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Aging Predicts Decline in Explicit and Implicit Memory: A Life-Span Study

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Aging predicts decline in explicit and implicit memory: A lifespan study

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Abstract

Explicit memory declines with age, but age effects on implicit memory are debated. This issue is important because if implicit memory is age-invariant, it may support effective interventions in individuals experiencing memory decline. This study overcame several methodological issues in past research to clarify age effects on implicit memory (priming) and their relationship to explicit memory (recognition, source memory). It aimed to (1) recruit a large lifespan sample of participants (*N*=1072) during a residency at the Science Museum, London, (2) employ an implicit task that is unaffected by explicit contamination, and (3) systematically manipulate depth-of-processing and attention to assess their contribution to age effects. Participants witnessed a succession of overlapping colored objects, attending to one colour stream and ignoring the other, and at test identified masked objects before judging whether they were previously attended, unattended, or new. Age significantly predicted decline in both explicit and implicit memory for attended objects.

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

Introduction

As the proportion of the global population over 65 years of age rises, efforts to clarify age-related changes in memory are increasingly urgent. Explicit memory – the conscious retrieval of previously studied information – declines with age. However, age effects on implicit memory – a change in task performance due to prior exposure to stimuli that does not require conscious recollection – remain debated. Discrepancy in the literature means that no conclusion surrounding age effects on implicit memory can be drawn. This issue is important because if implicit memory is age-invariant, it may support effective interventions in individuals experiencing memory decline. For instance, errorless learning, mediated by implicit memory, may help older adults learn new face-name pairings (Haslam, Hodder, & Yates, 2011).

Reviews have attributed inconsistencies between studies to a range of methodological factors (Fleischman, 2007; Mitchell & Bruss, 2003; Ward & Shanks, 2018), but no study has leveraged critical recommendations to provide conclusive evidence as to whether implicit memory declines or is spared with age. Key issues are summarized next.

Samples, power, and reliability

A substantial body of research suggests that, despite significant reductions in explicit memory, implicit memory remains stable over the lifespan, and is similar in young and older adults (reviewed in Ward & Shanks, 2018). However, sample sizes have varied considerably, and small but real age differences may have gone undetected due to low statistical power. In cross-sectional studies reporting no reliable age difference in priming (a common measure of implicit memory), it has usually been numerically lower in older than young adults, and a meta-analysis by La Voie and Light (1994) uncovered a significant age effect.

This issue is exacerbated by inherent differences in task sensitivity to age effects. Comparisons are frequently made between recognition and word-stem completion as explicit and implicit tasks, but Buchner and Wippich (2000) showed that word-stem completion has statistically lower reliability than recognition, and this can explain age-differential patterns (see also West, Vadillo, Shanks, & Hulme, 2017). The goal of a recognition task, to discriminate between studied and new items, is highly constrained, whereas word-stem completion, which involves completing stems (e.g., HO___) with the first word that comes to mind, is less so. This flexibility leads to response variability and increased error variance making it difficult to detect small effects, and may explain why many prior studies have uncovered significant age differences in explicit but not implicit memory. Word-stem and word-fragment completion are common implicit tests, yet poor reliability may mask a genuine age-related decline in implicit memory. Buchner and Wippich found that a perceptual identification task had greater reliability than word-stem completion and equivalent to recognition. Perceptual identification, like recognition, has a constrained goal (to quickly identify items), and response variability is further reduced by its speeded nature.

Processing and task characteristics

Depth-of-processing during encoding has varied across studies, with some encouraging deep/conceptual processing, and others shallow/perceptual processing (see Mitchell & Bruss, 2003). However, older adults are impaired in elaborative/conceptual encoding (e.g., Rybash, 1996), which may explain greater age effects in studies involving conceptual processing (e.g., Ward, Berry, & Shanks, 2013) and smaller/absent age effects in studies involving perceptual processing (e.g., Soldan, Hilton, Cooper, & Stern, 2009).

Moreover, sometimes items are presented in an unattended stream or as irrelevant information during encoding (e.g., Gopie, Craik, & Hasher, 2011). However, older individuals experience greater difficulty with focussed attention and filtering of irrelevant information (Healey, Campbell, & Hasher, 2008), so processing may differ. Depth-of-processing and attention are thus key potential moderators of age effects on implicit memory, yet have never been systematically manipulated to gain a clear understanding.

Explicit contamination

Some implicit tasks may be susceptible to contamination by explicit memory strategies. This is a significant issue when it comes to aging; reduced priming with age could reflect the use of explicit strategies that are more beneficial to young adults. Mitchell (1995) reported that age differences in implicit memory disappeared when data were adjusted for explicit contamination, and Russo and Parkin (1993) found an age effect that disappeared when explicit memory was equated between groups. Importantly, the meta-analysis by La Voie and Light (1994), that uncovered a significant age effect on implicit memory, did not account for explicit contamination.

A range of recommendations to circumvent explicit contamination have been put forward, largely centred on reducing awareness of the connection between study and test (MacLeod, 2008). However, a valuable method for studying the relationship between explicit and implicit memory is to measure them concurrently using the continuous identification with recognition (CID-R) task (e.g., Stark & McClelland, 2000). On each trial a word/object is identified prior to a recognition judgement. Indices of explicit and implicit memory for each item are captured within a few hundred milliseconds of one another, making them more suitable for comparison than measures sampled in separate experimental phases involving a delay.

