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Age differences in priming as a function of processing at encoding

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ABSTRACT

It is unclear whether implicit memory (priming) is affected by aging. Some studies have reported no difference between young and older adults, while others have uncovered reliable reductions. An important factor that may explain these discrepancies is the manner of encoding. Processing requirements (perceptual/conceptual) have varied considerably between studies, yet processing abilities are not equally affected by aging. This study examined whether processing during encoding moderates age effects on priming. Young and older participants studied object-word pairs and made natural/manufactured (conceptual) and left/right rotation (perceptual) judgements in relation to the word or object. Objects served as targets on a subsequent continuous identification with recognition task to assess priming and recognition. Priming and recognition were greater in young than older adults for attended items, with a larger effect size in the conceptual than the perceptual condition. Findings suggest that age differences in priming may be a function of processing at encoding.

1. Introduction

Explicit (declarative) memory – the conscious retrieval of previously learned information – declines with age. However, age effects on implicit (nondeclarative) memory – facilitation in task performance due to prior exposure to stimuli that does not require conscious recollection – are poorly understood. A number of studies have reported age-invariant implicit memory, while others have reported reductions with age (reviewed in Fleischman, 2007; Mitchell & Bruss, 2003; Ward & Shanks, 2018). This debate carries important practical and theoretical implications. Preserved priming in normal aging may provide a valuable diagnostic tool for Alzheimer's disease (e.g., Fleischman, 2007), or be used to aid everyday tasks such as learning medication routines (Haslam, Hodder, & Yates, 2011). Further, the decline versus stability of implicit memory with age is often used as a key strand of evidence in debates around the structure and operations of memory (e.g., Gabrieli, 1998; Schacter & Tulving, 1994; Squire, 2004). However, at present there is no clear answer to the question of whether aging affects implicit memory.

In a typical perceptual identification implicit memory task, participants are presented with stimuli (words/objects) very briefly or in a degraded form, and are required to identify (i.e., name) them as quickly as possible. Stimuli include a mix of items that were previously presented in a seemingly unrelated encoding phase, and some new items, and priming (the common measure of implicit memory) is evidenced by faster identifications of previously presented relative to new items. A range of methodological factors may explain why age differences sometimes emerge on such paradigms and other times they do not, and issues such as statistical power, task reliability and sensitivity, explicit contamination, and priming task processing characteristics have received a great deal of attention over the years (reviewed in Fleischman, 2007; Rybash, 1996; Mitchell & Bruss, 2003; Ward & Shanks, 2018). Another factor

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that may affect whether age differences in priming emerge is the manner in which participants engage with stimuli during the initial encoding of items that are later tested. A distinction is often made between perceptual and conceptual processing. Perceptual processing is data driven and engages participants with purely physical features of stimuli, while conceptual processing draws upon more elaborate processing of the content and meaning of items. There is evidence that older adults are less effective than young adults at encoding information when the orienting task involves conceptual processing – known as the processing deficit hypothesis (e.g., Eysenck, 1974). The processing deficit hypothesis predicts that age differences in memory will increase as the depth of processing required by the encoding task increases. Indeed, a number of studies have shown that older adults benefit less from conceptual orienting tasks than young adults (e.g., Eysenck, 1974; Mason, 1979; Simon, 1979). Eysenck (1974) reported an interaction between age and type of encoding (semantic versus nonsemantic), whereby recall was only greater in young than older adults following semantic encoding. In a study by Mitchell and Perlmutter (1986), young adults' memory surpassed that of older adults' only when encoding was intentional, leading the authors to conclude that the young were more effective in their use of mnemonic (semantic) strategies. Further, Craik (1968) found that while young and older adults did not differ in recall of color names, older adults showed poorer recall of text and scrambled proverbs. They argued that text and scrambled proverbs require semantic analysis, that is, greater processing, during encoding than unrelated color names.

It is well-documented that aging is associated with a general increase in semantic knowledge (reviewed in Park et al., 2002). Compared with young adults, older adults have a superior vocabulary (Park & Reuter-Lorenz, 2009) and a greater ability to build mental representations (Madden & Dijkstra, 2010). Despite this, a number of studies have reported poorer performance in older adults compared to young on tasks that require semantic processing (reviewed in Wlotko et al., 2010). In one study by Zhu and colleagues (2018), accuracy on a sentence reading task in which participants had to make semantic acceptability judgements was reduced in older compared to young adults, and event related potential (ERP) analysis showed a reduced amplitude and delayed peak latency of the N400, representing semantic activity, in older relative to young adults. This age difference in semantic processing is typically small in individual studies, but a reliable decline in has been documented in a recent meta-analysis by Hoffman (2018) and systematic review by Joyal et al. (2022). In their review, Joyal et al. (2022) compared behavioural (accuracy and RTs) and neural (N400 ERP) indices in young and older adults with and without Alzheimer's disease (AD) on a range of tasks involving semantic processing. They found reduced accuracy, slower RTs, and a reduced N400 ERP effect in older compared to young adults, and in AD patients compared to healthy older adults. They also found that differences between young and older adults were similar for highly versus weakly associated stimuli.

