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Aging Shifts the Relative Contributions of Episodic and Semantic Memory to Decision-Making

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Healthy aging is accompanied by well-characterized shifts in memory systems: episodic memory tends to decline with age while semantic memory remains relatively intact, with some knowledge domains strengthening. Beyond reflecting on the past, these distinct memory systems often guide decisions about the future. Yet how such age-related memory shifts influence simple value-based choices remain understudied. Here, younger (18–24 years) and older (61–75 years) adults completed a card game in which they could use task-relevant episodic memories to maximize the number of points they earned. Critically, they could also use task-irrelevant semantic memories to guide their choices. Both younger and older adults successfully used episodic memory to make decisions, but older adults did so less reliably than younger adults. Further, while younger adults strategically suppressed task-irrelevant semantic memories when a relevant episodic memory could be used, older adults used semantic memory to guide their decisions regardless of the relevance of episodic memory. We provide evidence that declining inhibitory control may play a role in how older adults arbitrate between competing memory sources when making decisions. These effects are consistent with the literature on age-related shifts in memory and cognitive control systems and add to a growing body of work on how episodic memories inform reinforcement learning and value-based decision-making. Our findings highlight how patterns of age-related memory differences can have consequences for value-based choices, which has implications for other types of decision-making, from the economic to the mundane.

Public Significance Statement
This study finds that aging influences how memories are used to make even simple choices. While older adults are less likely than younger adults to use memories of single past experiences when choosing between options, they more consistently use their real-world knowledge, even when it is irrelevant. Our study has implications for how age-related differences in cognitive processes like memory and inhibitory control can influence decision-making.

Keywords: aging, decision-making, episodic memory, semantic memory, inhibitory control

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Choices about our futures are a product of the experiences of our pasts; yet the routes through which we leverage experience are as diverse as the ways in which we learn and remember. For example, when choosing a movie to watch, you could draw on a recent recommendation from a friend or select based on a genre you usually enjoy. This routine example highlights how equally valid information arising from episodic memory—memory for specific past events—and semantic memory—general knowledge of the world—can bias us down different paths. As there are well-described shifts in the balance of these memory systems across the lifespan, they likely carry important implications for the choices we make as we age (Healey & Hasher, 2009; Ofen & Shing, 2013). These observations, however, have received very little empirical investigation. With a growing appreciation that episodic memories—those most

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prone to age-related declines—make unique contributions to reinforcement learning and value-based decision-making (Bornstein & Norman, 2017; Duncan et al., 2019; Duncan & Shohamy, 2016; Murty et al., 2016; Wimmer & Büchel, 2016), this gap is all the more glaring.

To address this gap, we leveraged extensive research into age-related differences in episodic memory. Of particular relevance, older adults' have been shown to have (a) impairments in explicit associative memory tasks (for a review, see Hoyer & Verhaeghen, 2006) and (b) declining recollection but comparatively intact familiarity (Yonelinas, 2002). Previous accounts postulate that older adults have a specific deficit on explicit associative memory tasks, which require intentionally retrieving memories containing the diverse components of an episode (Chalfonte & Johnson, 1996; Foos & Sarno, 2010; Lyle et al., 2006; Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2003, 2004; Old & Naveh-Benjamin, 2008a). As well, older adults show decrements in recollection, the ability to recall associated details about a specific episode (Craik & McDowd, 1987; Kemps & Newson, 2006; Nyberg et al., 2003). By contrast, the ability to recognize that individual items are familiar or new is argued to remain comparatively intact with age (Chalfonte & Johnson, 1996; Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2003; Old & Naveh-Benjamin, 2008b; Spencer & Raz, 1995). One notable exception is that older adults do not show intact item recognition when lures are similar to targets (Yassa et al., 2011). This leads to the hypothesis that (at least when stimuli are distinctive) older adults should exhibit a familiarity bias in the face of declining recollection of associations (Grady & Craik, 2000; Light et al., 2000; Yonelinas, 2002).

By contrast, how aging influences the direct use of past experiences and outcomes in decisions, or *experience-guided decisions*, is less clear (for reviews, see Healey & Hasher, 2009; Sparrow & Spaniol, 2016): some studies find impairments (Henninger et al., 2010; Mata et al., 2007, 2010) while others find improvements with age (Worthy et al., 2011). This apparent disparity may be due to experiment-specific variation in the type of memories (e.g., recollected associations vs. familiarity-mediated item recognition) required to make optimal decisions, in line with the aforementioned selective deficits in memory systems (Healey & Hasher, 2009; Ofen & Shing, 2013). How might impaired associative memory and comparatively intact item memory influence experience-guided choice? For choices guided by single experiences, it is not sufficient to simply recognize that an option is familiar—you must also remember the past consequences associated with its selection (Murty et al., 2016). This could have consequences for how older adults make value-based choices: an overreliance on familiarity-based memories may drive strong biases to explore novel options or exploit familiar ones, without regard for the prior consequences.