In the CID-R paradigm participants are aware that studied items are presented at test, and could feasibly attempt to use an explicit strategy. However, there is evidence that priming on this task is unaffected by explicit contamination. For instance, Brown, Jones, and Mitchell (1996) reported no difference in priming when identification and recognition were measured concurrently trial-by-trial relative to separate experimental phases. Brown, Neblett, Jones, and Mitchell (1991) (see also Mitchell & Bruss, 2003) found no difference in priming on picture and word naming tasks between participants who witnessed studied and new items in separate blocks (and were informed which block contained which type of item) versus interspersed. Ward et al. (2013) replicated the above finding of no difference in priming when the identification task was presented alone versus when concurrent recognition judgements were elicited (Experiment 2), and also found that identification task performance was not enhanced by informing participants whether the next item to appear was previously studied or new, nor was it hindered when such explicit cues were incorrect (Experiments 3a-3b). Thus, explicit processing does not appear to affect priming in the CID-R paradigm, and this may be because identification is accomplished too quickly for the engagement of effortful explicit strategies (MacLeod, 2008).

The current investigation

This study aimed to overcome the issues above to clarify age effects on implicit memory (priming), and their relationship to explicit memory (recognition, source memory). The study was highly powered and employed a CID-R task that evidence suggests is unaffected by explicit contamination. Depth-of-processing and attention were manipulated to reveal their contribution to age effects, and source memory (retrieval of contextual detail associated with an item’s presentation) was captured as an additional explicit measure as the relationship between priming, recognition, and source memory in aging has never been examined in this context. Evidence for preserved implicit memory with age would be stable priming with age (supported by Bayesian analyses providing evidence in favour of the null hypothesis) coupled with reliable reductions in explicit memory. To foreshow the central finding, age predicted decline in both explicit and implicit memory for attended items.

Method

The study took place during a residency at the Science Museum, London, in which adolescents through to older adults were recruited to map memory changes across the lifespan. This is an important departure from studies that habitually compare relatively small samples of young (~18-30 years) and older adults (~65+ years). Participants were exposed to overlapping line drawings of objects colored in cyan and magenta, attending to one color and ignoring the other. They judged whether objects were angular or rounded (shallow processing), or natural or manufactured (deep processing), before completing a CID-R task in which they identified a masked object on each trial before judging whether it was previously presented in cyan or magenta, or was new.

Participants and Design

Many prior studies have used inappropriately small sample sizes, and small effects may have gone undetected due to low statistical power. Added to this, most studies have compared the performance of small groups of young and older adults, whereas this study recruited a large lifespan sample. Over the course of a 6-week residency at the Science Museum, 1072 visitors (448 male) between the ages of 12 and 82 years volunteered to take part. Ethical approval was granted by the Middlesex University Research Ethics Committee, and all participants provided informed consent, including parent/guardian consent for those aged under 16. Participants were required to be fluent in English, have normal or corrected vision, no color blindness, and no history of memory problems. There was no upper age limit but it was a requirement that older participants were healthy and free of dementia. Twenty-one participants were excluded (9 adolescents, 2 young, 3 mid-young, 1 middle, 1 mid-older, and 5 who gave no age) due to missing information and/or accuracy levels <80% in the identification task (see Procedure). The final sample comprised 1051 participants (443 male) aged between 12 and 82 years (*M* = 29.36, *SD* = 14.31).

Due to the open environment and time restrictions applied by the museum, it was necessary to keep background tests to a minimum. Information was collected on age, sex, years of education, vision, intellectual functioning (Wechsler Test of Adult Reading [WTAR], Wechsler, 2001; participants aged 16 years and over), and processing speed. No formal assessment of cognitive impairment (e.g., Mini Mental State Exam) could be performed on older participants, but we can be confident that all were free of cognitive impairment as (1) they were asked to confirm this eligibility requirement when providing consent, and (2) there were no outliers or anomalies in the test data or WTAR scores to suggest abnormal function. Sample characteristics are provided in Table 1, segregating participants into six lifespan groups: adolescents (12-17 years), young adults (18-24 years), mid-young adults (25-34 years), middle adults (35-49 years), mid-older adults (50-64 years), and older adults (65+ years).

Priming (speed of perceptual identification), recognition and source memory were assessed using a CID-R task following a separate study phase in which attention was manipulated within-participants (attended, unattended objects), and depth-of-processing was manipulated between-participants (shallow, deep processing).

Table 1.

Participant Characteristics

	Adolescents	**Young Adults**	**Mid-Young Adults**	**Middle Adults**	**Mid-Older Adults**	**Older Adults**
	***N* = 211**	***N* = 291**	***N* = 261**	***N* = 170**	***N* = 83**	***N* = 35**
Age range (years)	12-17	18-24	25-34	35-49	50-64	65-82
Mean age (years)	14.67 (1.89)	21.07 (2.00)	28.83 (2.98)	41.42 (4.19)	55.30 (4.36)	70.60 (4.40)
***N* Male / Female**	72 / 139	122 / 169	123 / 138	78 / 92	32 / 51	16 / 19
***N* Deep / Shallow**	118 / 93	152 / 139	138 / 123	90 / 80	45 / 38	18 / 17
Education (years)*	10.51 (2.31)	15.60 (2.68)	17.45 (3.09)	17.98 (3.87)	17.88 (6.05)	16.26 (5.11)
WTAR*	38.51 (6.23)	39.91 (7.51)	42.06 (6.79)	43.18 (6.35)	42.46 (7.15)	45.94 (3.64)
Vision*	37.13 (12.17)	37.36 (13.26)	34.94 (7.04)	40.89 (16.27)	42.25 (11.68)	49.54 (27.89)
Processing speed (ms)*	2412 (461)	2217 (449)	2225 (453)	2414 (559)	2580 (638)	2870 (640)

Note: Standard deviations in parentheses. The WTAR (Wechsler Test of Adult Reading, Wechsler, 2001), in which participants are asked to pronounce uncommon English words (maximum score 50), is an assessment of intellectual functioning. This was administered to participants aged 16 years and over, thus the score for Adolescents is based on 97 participants who met this criterion. The mean for mid-older adults excludes one participant with a missing score. Visual acuity was measured using the Near Vision Test Card (Schneider, 2002), viewed at a distance of 16 inches. Scores can range from 16 (highest acuity) to 160 (lowest acuity). One adolescent with a score of 14 was not included. Processing speed was indexed as the mean of the baseline (new item) identification times in the CID-R task. *Significant main effect of age group (p's < .001). Bonferroni corrected follow-up comparisons indicated significant differences in Education (adolescents vs. all other groups; young adults vs. all groups apart from older adults), Vision (adolescents vs. mid-older adults and older adults; young adults vs. mid-older and older adults; mid-young vs. middle adults, mid-older adults, and older adults); WTAR (adolescents vs. all groups apart from young adults; young adults vs. all groups apart from adolescents; mid-young vs. older adults;), and Processing speed (adolescents vs. all groups apart from mid-young and middle adults; young adults vs. all groups apart from mid-young adults; mid-young vs. all groups apart from young adults; middle adults vs. all groups apart from adolescents and mid-older adults; older adults vs. all groups apart from mid-older adults).