Despite the semantic processing deficit in older adults, encoding phase requirements have varied considerably between studies looking at age differences in priming. Some have encouraged perceptual encoding (e.g., orientation judgements, letter judgments), while others have required conceptual encoding (e.g., semantic categorisation, preference judgments), and others have simply presented stimuli to participants, meaning that processing may have naturally differed between young and older adults. This may in turn affect the magnitude of age differences in priming and explain why such age differences are sometimes reliable and sometimes nonexistent. For example, one may expect age differences in priming to be apparent following conceptual encoding and smaller/absent following perceptual encoding. Indeed there are published examples of age differences following conceptual encoding (e.g., Light, Prull, & Kennison, 2000; Russo & Parkin, 1993; Ward, Berry, & Shanks, 2013b) and null effects following perceptual encoding (e.g., Park & Shaw, 1992; Soldan et al., 2009, Experiment 3), but few studies have systematically manipulated processing at encoding to examine how this affects the magnitude of age differences in priming. Stuart, Patel, & Bhagrath (2006) asked participants to count vowels (perceptual) or make preference judgements (conceptual) during encoding of words, and subsequent priming was significantly reduced by age in the conceptual but not the perceptual condition. However, participants who performed perceptual encoding completed a perceptual priming task (word-stem completion), and those who performed conceptual encoding completed a conceptual priming task (category exemplar generation), making it unclear whether age differences were driven by the type of processing required at encoding or test. Indeed, a review by Rybash (1996) concluded that aging impairs performance on priming tasks that require conceptual processing more so than those that require perceptual processing. However, different findings were recently reported by Ward (2022), who manipulated perceptual (letter judgements) versus conceptual (living/non-living judgements) encoding of words prior to perceptual identification (perceptual) and category verification (conceptual) priming tasks in a within-subjects design. When encoding was perceptual, priming was reliably greater in young than older adults on both tests, but there were no age differences in priming following conceptual encoding.

In another study, Ward et al. (2020) presented overlapping object pairs colored in cyan and magenta to a lifespan sample of participants aged 12 to 85 years, and participants attended to one color of object and ignored the other. Participants either made conceptual decisions (natural/manufactured) about the attended object, or perceptual judgements (angular/rounded). Priming and recognition were tested using a continuous identification with recognition (CID-R) task, in which participants identified an object (previously studied or new) as quickly as possible on each trial (priming measure) before making a recognition judgement. Age predicted significant reductions in both priming and recognition for attended items, and there was no interaction with processing. However, the authors concluded that the processing manipulation had been ineffective – response times were equivalent in the perceptual and conceptual encoding conditions, suggesting equal processing, and there was no reliable effect of processing on recognition (levels-of-processing effects on recognition are well-established, see Craik & Lockhart, 1972).

This study aimed to clarify interactions between processing at encoding and age effects on priming. Participants witnessed a stream of object-word pairs and made perceptual (left/right rotation) or conceptual (natural/manufactured) decisions about the object or word. At test participants performed a CID-R test in which they identified an object (studied/new) as quickly as possible on each trial before making a recognition judgement. The recognition judgement was included to allow comparison of age effects on explicit and implicit memory. Methods were similar to Ward et al. (2020) but with alterations to strengthen the processing manipulation: First, processing was manipulated within-subjects in a counterbalanced blocked design. Second, object-word pairs were used rather than object pairs, and participants attended to either the object or word rather than a particular color of object. It was reasoned that it would be simpler for participants to maintain attention on either an object or word across blocks of trials, rather than attend to a particular color of object. Finally, in the perceptual block stimuli were rotated to the left/right and participants made rotation judgements rather than angular/rounded judgements, with the aim of making the perceptual block as data driven as possible. That is, left/right decisions are less subjective and arguably even less effortful than angular/rounded decisions.

2. Materials and Methods

2.1. Participants

To calculate the sample size an a priori power analysis was conducted based on the effect size f = 0.19 observed in Ward et al. (2020) and power set at 0.85. A total of 48 participants were required. Twenty four young adults aged 18–30 years were recruited from Middlesex University, and 24 older adults aged 65+ years were recruited from the University of the Third Age. Eligibility requirements included normal/corrected vision, fluency in English language, and no cognitive impairment. Older adults were screened for cognitive impairment using the Mini Mental State Exam (MMSE; Folstein, Folstein, & McHugh, 1975), and other background tests included the Wechsler Test of Adult Reading (WTAR, Wechsler, 2001), and the Wechsler Adult Intelligence Scale (WAIS-III, Wechsler, 1997) Vocabulary and Digit Symbol Substitution Tests as measures of verbal comprehension, pre-morbid intelligence and processing speed (see Table 1 for participant characteristics and summary scores for the background tests). Ethical approval was granted by Middlesex University Research Ethics Committee. Participants were tested in individual sessions of approximately 60 min, and received payment of £10.

