A double-edged sword: the role of prior knowledge in memory across the adult lifespan

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Abstract

Objectives: This study aims to investigate the role of prior knowledge on memory across the adult lifespan, and specifically examines the effects of two material properties: congruency – whether the material is congruent with people’s prior knowledge, and ambiguity – whether the material is ambiguous to interpret based on prior knowledge.

Method: A total of 273 participants (aged 22-70 years old) completed an incidental memory task online. Participants were shown pictures depicting an object in a scene and judged if the object was likely or unlikely to be in the particular scene. Later, in the recognition test, participants were asked to identify if the picture was presented earlier. The pictures were manipulated to have varying levels of congruency, meaning that some depicted likely object-scene pairs and some unlikely, and varying levels of ambiguity, meaning that some were more ambiguous to judge than others. Mixed effects logistic regressions examined the effect of age, age², congruency/ambiguity, and their interactions on memory.

Results: The object-scene pairs perceived as congruent had both higher hit rates and higher false alarm rates than incongruent ones, especially in middle-aged and older people. Higher ambiguity was also related to both greater true and false memory, independent of age. Finally, the effect of ambiguity only emerged when the pair was perceived incongruent.

Discussion: The results suggest that knowledge improves recognition but also induces false memories, particularly in middle-aged and older people, suggesting a double-edged role in memory and its influence on memory aging.

Keywords: ambiguity, congruency, memory aging, object-scene, schema

Introduction

People accumulate knowledge throughout their lifespan, and these acquired knowledge structures influence how new information is encoded, integrated, and retrieved from memory (Van Kesteren et al., 2012; Ghosh & Gilboa, 2014). For example, a picture depicting a scenario consistent with one's knowledge is often better encoded and more likely to be remembered (Bransford & Johnson, 1972; Brod & Shing, 2019; Van Kesteren et al., 2012). This superior memory performance for knowledge-congruent information, known as the memory congruency effect (Craig & Tulving, 1975; Moscovitch & Craig, 1976), is believed to reflect a more elaborative encoding and facilitated retrieval using existing semantic knowledge structures (Ghosh & Gilboa, 2014; Staresina, Gray, & Davachi, 2009). In addition to material congruency, ambiguity is also known to interact with people's prior knowledge during memory processing; when a scenario is ambiguous, people rely more on their prior knowledge to interpret and decode the ambiguous information, which could lead to gist-based memory and higher false memories for ambiguous information (Koustaal et al., 2003; Tuckey & Brewer, 2003). Overall, the existing evidence suggests an important influence of prior knowledge on memory.

Recent studies have reported age-related differences in the role of prior knowledge on memory (Brod & Shing, 2019; Brod, Werkle-Bergner, & Shing, 2013; Wynn, Ryan, & Moscovitch, 2020). Specifically, older adults appear to show a stronger memory congruency effect, related to their higher reliance on prior knowledge to process knowledge-congruent information. For example, Wynn et al. (2020) instructed young and older adults to complete a visual search task, followed by two surprise memory tasks. During the visual search task, participants were asked to find a certain object in a scene; sometimes the location of the object in the scene was congruent with people's knowledge about the scene, meaning that the object was

in an expected location, or sometimes the pair was incongruent, meaning the object was not in an expected location. Participants were later presented a scene picture and asked to identify (1) where an object was in that scene in the first part of the study, and (2) which object had appeared in the scene. The authors found that people took less time to find target objects in the congruent condition and that this benefit was larger in older adults, suggesting that prior knowledge about the scene particularly aided in the visual processing in older adults. They also found that the reliance on prior knowledge enhanced people's memory for the object location in the congruent condition: people remembered the location of the object better when the object was in an expected location.