Stimuli

Stimuli comprised a subset of the 260 line drawings of everyday objects created by Snodgrass and Vanderwart (1980). Highly similar items (e.g., blouse, jacket) were removed, leaving 245 objects. Approximately half were naturally occurring items and half were manufactured. Objects were 240 x 240 pixels in size and presented in the centre of a white background screen. Forty were presented in the study phase, 20 colored in magenta and 20 in cyan, with approximately equal brightness and luminance. On each trial, two objects – one magenta and one cyan – overlapped, and participants attended to one color stream and ignored the other (Figure 1A). Eighty objects were presented at test, 40 from the study phase (20 attended, 20 unattended), and 40 new items. Objects were presented in black at test. Objects were randomly assigned to serve as attended, unattended or new items, and a different random assignment was used for each participant.

The mask used in the identification task (Figure 1B) was 400 x 400 pixels in size, created using a script that randomly superimposed lines and arcs of a similar thickness to the lines of objects in the stimulus set.

Procedure

The experiment took place within the Live Science space at the Science Museum in South Kensington, London. There were five desktop PCs with a screen resolution of 1280 x 1024 pixels. Participants performed the experiment individually, but up to five could take part at a time. An adjustable screen surrounding the area gave privacy and ensured that any waiting participants could not view the experiment. Guidelines for the residency stated that the procedure should not exceed 30 minutes, so the experimental task was designed to take 20-25 minutes and the remaining 5-10 minutes was spent collecting background information, including age, sex, years of education, vision and intellectual functioning (WTAR; Table 1). This was done prior to the experimental task and after eligibility check.

The experiment was programmed using MATLAB 2016b. Viewing distance was approximately 50 cm. During the study phase participants witnessed a steam of overlapping object pairs. One of the objects was presented in magenta and the other in cyan. Participants were told that the objects would be presented briefly and that they should attend to one color (either magenta or cyan) and ignore the other. The attended color was randomized between participants and collapsed for analysis. Each object pair was presented for 250 ms, followed by a black fixation point for 1250 ms. The duration of the interstimulus interval was chosen to allow time for a response on each trial. The response depended on the depth-of-processing manipulation, which was randomized between participants. In the deep processing condition participants decided whether the attended object was natural or manufactured, and in the shallow condition whether it was angular or rounded, using the Z and M keys. Participants were instructed to respond as quickly as possible based on their first impression. The response cue "*Z = natural*; *M = manufactured*" or "*Z = angular*; *M = rounded*" remained on the screen at all times, in a font color to match the attended stream of objects. There were 8 practice trials prior to the 40 experimental trials.

Following the study phase there was a retention interval of approximately 3 minutes while participants read instructions for the CID-R task. Each trial consisted of a speeded object identification followed by a recognition/source judgment. Forty randomly chosen old objects from the study phase (20 attended, 20 unattended) appeared at test, along with 40 new objects, presented in black on a white background. Participants were informed that on each trial they would first have to identify an object that would be masked and difficult to make out. They were informed that the object would appear to gradually emerge and their task was to press the enter key as soon as they could identify it. Speed was emphasized, but participants were asked to be as accurate as possible. Each trial ran as follows: The mask was presented for 250 ms, followed by an object for 17 ms (one screen refresh at 60 Hz), and then the mask again for 233 ms, forming a 250 ms block. The block presentations continued with the object presentation increasing by 17 ms on each alternate cycle and the mask duration decreasing by the same amount, with the effect that the object appeared to gradually clarify (Figure 1B). Identification time was captured upon pressing the enter key, at which time the object disappeared and participants were prompted to type their response (e.g., 'basket') into a box. If the enter key had not been pressed after 7500 ms (i.e., when the object was fully displayed), the trial was discarded and the cue "Please try to be faster on the next trial" appeared for 1000 ms.

After identifying the object participants judged whether it was shown in the study phase, and if so, in what color – the color that they attended to, or the color that they ignored. The object was presented once more (in full view) along with the instruction "*Was the object shown in the very first part of the experiment or is it new?*", "1 = *previously purple*", "2 = *previously blue*", "3 = *new*". Participants responded via a number keypress. They were informed that half of the objects were presented previously (an equal number of attended and unattended objects) and half were new. No time limit was imposed. Following a response, a fixation point was presented for 500 ms prior to the next trial. At the end of the experiment participants received on-screen feedback with their average response times and recognition scores (percent) for attended, unattended, and new objects.