2.2. Stimuli

Stimuli in the encoding phase included 120 words superimposed on objects, presented in the center of a white background screen. Object-word pairs were not semantically or phonologically related. Word stimuli were concrete nouns from 24 taxonomic categories selected from the updated category norms by Van Overschelde, Rawson, and Dunlosky (2004). Words of medium frequency were used (e.g., ‘owl, ‘chisel’), with number of letters ranging from 3 to 11 and number of syllables ranging from 1 to 4. They appeared across the centre of objects, capitalized in Calibri 26 point font. Objects (400 × 400 pixels) were line drawings of everyday objects, originally developed by Snodgrass and Vanderwart (1980). Half were naturally occurring items, and half manufactured. The encoding phase was arranged in two counterbalanced blocks of 60 items, one for perceptual processing and one for conceptual processing. Within each block, participants made a decision about the object (object attended) on 30 trials, and about the word (object unattended) on the other 30. This was also arranged in blocks (i.e., perceptual attended, perceptual unattended, conceptual attended, conceptual unattended). In the perceptual block, items were rotated 15 degrees to the left or right (equally distributed between left/right), with the rotation of the word and object matching on half of the trials (i.e., both the word and object rotated to the left/right) and mismatching on the other half (i.e., the word rotated to the left and the object to the right, or vice versa). This was to ensure that participants attended to the relevant feature (word or object) when making rotation judgements (see Procedure). Objects served as targets in the test phase, and 240 were presented in total – 120 previously studied (60 from the perceptual block and 60 from the conceptual block) and 120 new. Eight sets of 30 items were rotated between participants, with four appearing during encoding to serve as studied items (one set per block, counterbalanced), and all eight appearing at test.

Table 1
Participant characteristics.

	Young M (SD) [range]	Older M (SD) [range]
Age (years)	22.83 (3.06) [18–30]	73.13 (4.68) [65–81]
N Male/Female	7/17	8/16
Education (years)	14.13 (1.70) [12–18]	15.08 (2.24) [10–18]
Vision*	30.00 (5.41) [24–40]	38.00 (7.91) [24–56]
WAIS-III Digit Symbol Substitution*	72.75 (10.40) [64–96]	63.00 (10.19) [37–80]
WAIS-III Vocabulary*	36.17 (9.84) [18–64]	54.04 (8.33) [32–65]
WTAR*	38.46 (6.43) [20–44]	47.58 (3.73) [40–50]
MMSE	–	29.50 (0.66) [28–30]

Note. The MMSE (Mini Mental State Exam, Folstein et al., 1975) was administered on older adults only, with a maximum score of 30 and cutoff of <24 indicating probable cognitive impairment. No participant scored below 28. Visual acuity was measured using the Near Vision Test Card (Schneider, 2002), viewed at a distance of 16 in. while wearing corrective glasses if necessary. Scores range from 16 (highest acuity) to 160 (lowest acuity). Other background measures included the Wechsler Adult Intelligence Scale (WAIS-III) Vocabulary test (maximum score = 66) and the Wechsler Test of Adult Reading (WTAR; maximum score = 50) as verbal comprehension and pre-morbid intelligence tests, and the WAIS-III Digit Symbol Substitution Test as a measure of processing speed (maximum score = 133).