In addition to the enhanced memory performance, some studies also found that participants had more false memories in conditions where people had to rely on prior knowledge (Kleider, Pezdek, Goldinger, & Kirk, 2008; Roediger, Meade, & Bergman, 2001), particularly in older people (Umanath & Marsh, 2014). For example, a recent study (Brod & Shing, 2019) used object-scene pairs, consisting of one object picture and one scene picture side-by-side, and examined the associative memory for knowledge-congruent (if the object and the scene “fit together”) and knowledge-incongruent (if the object and the scene “do not fit together”) pairs in children, young, and older adults. They found that the older group had a stronger memory congruency effect than younger adults, but also a higher tendency to commit knowledge-congruent errors, where older adults were most likely to misremember a new object-scene pair as “old” when the object and scene fit together, suggesting a negative influence of relying on prior knowledge in memory. Similarly, an earlier study (Koustaal et al., 2003) examined young and older adults' memory for ambiguous shapes with or without semantic labels and found that older adults had more false recognitions when labels were present than when they were not. This

suggests that older adults had a greater reliance on the semantic information of the label to encode the perceptual information, likely leading to an over-generalization of the shape based on their existing semantic knowledge, which results in a higher susceptibility for memory errors. These findings suggest that prior knowledge may also have a negative effect on memory, especially in older adults.

The present study aims to investigate the role of prior knowledge on memory, and particularly examine both the positive and negative influence of congruency and ambiguity of test stimuli on memorability to people across the adult lifespan. We focus on these two properties because they are inherent in experimental materials of many memory studies and are central to associative memory, which is a vulnerable memory domain frequently studied in cognitive and aging research (Dunlosky & Hertzog, 1998; Naveh-Benjamin & Mayr, 2018; Old & Naveh-Benjamin, 2008). The influence of material congruency and ambiguity on memory in people of different ages is not only important for understanding mechanistic differences in the role of knowledge for memory between young and older adults, but also necessary to assess potential material bias that may affect certain memory assessments in older people. We used a lifespan sample that includes young, middle-aged, and older adults to examine the dynamic change of effects of prior knowledge in memory. This also allowed us to measure any nonlinear, age-related effect that is not possible to detect without a middle-aged sample.

Methods

Participants

Participants were recruited from the online crowdsourcing platform Amazon Mechanical Turk (Mturk) (<https://www.mturk.com/>) using CloudResearch (Litman, Robinson, & Abberbock,

2017). The experiment was hosted via Pavlovia (<https://pavlovia.org/>). A total of 283 participants completed the task, among which 273 were approved as valid data -- 10 were rejected due to low data quality (see *Data Quality Assurance* section for details). The 273 participants (age range 22 to 70 years old) included 157 females (57.7%), 113 males (41.5%), and 3 missing sex information; 210 White (77.2%), 29 Black/African American (10.7%), 3 American Indian/Alaska Native (1.1%), 20 Asian/Pacific Islander (7.4%), 8 other (3%), and 2 missing race information. The average education was 15.26 years. All participants gave informed consent for their participation by pressing “y” on the consent form. Participants were compensated \$10 for their participation. The study was approved by the Institutional Review Board at the University of California, Berkeley.

Materials and Procedure

We used a newly developed memory task to assess memory with incidental encoding (Figure 1a). During encoding, participants were shown 96 *object*, 96 *scene*, and 192 *object-in-scene pair* images, presented in 32 blocks -- eight *object* blocks, eight *scene* blocks, and 16 *object-in-scene pair* blocks -- with 12 trials in each block. During each trial, participants were first shown a fixation cross jittered for 1-3s, followed by 3s of the image. Participants were instructed to indicate, by pressing the “F” or “J” keys, if the object depicted a living or nonliving object in the object blocks, if the scene depicted an indoor or outdoor scene in the scene blocks, and if the object appeared to be likely or unlikely to be in the particular scene in the object-in-scene pair blocks. At the start of each block, instructions and key mappings for the judgment questions were shown. The order of the blocks and trials was randomized.