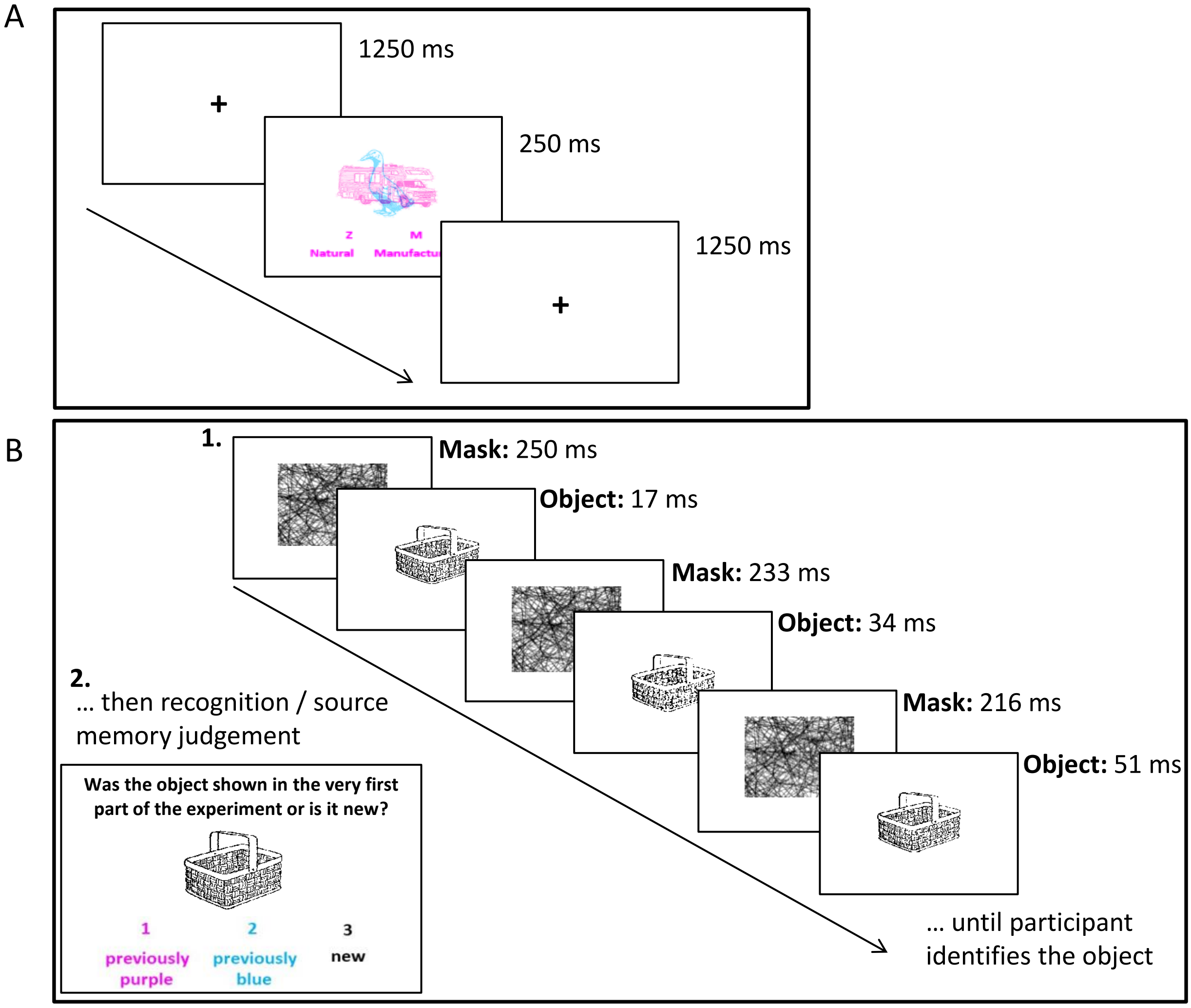

Figure 1. A. Events in the study phase. Participants were presented with a stream of overlapping objects, one colored in cyan and the other in magenta, and attended to one color stream and ignored the other (counterbalanced). The text color of the response cue served as a reminder of the color stream to attend to (magenta in the example). On each trial participants either judged whether the attended object was natural or manufactured (deep processing), or angular or rounded (shallow processing). **B.** Events in a single trial in the CID-R task. An object (old [attended/unattended] or new) gradually clarified from a background mask and participants identified the object as quickly as possible (priming measure), before making a recognition/source memory judgment (explicit measures). During the clarification procedure the background mask was initially presented for 250 ms prior to a flash of the object for 17 ms. Presentations of the mask and object were then alternated with the object duration increasing by 17 ms and the mask duration decreasing by 17 ms each alternate cycle, with the effect that the object gradually emerged. A keypress ended the clarification procedure, at which point the object disappeared and the participant's identification RT was captured. The participant then typed the object name into a box before the object was presented again for the recognition/source memory judgment.

Results

An alpha level of .05 was used for all tests, and *t*-tests are two-tailed. Partial eta squared (η_p^2) effect size is reported for significant ANOVA effects, and Cohen's *d* for *t*-tests.

Study phase

Trials on which no keypress was made, or with response times <200 ms were excluded. One older participant made no keypresses in the study phase and was not included in this analysis. Mean classification response times did not significantly differ between the deep (M = 701 ms, SE = 6) and shallow (M = 700 ms, SE = 7) conditions, $t(1048) = 0.02$, $p = .985$, d = 0.001, 95% CI [-0.12, 0.12].

Priming

Trials associated with incorrect identifications and/or RTs <200 ms or >3 SD from the mean were excluded (4.90% of trials). Table 2 reports identification rates and RTs for attended, unattended, and new items. Priming was calculated by subtracting each participant's mean old item RT (attended/unattended) from their mean new item RT, expressed in proportion to their mean baseline (new item) RT: (*RT new* – *RT old*) / *RT new*. A proportional measure is deemed most suitable for age comparisons, because slower baseline responding in older than young adults can artificially elevate priming when an RT difference score is used (e.g., Faust, Balota, Spieler, & Ferraro, 1999).

Table 2.