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

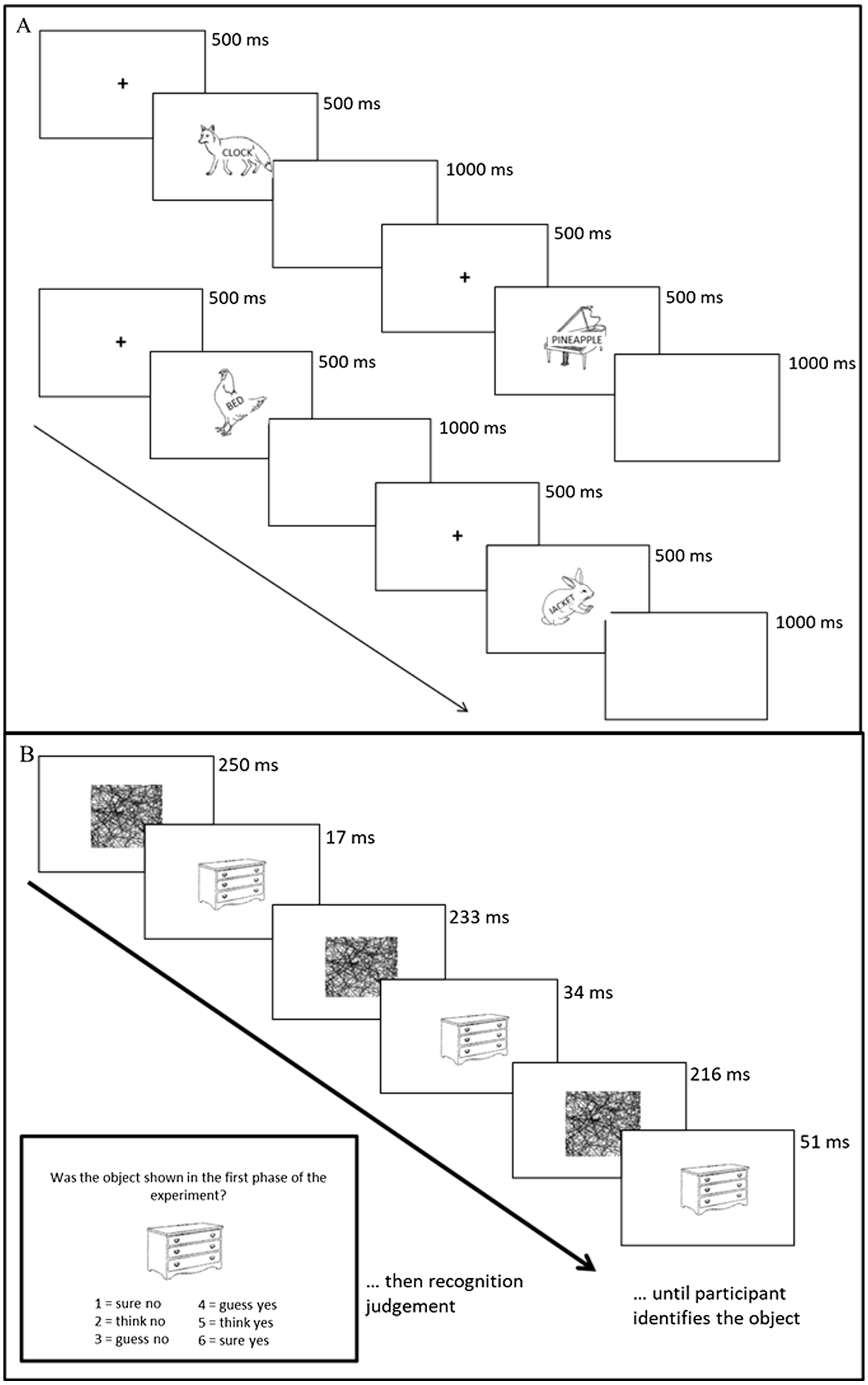

Fig. 1. A: Events in the encoding phase. On each trial, participants judged whether the attended item (object/word) was natural or manufactured (conceptual block, upper panel) or rotated to the left or right (perceptual block, lower panel). B. Events in a single trial in the CID-R test. An object – previously studied (perceptual or conceptual, attended or unattended) or new – gradually clarified from a background mask, and participants identified the item as quickly as possible (priming measure) before making a recognition judgment.

2.3. Procedure

Participants completed the experiment in a sound attenuated cubicle. During encoding participants were presented with object-word pairs, and processing (perceptual/conceptual) was manipulated within-participants in a counterbalanced blocked design. Each block contained 60 items presented in a new random order for each participant, with each trial presented as follows: a central fixation cross for 500 ms, a stimulus for 500 ms, and an interstimulus interval (blank screen) of 1000 ms (Fig. 1A). Participants made a decision about the object (object attended) on half of the trials, and about the word (object unattended) on the other half. This was also arranged in counterbalanced blocks, so in total there were four blocks: perceptual attended, perceptual unattended, conceptual attended, conceptual unattended. Blocks were used rather than intermixed trials to avoid processing overlap and reduce interference between conditions. In the perceptual block the task was to judge the left/right rotation of the attended item, and in the conceptual block the task was to categorize attended items as natural or manufactured. Rotation judgements are data driven, engaging participants with perceptual detail about which way the item is rotated, while natural/manufactured judgements require more elaborate appraisal of the content of the item to make a classification. Participants used the F and J keys to respond, where F = *left/natural*, and J = *right/manufactured*. Participants received instructions relevant to the first block at the start of the experiment and completed 8 practice trials, and updated instructions were presented prior to subsequent blocks.

Following encoding there was an interval of approximately 3 min while participants read instructions and completed practice for the CID-R test. Participants were not made aware of the test phase in advance. Objects served as targets, and 240 were presented in total – 120 previously studied (60 from the perceptual block; 60 from the conceptual block) and 120 new. Each trial consisted of an object identification (priming measure) followed by a recognition judgment and ran as follows: A mask was initially presented for 250 ms. This was followed by an object for 17 ms (one screen refresh at 60 Hz) and the mask again for 233 ms, forming a 250 ms block. These block presentations continued with the object duration increasing by 17 ms on each cycle and the mask duration decreasing by the same amount, making the object appear to gradually emerge. Participants were instructed to press the Enter key (RT captured) as soon as they could identify the object, at which point the object disappeared and they were prompted to type their response into a box on the screen. If the Enter key had not been pressed by 7000 ms, the point at which the object was fully displayed, the trial was discarded and the prompt "*Please try to be faster*" appeared on the screen for 1000 ms prior to the next trial. Immediately after identifying the object, participants made a recognition judgement (Fig. 1B). The object was presented once more along with instruction, "*Was the object shown in the first phase of the experiment?*", and participants responded by pressing: 1 = *sure no*; 2 = *think no*; 3 = *guess no*; 4 = *guess yes*; 5 = *think yes*; 6 = *sure yes*. No time limit was imposed, and participants were informed that half of the objects had been presented previously and half were new. Following response, a fixation cross was presented for 500 ms prior to the next trial.

3. Results

One young participant was excluded prior to analysis due to a failure to follow the CID-R task instructions. Analyses on the final sample were performed using JASP 0.9.2, with an alpha level of 0.05. Partial eta squared (η_p^2) effect sizes are reported for ANOVA effects, and Cohen's *d* for *t* tests. For nonsignificant effects, Bayes Factor analysis was conducted, with BF10 values < 1/3 considered as support for the null hypothesis (Dienes, 2014). The de-identified raw data and analysis files are available on the Open Science Framework at https://osf.io/r2n53/.