Among all the materials, half of the objects were living and half were nonliving; half of the scenes were indoor and half were outdoor; roughly half of the pairs were designed to be

A. Incidental Encoding (inside scanner)

B. Recognition Test (outside scanner)

Figure 1: Experimental paradigm for encoding (A) and retrieval (B) phases in memory task.

likely and half were unlikely. The likely/unlikely judgment for pairs was designed to be variable based on participant's prior knowledge and their interpretation, but no pairs were bizarre or impossible. All pairs also had varying levels of ambiguity -- some pairs were harder to judge than others (Figure 2a). After encoding, participants completed a 15-minute survey on their

A. Materials with different congruency and ambiguity levels

B. Lure images for object and scene materials.

C. Lure images for object-in-scene pair materials.

Figure 2: Examples of experimental materials used in the study. (A). Materials with different congruency and ambiguity levels. (B). Lure images for object and scene materials. (C). Lure images for object-in-scene pair materials.

demographic information, socioeconomic status, subjective memory, and family history of Alzheimer's disease. Lastly, a surprise recognition test was given.

The recognition phase (Figure 1b) consisted of 24 blocks: six *object* blocks, six *scene* blocks, and 12 *object-in-scene pair* blocks, with 18 trials in each *object* and each *scene* block and 20 trials in each *object-in-scene pair* block. All images presented in the recognition phase were represented as either an identical old image from the encoding phase or a similar lure. Lures all had the same thematic and similar perceptual information, but visible differences from the old images (Figure 2b). For object-in-scene pairs, the lures had three forms: same object but in a lure

scene, same scene but with a lure object, and same object and scene but in a different spatial relationship (Figure 2c). New images, including 24 *object*, 24 *scene*, and 24 *pair* images, that were distinct from all old and lure images were also included. Whether a studied image was represented as old or lure (and what type of lure, for pairs) was randomly determined for each participant, with an equal chance of being old or lure (or different types of lures, for pairs).

During each recognition trial, participants were shown an image to judge if they remembered seeing the exact picture from the first part of the experiment with high confidence, with low confidence, or if they did not remember seeing the exact picture, by pressing “F”, “H”, or “J”, respectively. In addition, for *object-in-scene* pairs, if they indicated they did not remember seeing the exact picture, they were asked a follow-up question to indicate if they remembered the scene but not the object (“F”), the object but not the scene (“G”), both the object and the scene but in a different spatial relation (“H”), or if they didn’t remember seeing either the scene or object (“J”). The order of the blocks and trials were randomized. The instructions and key mappings for the memory questions were shown at the beginning of each block. In addition, the key mappings for each question stayed on the bottom of the screen during the presentation of the image.

Data Quality Assurance

We employed several procedures to ensure data quality. First, the task was only available to a pool of “high-quality” participants who had no history of dishonest participation with fraud detection (Litman et al., 2017). Second, before the start of the task, 12 practice trials were administered. Participants with lower than 75% accuracy for the study judgment (living/nonliving for object, indoor/outdoor for scene, likely/unlikely for pair) were required to read the instructions and complete the practice again until they passed it. This was done to make

sure that participants understood the instructions. Third, participants were told that their accuracy was recorded and assessed in the study, and that they were expected to always pay full attention. And throughout the experiment, multiple nonsensical check questions were included. These procedures were done to ensure that participants paid full attention at all times. Data with more than two check failures were rejected. Finally, after the participant completed the task, we carefully inspected each participant's data, and multiple factors were taken into consideration to decide if the data would be approved. We reviewed their study judgment response during encoding, time to complete the survey, number of trials with reaction time under 200ms, and their optional voluntary feedback after task completion. A total of 10 participants were rejected after careful data quality checking.

Statistical analysis

To examine the effect of material properties (i.e., congruency, ambiguity) on memory, we focused on the performance of the first recognition judgment in pair blocks, in which participants indicate if they remember seeing the object-in-scene pair image. We analyzed participant's responses trial-by-trial using mixed effects logistic regressions. First, to examine the effect of congruency, we used age, age², congruency judgment response (yes/no), and their interactions to predict whether the memory outcome was a high-confidence hit (i.e., high-confidence yes response for an old trial), with intercepts of subject and image as the random effects. We *a priori* included age² to capture any non-linear age-related change in memory. Using the same predictors, we also examined their prediction on high-confidence false alarm (i.e., high-confidence yes response for a lure trial). This allowed us to examine the effects of congruency on true and false memory separately.