Perceptual identification and priming across age groups

	Adolescents 12-17 years	Young Adults 18-24 years	Mid-Young Adults 25-34 years	Middle Adults 35-49 years	Mid-Older Adults 50-64 years	Older Adults 65+ years
Identification rate (%)	93.73 (3.87)	95.18 (3.82)	95.69 (3.14)	95.75 (5.91)	95.29 (3.85)	94.68 (3.16)
Deep Processing						
Mean Old Item RT (ms)						
Attended	2227 (417)	2081 (489)	2019 (436)	2351 (573)	2545 (680)	2579 (684)
Unattended	2351 (433)	2223 (497)	2197 (469)	2410 (546)	2676 (645)	2673 (617)
Mean New Item RT (ms)	2396 (449)	2233 (461)	2208 (436)	2446 (553)	2695 (651)	2679 (610)
Prop. Priming						
Attended	.07 (.08)	.07 (.08)	.08 (.08)	.04 (.08)	.06 (.07)	.04 (.06)
Unattended	.01 (.09)	.01 (.08)	.00 (.08)	.01 (.08)	.00 (.07)	.00 (.05)
Shallow Processing						
Mean Old Item RT (ms)						
Attended	2300 (526)	2056 (420)	2105 (454)	2254 (576)	2337 (607)	2944 (599)
Unattended	2387 (464)	2176 (445)	2234 (484)	2349 (555)	2418 (632)	3021 (521)
Mean New Item RT (ms)	2433 (478)	2199 (437)	2243 (473)	2378 (566)	2445 (602)	3072 (625)
Prop. Priming						
Attended	.06 (.08)	.06 (.07)	.06 (.08)	.05 (.07)	.04 (.07)	.04 (.06)
Unattended	.02 (.07)	.01 (.08)	.00 (.07)	.01 (.06)	.01 (07)	.01 (.08)

Note. Standard deviations in parentheses. Identification rate refers to the percentage of CID-R trials remaining post screening. Trials associated with incorrect identifications and/or response times < 200 ms or >3 SD from the mean were excluded. Proportional priming (Prop. Priming) was calculated as (RT new – RT old) / RT new.

A 6 (age) × 2 (attention) × 2 (depth-of-processing) mixed ANOVA revealed a significant main effect of attention on priming, $F(1,1039) = 172.02$, $p < .001$, $\eta_p^2 = .142$, and a significant interaction between attention and age, $F(5,1039) = 3.84$, $p = .002$, $\eta_p^2 = .018$. No other main effects or interactions were significant (p's > .05). The attention × age interaction suggests a statistical age effect for attended but not unattended items. Priming for attended items was statistically above zero in all age groups (*p*'s < .008, *d*'s > 1.38 [Bonferroni adjusted alpha]), while priming for unattended items was not significant in any group apart from adolescents, $t(210) = 2.86$, $p = .005$, $d = 0.20$, 95% CI [0.06, 0.33], so a one-way ANOVA was performed on attended items where priming was present. Given no main effect of depth-of-processing ($F(1,1039) = 0.25$, $p = .616$, $\eta_p^2 < .001$), deep and shallow conditions were collapsed. This revealed a significant main effect of age, $F(5,1045) = 3.59$, $p = .003$, $\eta_p^2 = .017$. Confirming these findings, multiple regression with age as a continuous variable revealed a significant linear decline in priming for attended items with age, $F(1,1049) = 7.82$, $p = .005$, $r = -.086$. No extra variance was explained by adding a quadratic component of age (R^2 change < .001, $p = .483$). An orthogonal component with a correlation of 0 was used to overcome multicollinearity.

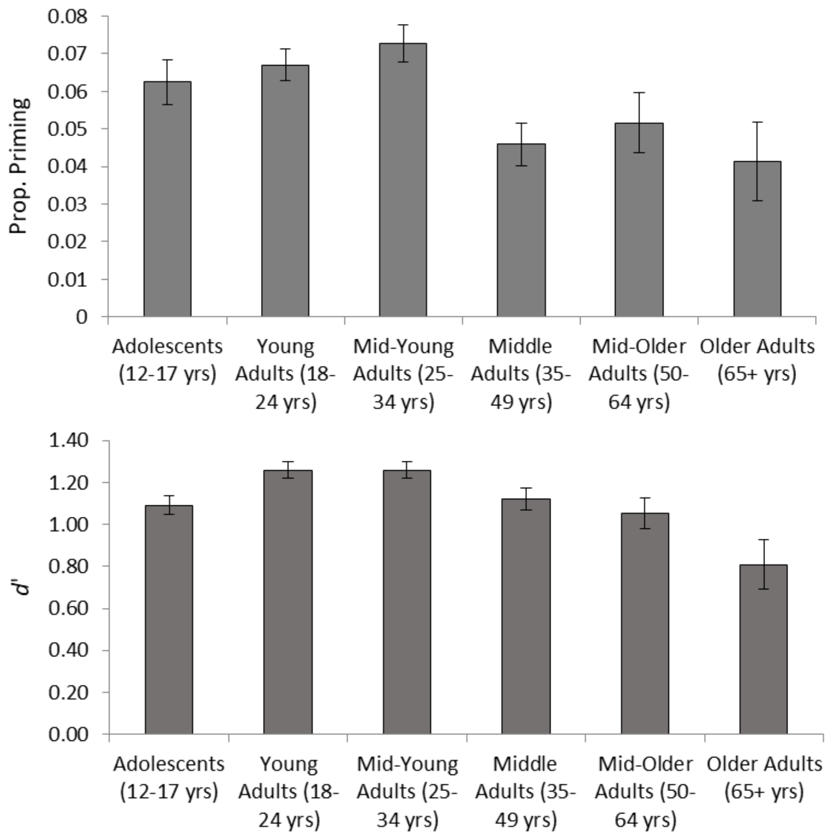

Figure 2. Mean proportional priming (top panel) and mean *d'* scores (lower panel) across age groups for attended items, collapsed across depth-of-processing condition. Bars indicate standard error of the mean (SE).

Recognition and source memory

On each trial participants judged whether an object was previously presented in blue or purple (old judgment) or was not previously presented (new judgment). For recognition analyses, ratings 1 (previously purple) and 2 (previously blue) were collapsed to a single ‘old’ judgment. For each participant, *d*' was calculated as *z*-transformed Hit rate (proportion old items judged old) minus the *z*-transformed False Alarm rate (proportion new items judged old), separately for attended and unattended items (Table 3).

