabulary *	54.9 (10.2)	64.7 (2.2)
WAIS-III Digit Symbol (processing speed) *	89.9 (14.0)	66.4 (15.8)
Wechsler Test of Adult Reading (WTAR)	46.9 (3.8)	48.8 (2.5)
Mini Mental State Exam (MMSE)	-	29.8 (0.6)

Note. Visual acuity measured using the Near Vision Test Card (Schneider, 2002), expressed as scores ranging from 16/160 (low acuity) to 16/16 (high acuity). WAIS-III (Wechsler Adult Intelligence Scale III) subtest: Vocabulary, maximum score = 66; Digit Symbol Substitution Test, maximum score = 133; WTAR, maximum score = 50; MMSE, maximum score = 30.

* Significant difference between groups, $p < .05$

Table 2

Mean of median identification RTs for old and new items in the Young and Older adult groups in Experiments 1 and 2

	Young			Older		
	Old (immediate)	Old (delayed)	New	Old (immediate)	Old (delayed)	New
Experiment 1	1116 (310)	1110 (262)	1305 (471)	1807 (598)	1784 (541)	1962 (650)
Experiment 2	1174 (349)	1221 (366)	1405 (462)	2278 (857)	2322 (372)	2471 (785)

Note. Standard deviations in parenthesis. Collapsed across young and older individuals, baseline (new item) RTs did not significantly differ between experiments, $t(74) = 1.78$, $p = .08$.

Table 3

Participant characteristics for Experiment 2

	Young (n = 18)	Older (n = 18)
	M (SD)	*M (SD)*
Age (years)	23.9 (3.5)	73.3 (6.7)
Education (years)	16.0 (1.6)	15.8 (1.4)
Visual acuity *	29.4 (6.9)	37.8 (8.1)
WAIS-III Vocabulary *	56.6 (8.7)	65.4 (1.1)
WAIS-III Digit Symbol *	80.5 (17.9)	64.7 (18.0)
WTAR	42.7 (5.1)	49.3 (0.7)
MMSE	-	29.7 (0.5)

* Significant difference between groups, $p < .05$

Table 4

Recognition and priming scores for Young and Older adults in the additional experiment used in the pooled-data analysis

	Young (n = 20)		Older (n = 20)	
	Immediate Test	Delayed Test	Immediate Test	Delayed Test
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*
d′	1.69 (.89)	1.38 (.92)	1.17 (.71)	.87 (.59)
Proportion priming	.24 (.13)	.18 (.15)	.14 (.14)	.19 (.11)

Note. A repeated measures ANOVA with the between-subjects factor Age-group yielded significant main effects of Age-group, $F(1, 38) = 5.61$, $p < .05$, and Delay, $F(1, 38) = 6.81$, $p < .05$, on recognition (*d*´), and no significant interaction, $F < 1$, $p = .964$. There was no main effect of Age-group, $F(1, 38) = 1.35$, $p = .252$, or Delay, $F < 1$, $p = .810$, on priming, but the interaction approached significance, $F(1, 38) = 4.00$, $p = .053$.

Table 5

Identification RTs for old and new items in Experiments 3 and 4

	Old *M (SD)*	New *M (SD)*
Experiment 3		
First test		
CID	1268 (521)	1410 (531)
CID-R	1505 (812)	1679 (755)
Second test		
CID	1161 (553)	1253 (567)
CID-R	1312 (344)	1590 (385)
Experiment 4a		
Informed-High	1479 (375)	1665 (447)
Informed-Low	1652 (303)	1757 (236)
Uninformed-High	1512 (292)	1677 (316)
Uninformed-Low	1667 (348)	1767 (292)
Experiment 4b		
Informed	1717 (470)	1897 (469)
Uninformed	1735 (331)	1937 (346)

Note. Mean of median identification RTs are listed for Experiments 3 and 4b.

Figure 1. A: Priming mask used in the identification task and examples of picture stimuli. B: Example of the CID portion of the CID-R trial. Pictures gradually clarify from a background mask and participants must identify the objects as quickly as possible. RTs captured upon an 'Enter' keypress.