Next, we examined the effect of ambiguity on memory. An ambiguity index was calculated for each pair image based on the proportion of participants with a congruency judgment response different from the majority. We then centered the variable so that a higher, positive value indicated the pair was more ambiguous among all participants, a lower, negative value indicated a general consensus. We performed two mixed effects logistic regressions using age, age², the ambiguity index, and their interactions to predict high-confidence hit and high-confidence false alarm, separately, with the subject intercept as the random effect.

Finally, we examined the independent and interactive effects of congruency and ambiguity in the same model. We first used age, age², congruency judgment, ambiguity index, and their interactions to predict high-confidence hit and high-confidence false alarm, separately, with the subject intercept as the random effect. Due to the complexity of the model, this initial model did not converge. We, therefore, removed age² and its interaction terms and only included linear age effects. This updated model successfully converged. We report results from this final model that included age, congruency judgment, ambiguity index, and their interactions as the predictors, with the subject intercept as the random effect.

All continuous variables were mean-centered to minimize multicollinearity. We also examined the variance inflation factor (VIF) for all variables and found all VIFs were smaller than 5, suggesting little evidence of collinearity (James, Witten, Hastie, & Tibshirani, 2013).

Results

The first set of mixed effects logistic regressions examined the effect of age, age², congruency judgment (yes/no), and their interactions in predicting high-confidence hit and high-confidence false alarms. We found that neither age nor age² predicted high-confidence hits

($p>.30$; Figure 3A), consistent with previous reports of no age difference in high confidence hits between young and older adults (e.g., Dennis, Kim, & Cabeza, 2007; Gutchess et al., 2005). Congruency, on the other hand, significantly predicted high-confidence hits ($\beta = 0.291, p<0.001$, Figure 4A); people were more likely to remember the pairs if they judged them to be congruent rather than incongruent. There was also a marginal age $\times$ congruency interaction ($\beta = 0.061, p=0.056$) and a significant age² $\times$ congruency interaction ($\beta = 0.055, p=0.033$). Both interactions occurred because the effect of congruency on memory was disproportionately stronger as age increased. Using the Johnson-Neyman procedure (Johnson & Fay, 1950; Aiken et al., 1991), we found the effect of congruency became significant after age 31 and continued to accelerate with increasing age. For high-confidence false alarms, the mixed effects logistic regression revealed significant effects of age ($\beta = 0.166, p<0.001$) and age² ($\beta = 0.079, p=0.034$), where older adults showed a significant and faster increase in false alarms as age increased (Figure 3B). We also found a significant effect of congruency judgment ($\beta = 0.149, p<0.001$) in which people made more false recognitions for lures of congruent pairs than of incongruent pairs. There was also a significant interaction between age and congruency judgment ($\beta = 0.043, p=0.043$; Figure 4B); people over 45 were particularly more likely to have false recognitions for congruent lures than for incongruent lures.

Next, to examine the effect of ambiguity on true and false memory, we performed two mixed effects logistic regressions using age, age², ambiguity index, and their interactions to predict high-confidence hits and high-confidence false alarms, separately. Ambiguity index significantly predicted high-confidence hits ($\beta = 1.405, p<0.001$); more ambiguous pairs were more likely to be correctly recognized (Figure 4C). No age-related interactions with ambiguity were found ($p>.20$). For high-confidence false alarms, we found significant effects of ambiguity

Figure 3: The relationship between age and memory performance – hits and false alarm rates. People at different ages performed similarly in hit rates (A) but older age was significantly related to an accelerated increase in false alarm rate (B).

($\beta = 0.835, p < 0.001$; Figure 4D), age ($\beta = 0.179, p < 0.001$), and age² ($\beta = 0.078, p = 0.028$) where higher ambiguity and older age were both significantly related to higher false alarms. Neither age $\times$ ambiguity nor age² $\times$ ambiguity interactions were significant ($ps > .16$).