Recognition was significantly above chance ($d' > 0$) for attended items in all age groups (Bonferroni adjusted *p*’s < .008, *d*’s > 3.53), but not for unattended items in middle adults $t(169) = 2.54$, $p = .012$, $d = 0.20$, 95% CI [0.04, 0.35], or older adults, $t(34) = 2.57$, $p = .015$, 95%, $d = 0.43$, 95% CI [0.08, 0.78]. A 6 (age) × 2 (attention) × 2 (depth-of-processing) ANOVA revealed significant main effects of attention, $F(1,1039) = 1290.60$, $p < .001$, $\eta_p^2 = .554$, and age, $F(5,1039) = 2.33$, $p = .041$, $\eta_p^2 = .011$, and an interaction between the two, $F(5,1039) = 6.98$, $p < .001$, $\eta_p^2 = .033$. There was no effect of depth-of-processing, $F(1,1039) = 0.03$, $p = .873$, $\eta_p^2 < .001$, and no other interactions (*p*’s > .05). Collapsed across depth-of-processing, a one-way ANOVA revealed a significant main effect of age for attended items, $F(5,1045) = 5.52$, $p < .001$, $\eta_p^2 = .026$. There was no main effect of age on unattended items, $F(5,1045) = 0.61$, $p = .694$, $\eta_p^2 = .003$. As with priming, multiple regression revealed that age as a continuous variable significantly predicted a linear decline in recognition of attended items, $F(1,1049) = 7.19$, $p = .007$, $r = -.083$. An additional 1.16% of variance was explained by adding the quadratic component of age (R^2 change = .0116, $p < .001$).

The adolescent data were included to shed light on lifespan changes in priming and recognition. For readers interested specifically in adult age differences, an analysis excluding adolescents revealed a consistent pattern. Collapsed across depth-of-processing there were significant main effects of age on recognition (*d*'), $F(4,835) = 5.85$, $p < .001$, $\eta_p^2 = .027$, and priming, $F(4,835) = 4.65$, $p = .001$, $\eta_p^2 = .022$ (attended items), and age as a continuous variable predicted significant linear declines in recognition, $F(1,838) = 19.28$, $p < .001$, $r = -.15$, and priming, $F(1,838) = 10.94$, $p = .001$, $r = -.11$.

Table 3.

Recognition memory across age groups

	Adolescents 12-17 years	Young Adults 18-24 years	Mid-Young Adults 25-34 years	Middle Adults 35-49 years	Mid-Older Adults 50-64 years	Older Adults 65+ years
			Deep Processing			
Hit rate						
Attended	.77 (.21)	.79 (.17)	.81 (.14)	.74 (.18)	.70 (.22)	.60 (.24)
Unattended	.41 (.21)	.39 (.21)	.37 (.20)	.40 (.24)	.37 (.26)	.41 (.20)
FA rate	.38 (.19)	.37 (.19)	.35 (.18)	.37 (.21)	.33 (.22)	.34 (.19)
d'						
Attended	1.15 (0.68)	1.26 (0.67)	1.31 (0.61)	1.10 (0.69)	1.04 (0.60)	.74 (0.76)
Unattended	.09 (0.41)	.06 (0.39)	.07 (0.42)	.12 (0.45)	.09 (0.38)	.22 (0.30)
			Shallow Processing			
Hit rate						
Attended	.75 (.21)	.84 (.13)	.76 (.19)	.73 (.23)	.68 (.24)	.58 (.31)
Unattended	.44 (.22)	.44 (.19)	.39 (.20)	.35 (.25)	.39 (.24)	.30 (.20)
FA rate	.40 (.21)	.42 (.18)	.35 (.18)	.33 (.22)	.34 (.23)	.29 (.18)
d'						
Attended	1.01 (0.59)	1.26 (0.63)	1.20 (0.64)	1.15 (0.67)	1.07 (0.75)	.88 (0.64)
Unattended	.12 (0.40)	.07 (0.39)	.12 (0.38)	.05 (0.44)	.18 (0.36)	.08 (0.39)

Note. Standard deviations in parentheses. Hit rate = Mean proportion ‘old’ judgments to old items (attended/unattended). Responses 1 and 2 on the scale were collapsed to a single ‘old’ judgment. FA (false alarm) rate = Mean proportion ‘old’ judgments to new items. $d' = z(\text{Hit rate}) - z(\text{FA rate})$. The Snodgrass and Corwin (1988) correction was applied to Hit and FA rates with values of 0 or 1 (i.e., Hit rate = (n Hits + 0.5) / (n old + 1); FA rate = (n FAs + 0.5) / (n new + 1).

Breakdown of attended/unattended (i.e., color) and new judgments, collapsed across depth-of-processing, revealed that attended items tended to be correctly judged as attended rather than as unattended/new, $F(1.67, 1746.75) = 409.18$, $p < .001$, $\eta_p^2 = .281$ (Greenhouse-

Geisser adjusted degrees of freedom are reported as the assumption of sphericity was violated). This ability peaked in young adults before declining (judgment × age interaction: $F(8.36, 1746.75) = 11.33$, $p < .001$, $\eta_p^2 = .051$). There was an increasing tendency to judge items as new with age, and at the extreme older adults were unable to judge whether attended items were attended or new, $t(34) = .26$, $p = .796$, $d = 0.04$, 95% CI [-0.29, 0.38] (see Figure 3 for judgments and accuracy by item type). Both unattended and new items tended to be judged as new ($F(1.56, 1631.69) = 789.19$, $p < .001$, $\eta_p^2 = .430$, and $F(1.46, 1537.93) = 1257.72$, $p < .001$, $\eta_p^2 = .546$, respectively), and unattended items were not accurately judged as such by any group.