3.1. Encoding

Table 2 shows accuracy (% correct left/right and natural/manufactured judgements in the perceptual and conceptual blocks) and RTs in young and older adults. A 2(Age) × 2(Processing) × 2(Item [word/object attended]) mixed ANOVA revealed no main effect of Age on accuracy, $F(1, 45) = 0.29$, $p = .593$, $\eta_p^2 = 0.01$ (BF10 = 0.302), no main effect of Processing (perceptual/conceptual), $F(1, 45) = 1.78$, $p = .189 \eta_p^2 = 0.04$ (BF10 = 0.443), and no main effect of Item (object/word), $F(1, 45) = 1.70$, $p = .199$, $\eta_p^2 = 0.04$ (BF10 = 0.263). The only significant effect was a Processing × Item interaction, $F(1, 45) = 4.43$, $p = .041$, $\eta_p^2 = 0.09$, showing greater accuracy in the perceptual block when words were the attended feature, and vice versa in the conceptual block. The same analysis on RTs also revealed no main effect of Age, $F(1, 45) = 1.67$, $p = .201$, $\eta_p^2 = 0.04$ (BF10 = 0.690), and no main effect of Item, $F(1, 45) = 2.12$, $p = .152$, $\eta_p^2 = 0.05$ (BF10 = 0.318), but a significant main effect of Processing, $F(1, 45) = 9.77$, $p = .003$, $\eta_p^2 = 0.18$, and Processing × Item and Age × Item interactions ($F(1, 45) = 7.63$, $p = .008$, $\eta_p^2 = 0.15$, and $F(1, 45) = 5.34$, $p = .025$, $\eta_p^2 = 0.11$, respectively) (see Table 2).

Table 2
Encoding phase performance.

	Young Perceptual block M (SD)	Conceptual block M (SD)	Older Perceptual block M (SD)	Conceptual block M (SD)
Correct judgements (%)				
Object attended	77.61 (8.27)	82.48 (7.84)	79.08 (10.00)	81.29 (9.02)
Word attended	83.30 (6.53)	81.17 (7.21)	79.79 (9.18)	80.54 (8.70)
RT				
Object attended	643 (222)	614 (188)	638 (214)	676 (163)
Word attended	556 (195)	676 (195)	670 (156)	758 (213)

3.2. Priming

Identification trials associated with incorrect responses and RTs < 200 ms or > 3 SD from the mean were trimmed. A priming score per participant was calculated for each condition as (RTnew–RTold)/RTnew (Fig. 2; See Table 3 for raw RTs). Priming scores proportional to baseline RTs were used as slower responding in older than young adults can artificially elevate priming when RT difference scores are used (e.g., Faust et al., 1999; but note that there are also arguments in favour of using RT difference scores, Mitchell, 1989).

A 2(Age) × 2(Processing) × 2(Attention) mixed ANOVA on priming scores uncovered significant main effects of Attention, $F(1, 45) = 143.34$, $p < .001$, $\eta_p^2 = 0.76$, and Processing, $F(1,45) = 23.75$, $p < .001$, $\eta_p^2 = 0.35$, showing greater priming for attended than unattended objects and conceptual over perceptual processing at encoding. There was no main effect of Age, $F(1, 45) = 0.21$, $p = .649$, $\eta_p^2 = 0.01$ (BF10 = 0.277), no Age × Processing interaction, $F(1, 45) = 0.32$, $p = .576$, $\eta_p^2 = 0.01$ (BF10 = 0.229), and no Age × Processing × Attention interaction, $F(1,45) = 0.06$, $p = .806$, $\eta_p^2 < 0.001$ (BF10 = 0.550). However, there was a significant Attention × Processing interaction, $F(1, 45) = 13.02$, $p < .001$, $\eta_p^2 = 0.23$, and Age × Attention interaction, $F(1, 45) = 9.48$, $p = .004$, $\eta_p^2 = 0.17$, showing greater priming in young than older adults for attended items. Although the three-way interaction was not significant, a priori planned analysis revealed that the age difference in priming for attended items was larger in the conceptual condition, $t(45) = 1.61$, $p = .057$, $d = 0.47$ (BF10 = 1.527) than the perceptual condition, $t(45) = 0.85$, $p = .200$, $d = 0.25$ (BF10 = 0.604).