Lastly, to examine the independent and interactive effects of congruency and ambiguity in the same model, we used mixed effects logistic regressions with age, congruency judgment (yes/no), ambiguity index, and their interactions to predict high-confidence hits and high-confidence false alarms, separately. For high-confidence hits, we found that the effects of congruency ($\beta = 0.441, p < 0.001$), ambiguity ($\beta = 1.292, p < 0.001$) and the age $\times$ congruency interaction ($\beta = 0.065, p = 0.040$) all remained significant. The model also revealed a significant three-way interaction between age, congruency, and ambiguity ($\beta = -0.459, p = 0.037$). The interaction occurred because the effect of ambiguity diminished when the pairs were judged as

Figure 4: Effect of congruency and ambiguity on memory hit rate and false alarm rate. Congruent pairs were related to a higher hit rate ($p < .001$) particularly in people over 31 years (A), as well as a higher false alarm rate ($p < .001$) in people over 45 years ($p = 0.043$) (B). More ambiguous pairs were related to a higher hit rate ($p < .001$) (C) and a higher false alarm rate ($p < .001$) (D) across all ages.

congruent in older adults over 58 years (Figure 5A). Finally, the model examining the same effects on high-confidence false alarms showed significant effects of age ($\beta = 0.162$, $p < .001$), congruency judgment ($\beta = 0.277$, $p < .001$), and ambiguity ($\beta = 1.007$, $p < .001$), as well as significant age $\times$ congruency judgment ($\beta = 0.035$, $p = 0.028$) and congruency $\times$ ambiguity interactions ($\beta = -0.652$, $p < .001$). The congruency $\times$ ambiguity interaction occurred because

Figure 5: Interactive effects of congruency and ambiguity on memory hit rate and false alarm rate. (A) For hit rate, ambiguity effect diminished for pairs perceived as congruent in people above 58 years old. (B) For false alarm rate, ambiguity only appeared to affect memory for pairs perceived as incongruent.

ambiguity was only significantly related to greater false alarms for incongruent pairs (Figure 5B).

Discussion

This study investigated the role of prior knowledge on memory across the adult lifespan. We used two measures – congruency and ambiguity – to assess how each object-scene pair was perceived by people based on their prior knowledge. When relating those measures to subsequent memory performance in a sample across the adult lifespan, we found that congruency was related to an overall tendency of more positive responses (Webb & Dennis, 2020), implicating both higher true and false memory, especially in middle-aged and older people. Ambiguity was also related to both higher true and false memory, but its effect was independent of age. Finally, it appears that the influence of congruency may “override” the ambiguity effect as ambiguity only predicted false memory when the pair was perceived incongruent and the ambiguity effect for true memory was greater for incongruent pairs in older adults. Overall, the results suggest that older individuals demonstrate greater reliance on prior knowledge during memory, which can be both beneficial and detrimental.

The influence of congruency on memory has been controversial in the literature. Studies have revealed memory enhancement related to both congruent and incongruent conditions (Greve, Cooper, Tibon, & Henson, 2019; Poppenk, Köhler, & Moscovitch, 2010), and have found both positive and negative effects of congruency on memory (Brod & Shing, 2019; Umanath & Marsh, 2014; Webb & Dennis, 2020). Here, in this study across the adult lifespan, we present strong evidence for both higher recognition (after the age of 31 years) and more false memories (after the age of 45 years old) related to congruency at the same time. The use of a

lifespan sample allowed us to demonstrate that these influences begin to merge in young to middle age and accelerate with increasing age, suggesting a greater reliance on knowledge in memory in older people. These findings highlight the complex influence of knowledge on memory (Ghosh & Gilboa, 2014; Van Kesteren et al., 2012) and suggest age may be a moderating factor in how knowledge affects memory.

The greater reliance on knowledge in older adults has been documented in other cognitive domains (Chen, Hertzog, & Park, 2017; Hedden, Lautenschlager, & Park, 2005; Mata, Schooler, & Rieskamp, 2007) and has been interpreted as an adaptive process: older people utilize the semantic knowledge accumulated through their life when facing the decreases in their fluid cognitive resources (Park et al., 2002; Salthouse, 2003). Although this shift allows older adults to take advantage of the better-preserved crystallized knowledge and thus recognize knowledge-congruent information with little performance deficit, it also appears to create an age-related susceptibility that results in more false memories. This may be due to older adults having a more generic encoding strategy (Koutstaal & Schacter, 1997), facilitated by their over-reliance on schematic knowledge, which makes them more susceptible to misleading information during retrieval.