A

B

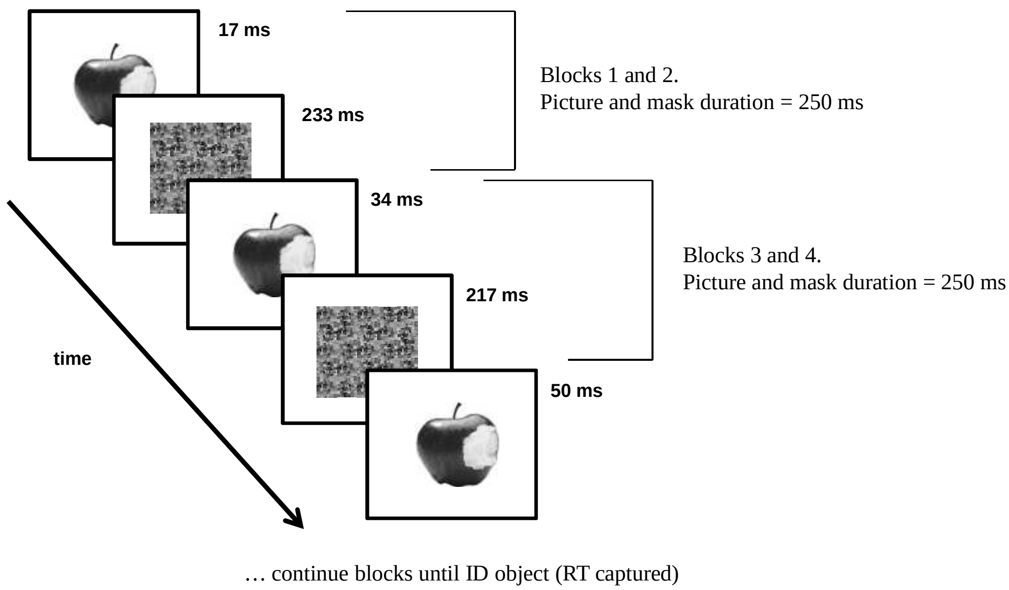


Figure 2. A: Mean *d'* scores for Young and Older adults in Experiment 1 as a function of delay. B: Mean *d'* scores for Young and Older adults in Experiment 2. C: Mean *d'* scores for the two CID-R tests (first and second) in Experiment 3. Error bars in indicate standard error of the mean (SEM).

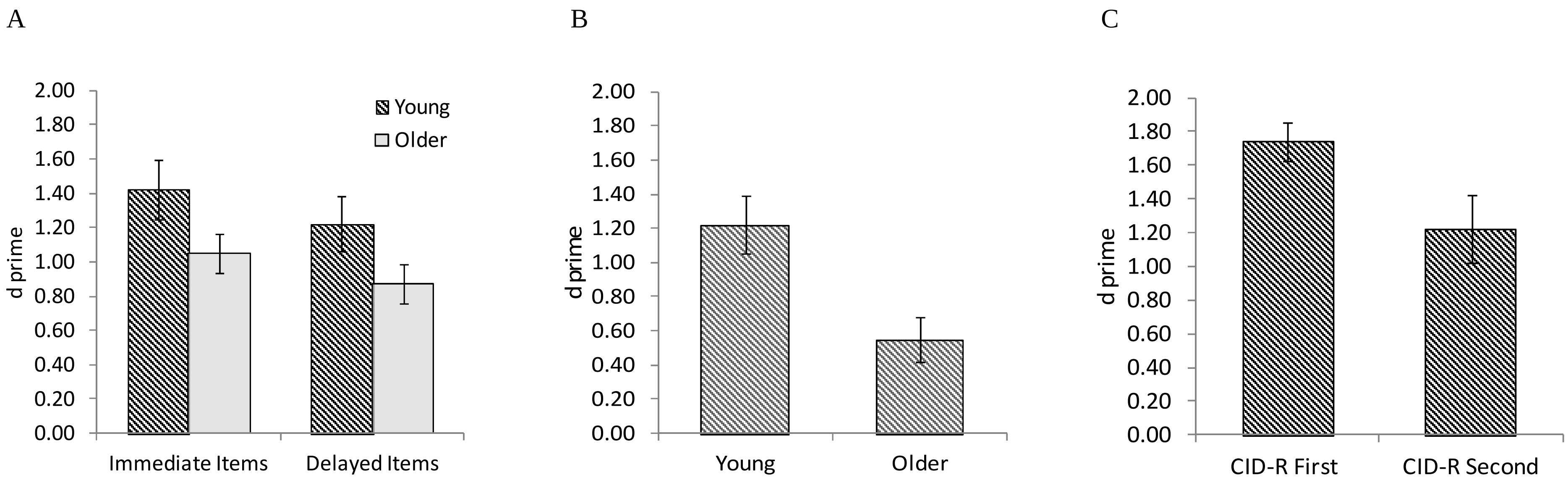
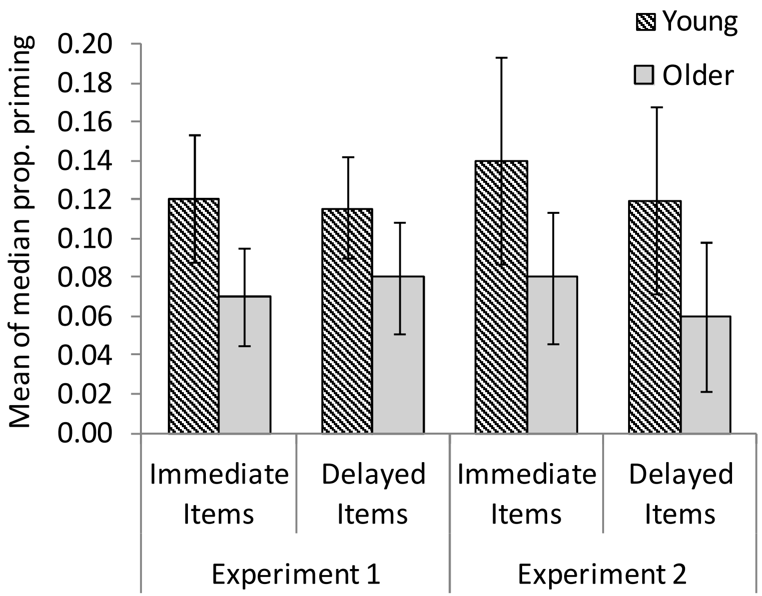


Figure 3. A: Priming in Young and Older adults as a function of delay in Experiments 1 and 2. B: Pooled priming data for Young and Older adults (immediate items; n = 58 per group). Error bars in indicate SEM.