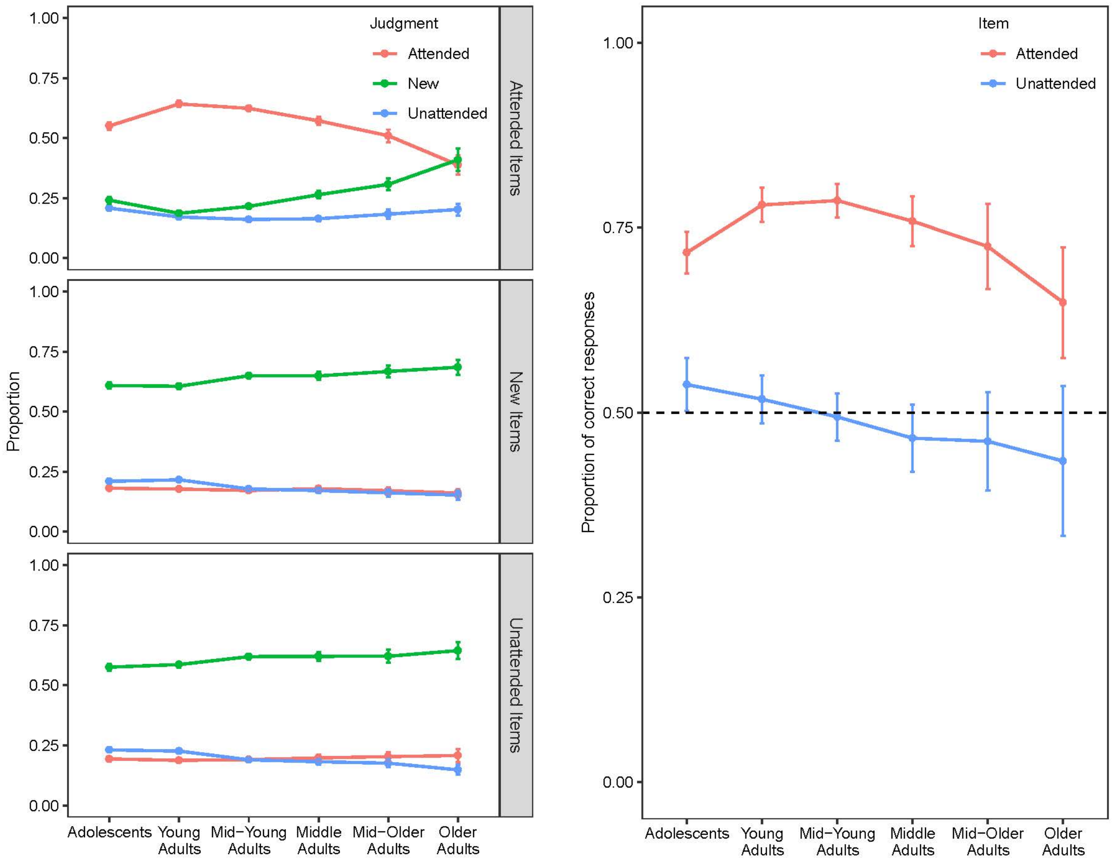

Figure 3. Left: Mean proportion of attended, unattended, and new judgments by item type collapsed across depth-of-processing condition. Bars indicate SE. Right: Accuracy of source judgments (attended/unattended) to attended and unattended items collapsed across depth-of-processing. Bars indicate 95% CI of the mean.

Associations between priming and recognition

Collapsed across depth-of-processing, these analyses examined whether identification RTs in the priming task varied according to whether the item was explicitly remembered (Table 4). RTs were significantly faster for items judged old compared to ones judged new, $F(1,1027) = 277.48$, $p < .001$, $\eta_p^2 = .213$, and this was consistent across age groups (no interaction with age, $p = .413$; all paired *t*-tests $p < .001$).

Identification RTs were also analysed according to whether the recognition judgment was a hit, miss, false alarm, or correct rejection). RTs significantly varied according to recognition judgment, $F(3.58, 3303.28) = 54.86$, $p < .001$, $\eta_p^2 = .056$, and there was no interaction with age ($p = .862$) (all Greenhouse-Geisser adjusted). Collapsed across age, identification RTs were fastest overall for attended items that were recognized (attended hits, $M = 2151$, $SD = 528$), and slowest for correctly rejected new items ($M = 2364$, $SD = 525$), and this difference was significant, $t(1029) = 26.61$, $p < .001$, $d = 0.83$, 95% CI [0.76. 0.90]. Attended hits were associated with significantly faster identification times compared to attended misses, $t(957) = 13.82$, $p < .001$, $d = 0.45$, 95% CI [0.38, 0.51], but—revealing no evidence of priming for unrecognized objects—RTs for misses did not differ from RTs to correct rejections (attended misses: $M = 2361$, $SD = 518$; unattended misses: $M = 2352$, $SD = 548$; correct rejections: $M = 2364$, $SD = 525$, $p = .278$ and $.157$, respectively). These clear associations between priming and recognition are consistent with previous findings from the CID-R task (Berry et al., 2012).

Table 4.

Identification times (ms) by recognition judgment

	Adolescents 12-17 years	Young Adults 18-24 years	Mid-Young Adults 25-34 years	Middle Adults 35-49 years	Mid-Older Adults 50-64 years	Older Adults 65+ years
Items judged New	2419 (452)	2240 (445)	2245 (462)	2427 (568)	2595 (649)	2893 (645)
Items judged Old	2307 (464)	2100 (455)	2095 (439)	2298 (536)	2484 (643)	2745 (618)
Old items						
Attended Hits	2231 (487)	2028 (448)	2015 (442)	2256 (606)	2405 (657)	2644 (580)
Unattended Hits	2318 (506)	2133 (499)	2136 (518)	2317 (553)	2517 (679)	2828 (675)
Attended Misses	2386 (601)	2268 (616)	2211 (581)	2454 (690)	2647 (864)	2879 (779)
Unattended Misses	2411 (456)	2230 (487)	2251 (450)	2401 (600)	2609 (682)	2899 (676)
New items						
False Alarms	2367 (478)	2162 (498)	2166 (478)	2344 (569)	2588 (709)	2816 (734)
Correct Rejections	2431 (478)	2247 (446)	2248 (471)	2442 (574)	2587 (636)	2892 (641)

Note. Collapsed across depth-of processing condition. Standard deviations in parentheses.