The other novel finding of the study is that higher ambiguity was related to both higher true positives and false memories. The effect of ambiguity on memory has not attracted much attention in memory aging research. We found that similar to the congruency effect, higher ambiguity was related to better remembering of the old pairs, but also higher false memories for lures. Ambiguous pairs likely represent ill-defined scenarios that require deeper levels of processing, leading to a better encoding quality and thus enhanced recognition (Bock, 1978; Craik & Tulving, 1975). Meanwhile, higher ambiguity also indicates that greater interpretation is

needed, leading to a higher likelihood of intrusions (Tuckey & Brewer, 2003). In our study, the effect of ambiguity was stronger when the material was perceived to be incongruent with prior knowledge, suggesting a particular vulnerability of memory to ambiguity when the pair does not easily align with one's knowledge and the elaborative encoding may thus be dampened. It is not the case, however, when the material is consistent with one's knowledge, suggesting that once people successfully configure and register the pair with their existing knowledge structure, whether or not the material was ambiguous to decode and judge does not play a big role in the memorability of the information anymore. This interactive effect of ambiguity and congruency on true memory was particularly strong in older adults, suggesting that the congruency of the material appears to be a stronger determinant for older adults' recognition.

Some recent studies have explored the neural mechanisms underlying how knowledge influences memory using neuroimaging techniques and suggested that prior knowledge may affect the efficiency of the interaction between the ventromedial prefrontal cortex (vmPFC) and medial temporal lobe (MTL) during encoding and retrieval (for reviews, see Gilboa & Marlatte, 2017 and Van Kesteren et al., 2012). Specifically, memory processing for knowledge-congruent items is believed to be largely mediated by vmPFC, whereas MTL, particularly the hippocampus, compares and configures the incongruent information with existing knowledge. Given the significant degradations in the MTL structures in older adults (Raz et al., 2005), it is likely that aging is accompanied by a disruption of the balance between the two systems, which leads to a bias towards knowledge-congruent processing. This bias may explain the diminishing ambiguity effect with congruency in aging. This bias may also facilitate memory processing of knowledge-congruent information and compensate for age-related deficits (Umanath & Marsh, 2014), which could partly explain the lack of age-related differences in hit rates across many memory aging

studies (Dennis et al., 2007; Gutchess et al., 2005). This bias, however, may also contribute to a tendency of gist-based, generalized processing in older adults (Greene & Naveh-Benjamin, 2020; Koutstaal, Schacter, Galluccio, & Stofer, 1999), as well as a decreased inhibition of misleading information consistent with prior knowledge in older people (Colombel, Tessoulin, Gilet, & Corson, 2016; Lustig, Hasher, & Zacks, 2007). These processes together result in a lack of detailed, specific encoding that is necessary for rejecting highly similar lures during recognition. Future studies may investigate the interactions of the two memory systems as age increases to better understand the role of knowledge in memory aging.

We acknowledge that the cross-sectional nature of the study limits our interpretation of the observed age-related differences. It is possible that older adults participating in this study were more selective than younger people and used different strategies, which might also contribute to the over-reliance on knowledge we observed in the study. Future longitudinal examinations may investigate whether this difference in the role of knowledge is a developmental change in aging or an individual characteristic that is present in highly selective older adults. Another limitation of the study is that we only examined two particular material properties – congruency and ambiguity – that are known to interact with people’s prior knowledge (Kouststaal et al., 2003; Tulver, Aru, Rutiku, & Bachmann, 2019; Wynn et al., 2020), whereas many other aspects of the material may also affect the memorability of the information. Future studies may include more material properties (e.g., knowledge domain) and examine if and how we could minimize potential testing bias in cognitive aging research that is due to material properties.

In conclusion, this study examined the effects of material congruency and ambiguity on memory for object-scene pairs in adults across the lifespan. Congruent pairs were more

memorable, but also more likely to induce false memories, especially for middle-aged and older adults. Higher ambiguity was also related to both better recognition and more false memories, but only when the pair was perceived incongruent. We conclude that prior knowledge plays a double-edged role in memory and is increasingly influential with aging.

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