3.3. Recognition

Responses on the scale were collapsed into ‘yes’ (old object) and ‘no’ (new object) judgements. Recognition (d’) was calculated for each participant as z(hits[old objects judged old]) – z(FA[false alarms, new objects judged old]) (Fig. 3; See Table 3 for proportions of hits and FA). The Snodgrass and Corwin (1988) correction was applied to individual trials with values of 1 or 0: hit rate = (n hits + 0.5)/(n old + 1); FA rate = (n FAs + 0.5)/(n new + 1). The 2(Age) × 2(Processing) × 2(Attention) ANOVA revealed significant main effects of Age, $F(1, 45) = 11.79$, $p = .001$, $\eta_p^2 = 0.21$, Processing, $F(1, 45) = 9.09$, $p = .004$, $\eta_p^2 = 0.17$, and Attention, $F(1, 45) = 56.22$, $p < .001$, $\eta_p^2 = 0.56$. Recognition was greater in young than older adults, following conceptual than perceptual encoding, and for attended than unattended items. There were also significant Age × Attention and Age × Processing interactions ($F(1, 45) = 5.04$, $p = .030$, $\eta_p^2 = 0.10$ and $F(1, 45) = 8.17$, $p = .006$, $\eta_p^2 = 0.15$, respectively), indicating larger age differences in recognition for attended than

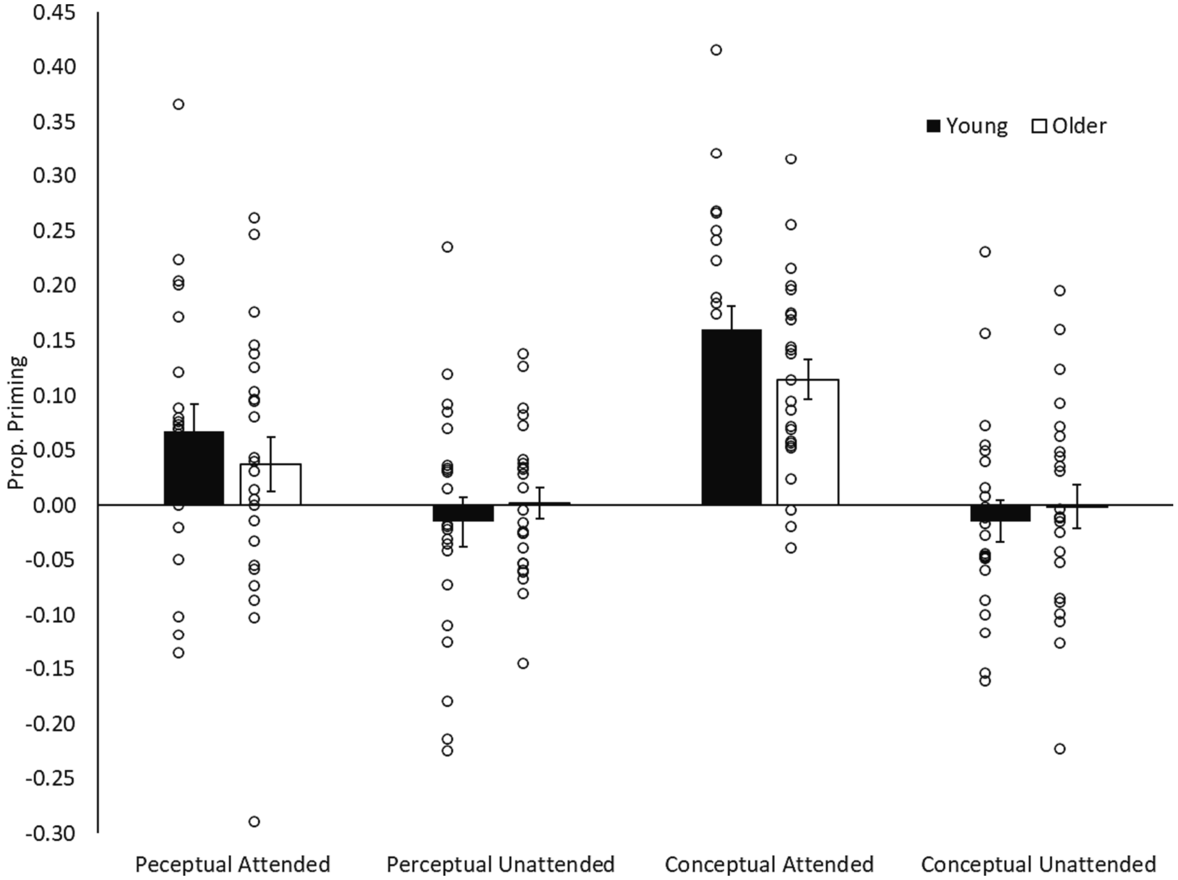

Fig. 2. Proportion priming in young and older adults (standard error bars). Dots indicate individual participant scores.

Table 3
Raw RTs (priming) and proportions hits and false alarms (recognition) in young and older adults.