Discussion

This study aimed to clarify age effects in implicit memory and their relationship with explicit memory by overcoming several issues that have compromised past research. The study used (1) a large lifespan sample rather than mere comparison of young and older participants, (2) an implicit task that evidence suggests is unaffected by explicit contamination, (3) a semi-naturalistic setting, and (4) directly manipulated depth-of-processing and attention, factors that have varied in prior studies, to reveal their contributions to age effects. The data revealed age-related declines in both implicit and explicit memory. Age effects were present for attended items, but not unattended items where performance was no greater than chance in the majority of cases. Age predicted a decline in explicit and implicit memory for attended items, with a quadratic trend in recognition indicating that it increased up to mid-young adulthood before declining. The ability to correctly judge attended items as attended rather than unattended/new peaked in young adults before declining, and older adults were unable to judge whether attended items were attended or new. There was no priming for items that were not recognized, and this was consistent across age groups.

Findings in relation to explicit memory are consistent with a body of literature. Nilsson (2003) reported an increase in explicit memory up to 25–30 years of age before gradual decline. A progressive decline has been shown longitudinally (e.g., Davis, Trussell, & Klebe, 2001; Fleischman, Wilson, Gabrieli, Bienias, & Bennet, 2004; Hultsch, Hertzog, Small, McDonald-Miszczak, & Dixon, 1992), and numerous cross-sectional studies show poorer performance in older compared to younger adults on recall and recognition tests (see Jelicic, Craik, & Moscovitch, 1996; Kausler, 1994).

In a field replete with contradictory findings surrounding age effects on implicit memory, this study provides much-needed clarification by addressing prominent issues to uncover evidence of decline that qualitatively mirrors that in explicit memory. Some prior studies have reported reductions in implicit memory with age on tests of word-stem completion and perceptual identification (e.g., Abbenhuis, Raaijmakers, Raaijmakers, & Van Woerden 1990; Hultsch, Mason, & Small, 1991; Ward et al., 2013), but the present study controls the possibility that the effect is mediated by explicit contamination and/or differences in processing or attention.

Although the qualitative patterns of change in explicit and implicit memory are consistent, the decline in implicit memory is smaller than that in explicit memory. This is consistent with the meta-analysis by Light and LaVoie (1994), and is likely a function of differences in task sensitivity. Implicit tasks are generally associated with greater variability than explicit tasks (e.g., Buchner & Wippich, 2000; West et al., 2017), meaning that it is more difficult to statistically detect effects in the former. Indeed, a single system computational model developed by Berry and colleagues predicts larger effects on recognition than priming by assuming that the error variance associated with the priming task is greater than that of recognition (e.g., Berry, Shanks, Speekenbrink, & Henson, 2012). Variability of baseline (new item) RTs was highest in the oldest group in the present study, and this may have been exacerbated by the relatively smaller size of this group.

The observed age-related decline would benefit from validation in a longitudinal design to determine within-individual changes in memory over time. Longitudinal studies are less common in the literature, but have largely revealed reductions in explicit memory with age coupled with null changes in priming (e.g., Davis et al., 2001; Fleischman et al., 2004). These studies are open to the same problems reviewed here and may have failed to statistically detect small changes in priming. Although extremely difficult to accomplish on a similar scale to the present study, we conjecture that a similar longitudinal study would be likely to expose a consistent pattern of decline in explicit and implicit memory.

There was no effect of depth-of-processing. This was manipulated in a manner that has produced effects on explicit memory in the past, albeit not unfailingly (see Intraub & Nicklos, 1985). However, most prior studies have used words as stimuli and free recall as the task. There is also evidence that semantic processing can occur with extremely brief presentations (e.g., Potter, Wyble, Hagmann, & McCourt, 2014), so exposure time in this study may have been sufficiently long to enable deep processing in both conditions. Indeed, classification times were similar in the deep and shallow conditions, suggesting equivalent processing. The observations suggest that differential processing during encoding (i.e., deep versus shallow, as may naturally occur in young versus older adults) is an unlikely mediator of age effects in implicit memory. Rather, variations in the magnitude of age differences are likely due to a combination of issues with power and task reliability.

To conclude, this study clarifies the effect of age on implicit memory, delivering robust evidence for a decline that qualitatively mirrors that in explicit memory. This has significant implications for an aging population, suggesting limits to the utility of implicit memory for supporting interventions in individuals experiencing memory decline. The findings also hold implications for our theoretical understanding of the organisation of memory, suggesting that explicit and implicit memory do not operate independently but are driven by a single underlying system (Berry et al., 2012).

Author Contributions

E. V. Ward developed the study concept. All authors contributed to the study design. C. J. Berry and E. V. Ward designed the experimental task, which was programmed by C. J. Berry. Data collection and data screening was managed by E. Czsiser and P. L. Moller under the supervision of E. V. Ward. Analysis was performed by E. V. Ward and C. J. Berry, and all authors contributed to interpretation. E. V. Ward drafted the manuscript, and critical revisions were provided by C. J. Berry and D. R. Shanks. All authors approved the final version of the manuscript for submission for publication. The project was supported by a Small Research Grant from the Experimental Psychology Society awarded to E.V. Ward. C. J. Berry (ES/N009916/1) and D. R. Shanks (ES/P009522/1) are supported by the UK Economic and Social Research Council.

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