A



B

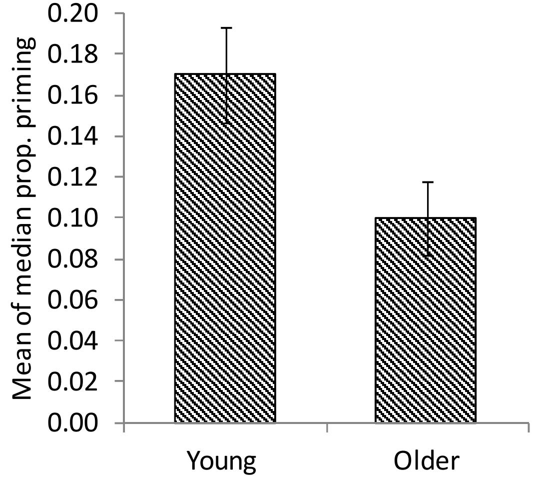


Figure 4. Priming in the first and second CID and CID-R tasks in Experiment 3. Error bars indicate SEM.

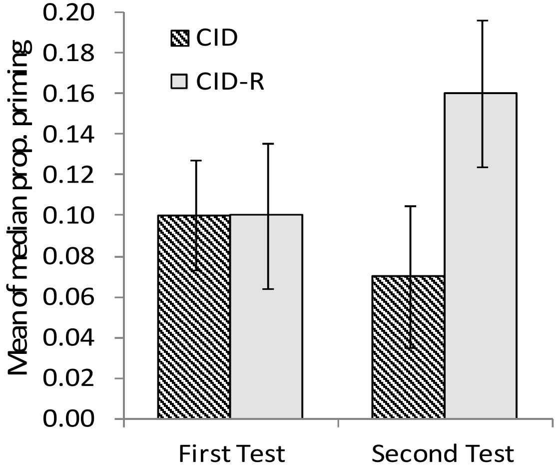
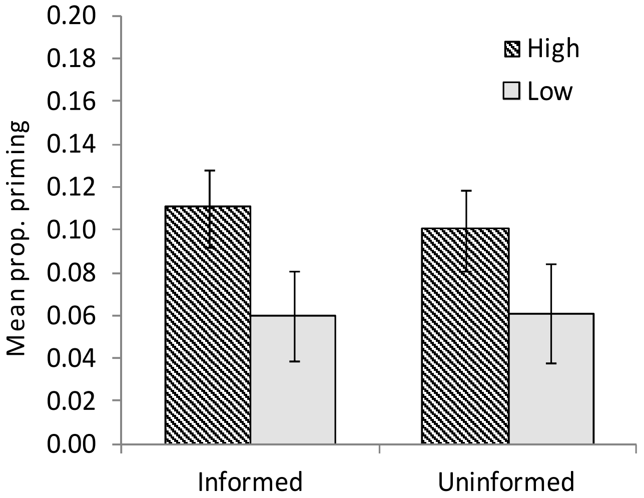


Figure 5. A: Priming in the Informed High, Informed Low, Uninformed High and Uninformed Low groups in Experiment 4a. B: Priming in the Informed and Uninformed groups in Experiment 4b. Error bars indicate SEM.

A



B

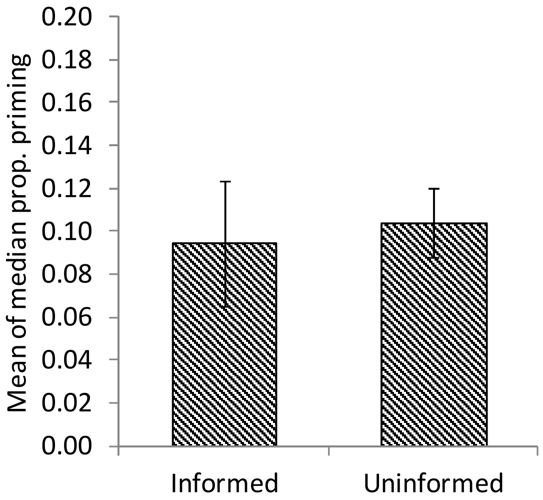


Figure 6. A: Identification times for correctly-cued old, correctly-cued new and incorrectly-cued new items in the Misinformed-New group in Experiment 5. B: Identification times for correctly-cued old, correctly-cued new and incorrectly-cued old items in the Misinformed-Old group in Experiment 5. C: Priming (calculated based on the true item status) in the Misinformed-New and Misinformed-Old groups in Experiment 5. Error bars indicate SEM.

A B C