	Young M (SD)	Older M (SD)
RTs		
Perceptual		
Attended	1636 (390)	2715 (839)
Unattended	1792 (486)	2824 (817)
Conceptual		
Attended	1476 (368)	2555 (957)
Unattended	1799 (506)	2839 (905)
New	1759 (415)	2857 (913)
Hits		
Perceptual		
Attended	0.70 (0.18)	0.60 (0.25)
Unattended	0.47 (0.13)	0.43 (0.26)
Conceptual		
Attended	0.83 (0.12)	0.58 (0.31)
Unattended	0.56 (0.17)	0.45 (0.25)
FA	0.38 (0.17)	0.41 (0.26)

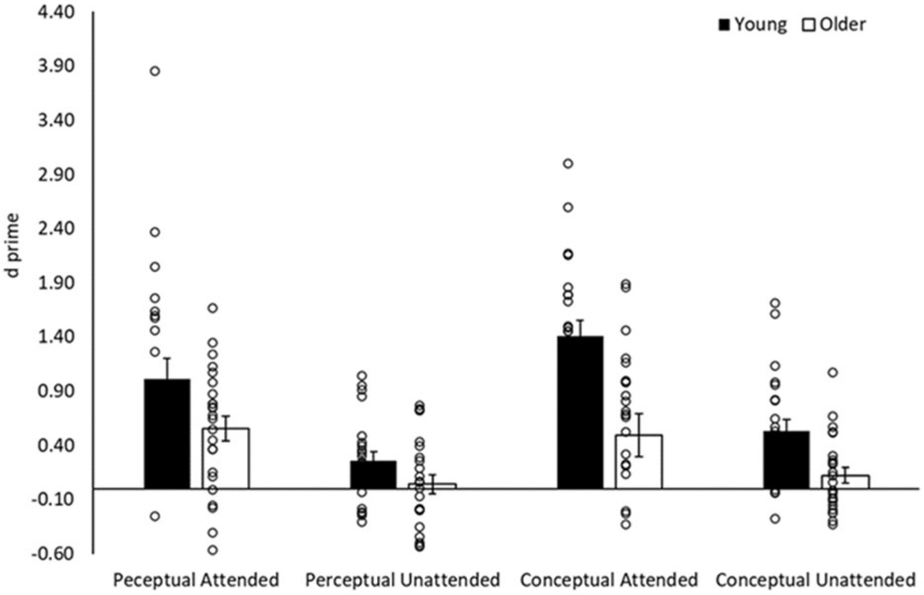

Fig. 3. Recognition (d') in young and older adults. (standard error bars). Dots indicate individual participant scores.

unattended items, and following conceptual than perceptual encoding. However, there was no Age × Processing × Attention interaction, $F(1, 45) = 1.197$, $p = .280$, $\eta_p^2 = 0.03$ (BF10 = 0.450).

Two older participants produced a high level of both hits and false alarms. That is, they responded "yes" to most items (as seen on the OSF data – participant 3: 97% false alarms and 95% hits, participant 10: 93% false alarms and 97% hits [collapsed across encoding condition]). To avoid the possibility that these participants failed to understand or follow the task instructions, the recognition analyses were reperformed while removing these two participants. The results were unchanged. There were significant main effects of Age, $F(1, 43) = 10.07, p = .003$, $\eta_p^2 = 0.19$, Processing, $F(1, 43) = 7.47, p = .009$, $\eta_p^2 = 0.15$, and Attention, $F(1, 43) = 52.17, p < .001$, $\eta_p^2 = 0.55$, as well as significant Age × Attention and Age × Processing interactions ($F(1, 43) = 4.57, p = .038$, $\eta_p^2 = 0.10$ and $F(1, 43) = 9.30$, $p = .004$, $\eta_p^2 = 0.18$, respectively), and no three-way Age × Processing × Attention interaction, $F(1, 43) = 1.36, p = .250$, $\eta_p^2 = 0.03$ (BF10 = 0.500).

4. Discussion

This study set out to clarify how the manner of encoding affects the magnitude of age differences in priming. The literature is replete with contradictory findings surrounding age effects on priming, and one factor that may account for this is different encoding phase requirements. This study systematically manipulated processing at encoding in an attempt to clarify age differences in priming. It extends upon the study by Ward et al. (2020), in which the processing manipulation was ineffective. Here, the processing manipulation was successfully strengthened – responses were slower in the conceptual than the perceptual encoding block as would be expected, and both priming and recognition were reliably affected. Although the Age × Processing × Attention interaction was not significant, the effect size for the age difference in priming for attended items was over twice as large in the conceptual than the perceptual condition, coupled with a Bayes Factor favoring the alternative hypothesis of an age difference only in the conceptual condition. Thus, the data supports that age differences in priming are larger following encoding that engages participants with semantic features of stimuli. This may be because, given the well-documented decline in semantic processing with age (e.g., Hoffman, 2018; Joyal et al., 2022; Wlotko et al., 2010), young adults are at a processing advantage in such situations. Stuart et al. (2006) also observed reduced priming in older relative to young adults following conceptual but not perceptual encoding. In their study, the type of processing was matched at test, making it difficult to interpret whether the observations were due to the type of processing required at encoding or test. However, given the present findings, the type of encoding likely played a significant role. How processing requirements at test affect priming is an important topic for future studies. Although there was no processing manipulation at encoding, Heyselaar, Wheeldon, and Segaert (2021) recently found a reliable reduction in conceptual priming with age, coupled with no change in perceptual priming.

Ward (2022) recently manipulated perceptual/conceptual encoding prior to perceptual identification (perceptual) and category verification (conceptual) priming tasks that were matched on all characteristics except processing. In contrast to the findings of the present study and those of Stuart et al., priming was significantly greater in young than older adults on both tests when encoding was perceptual, but there were no age differences following conceptual encoding. However, young adults in Ward (2022) were significantly slower than older adults in the perceptual encoding phase, which may point to additional processing by young adults that could have heightened their priming and exaggerated the age difference in this condition.

The observed reduced priming in older adults compared to young for attended items is consistent with several prior studies that have reported age-related reductions in priming (e.g., Abbenhuis, Raaijmakers, Raaijmakers, & Van Woerden, 1990; Keane, Wong, & Verfaellie, 2004; Russo & Parkin, 1993; Stuart et al., 2006; Ward & Shanks, 2018; Ward et al., 2013b; Ward et al., 2020; Wiggs & Martin, 1994), and the meta-analysis by La Voie and Light (1994). However, there are also a great number of published instances of preserved priming in older age (e.g., Henson et al., 2016; Isingrini, Vazou, & Leroy, 1995; Jelicic, Craik, & Moscovitch, 1996; Light et al., 2000; Mitchell & Bruss, 2003; Mitchell, Brown, & Murphy, 1990; Park & Shaw, 1992; Spaan & Raaijmaker, 2010; Wiggs, Weisberg, & Martin, 2006) (see also recent research by Zhivago et al., 2020, suggesting that perceptual priming remains intact in older adults in some situations and not others). The field as a whole is riddled with inconsistencies, and issues such as task reliability and sensitivity, explicit contamination, and priming task processing characteristics may all contribute to this (reviewed in Fleischman, 2007; Rybash, 1996; Mitchell & Bruss, 2003; Ward & Shanks, 2018). However, given the present data, it is likely that the different observations in the literature may also be due at least in part to different encoding phase requirements. It is worth noting that many of the aforementioned studies used firmly established tasks (e.g., perceptual identification, word-fragment completion, picture-fragment identification), but some used word-stem completion (WSC), which has been the subject of controversy (discussed in Mitchell & Bruss, 2003; see also Toth, 2000; Ryan, Ostergaard, Norton, & Johnson, 2001). All adequately powered studies using the continuous identification (CID) priming task employed here have uncovered a reliable reduction in priming with age (reviewed in Ward & Shanks, 2018; note that there are instances of age-invariant CID priming in amnesia, e.g., Conroy, Hopkins, & Squire, 2005). This task, and other such speeded perceptual measures, are generally considered to be among the most sensitive and 'clean' tests. The goal to identify items as quickly as possible does not generally allow participants to adopt different strategies, and as a result response variability is typically lower in comparison to other tasks like WSC in which the goal is less rigid and participants have more time. This issue was discussed in detail by Buchner and Wippich (2000), who demonstrated greater statistical reliability of a speeded perceptual identification task compared to WSC, and greater sensitivity to age differences.

The recognition judgement was included in the present study to allow comparison of effects on explicit and implicit memory. The effects of the processing and attention manipulations were mirrored in the recognition and priming data – namely, reduced recognition and priming for unattended than attended items and perceptual than conceptual encoding. Age effects were smaller on priming than recognition, but in both cases the largest age difference, numerically, was for attended items in the conceptual condition. Some participants showed chance levels of recognition in some conditions ($d' <= 0$), particularly when items were unattended and/or shallow processed. We would not expect high levels of recognition in these conditions in which encoding is so minimal. Indeed, many prior studies demonstrate that recognition for items unattended during encoding is not reliably different from chance (e.g., Berry, Henson, & Shanks, 2006; Berry et al., 2010; Butler & Klein, 2009; Merikle & Reingold, 1991; Vuilleumier et al., 2005). Further, participants in this study who showed chance recognition in the unattended/shallow processing conditions nearly always showed above chance performance in the attended/conceptual conditions. We would expect recognition to be greatest in the conceptual attended condition, and here there were four older participants (no young participants) with chance performance, yet these participants were able to achieve higher levels of recognition in other conditions. On the whole, chance recognition in some participants in some conditions, particularly older adults, is to be expected.

The concurrent method of assessing priming and recognition is beneficial as it allows the two to be captured within a few hundred milliseconds of one another for every test item, making them more suitable for comparison than when they are sampled in separate experimental phases. There is also a wealth of evidence that perceptual identification tasks including the CID task used in this study are not susceptible to contamination by explicit memory (e.g., Brown, Jones, & Mitchell, 1996; Ward et al., 2013a; reviewed in Ward & Shanks, 2018), possibly because identification is accomplished too quickly for the engagement of effortful explicit strategies (MacLeod, 2008). For example, Brown et al. (1996) found no difference in priming when identification and recognition were measured concurrently trial-by-trial compared to separate experimental phases. Ward et al. (2013a) replicated this finding and also observed that performance on the CID priming task was not affected by informing participants whether the next item to appear was previously studied or new.

5. Conclusions

This study systematically manipulated processing at encoding in an attempt to clarify age effects on priming. Priming was greater in young than older adults for attended items, with a larger effect size for items that were conceptually rather than perceptually encoded. This suggests that reductions in implicit memory, as with explicit memory, are a natural consequence of normal aging, but the magnitude of the effect may be a function of processing requirements at encoding.

CRediT authorship contribution statement

Emma V. Ward: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The de-identified raw data and analysis files are available on the Open Science Framework at https://osf.io/r2n53/

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