Complicating this prediction, though, is the fact that while age-related associative memory decline is robust in many laboratory assessments, it is far from absolute; in fact, associative memory is well-preserved in many contexts, particularly those relevant to decision-making. For example, associative memories for emotionally positive (as compared to negative) outcomes are retained (Charles et al., 2003; Mather & Johnson, 2000, 2003; Mather & Knight, 2005) as well as memory for stimuli associated with positive monetary values in some contexts (Castel et al., 2016; Mather & Schoeke, 2011). These memory effects may be related to stronger positivity biases in older as compared to younger adults (Del Missier et al., 2015; Kalenzaga et al., 2016; Peters et al., 2011; Sparrow & Spaniol, 2016; Thomas & Hasher, 2006) and older adults' comparatively intact processing of positive versus negative outcomes (Larkin et al., 2007; Wu et al., 2014). In the context of reinforcement learning, which seeks to explain how learning stimulus-reward associations guides decisions, this may translate into older adults showing comparatively intact abilities to use positive outcomes to guide future choices.

Similarly, memories for meaningful associations may be comparatively preserved, as older adults have been found to perform well on tasks that closely mirror real world situations, such as memory for grocery store prices (Amer et al., 2018, 2019; Castel, 2005; Flores et al., 2017; Hess, 2014; May et al., 2005; Mohanty et al., 2016; Rahhal et al., 2002). In particular, age differences in memory are ameliorated when the participants are tested on new associations that are consistent (rather than inconsistent) with existing schemas (Amer et al., 2018; Castel, 2005; Flores et al., 2017; Mohanty et al., 2016; Riby et al., 2010). While these findings are plausibly interpreted as showing how older adults use semantic memory to scaffold new episodic learning, it is also possible that older adults are disproportionately disadvantaged at using schematically incongruent associations because they find it challenging to inhibit strong, but contextually immaterial, semantic knowledge.

Indeed, declining inhibitory control with aging (Amer et al., 2016; Christ et al., 2001; Hasher & Zacks, 1988) may shape what older adults remember and how they use their memories to make decisions. Older adults are less likely to suppress task-irrelevant information during memory encoding (Amer et al., 2022; Campbell et al., 2010; Weeks & Hasher, 2017, 2018) and are more likely to experience interference from this extraneous information during memory retrieval (Dey et al., 2017; Healey et al., 2013). Age-related shifts in inhibitory control abilities may have important effects on the use of relevant memories to make effective decisions, especially when these necessitate filtering and arbitrating between memories (Shadlen & Shohamy, 2016). In fact, the susceptibility of older adults to decision-making biases and to source monitoring errors has been attributed to deficits in inhibitory control (Coolin et al., 2016; May et al., 2005; Pachur et al., 2009; Rahhal et al., 2002). Although older adults' less efficient inhibitory control may not always hinder them in real-world decisions due to the utility of semantic knowledge in everyday situations (Healey & Hasher, 2009), they may be hindered in contexts where both episodic and semantic information are available, but only one is relevant. When conflicting episodic and semantic memory sources are present, are older adults able to exert the inhibitory control required to suppress irrelevant information?

Accordingly, we asked how aging influences the use of episodic and semantic memories in a value-based decision-making task adapted from previous work investigating episodic value learning in younger adults (Duncan & Shohamy, 2016). In this computerized card game, participants selected one of two cards, individuated with images of unique commonplace objects, in order to earn points. Each card had one of five values (0, 25, 50, 75, or 100) and its value was revealed only if it had been selected. On critical old trials, participants were presented with one new card and one previously selected (old) card. Old cards always retained their prior value and were repeated only once during the task, allowing participants the opportunity to use episodic memories of their earlier experience to maximize their earnings. Importantly, the object-point association was arbitrary and unrelated to the real-world, semantic value of the objects (i.e., an object worth \$2 in the real world could be worth 100 points in the game and a \$100 object could be worth 0 points), enabling us to assess potential age differences in reliance on episodic versus irrelevant semantic knowledge. The optimal strategy toward maximizing earnings would therefore be to use episodic memories of previously experienced card values to make choices on critical trials, while suppressing the real-world semantic values of the objects on the cards.

We predicted that older adults would use episodic memory of associated point values less reliably than younger adults, as informed by past work showing age-related associative memory deficits (Old & Naveh-Benjamin, 2008b). We also predicted that this shift away from associative memory coupled with comparatively intact item recognition (Yonelinas, 2002) would result in older adults being more attracted to either familiar or novel card options, regardless of the card's point value. We further assessed whether age-related positivity biases (seen often in the emotional domain) extended to memory for value associations, predicting that older adults' decisions would be more sensitive to positive than negative outcomes, and that this bias would be greater than in younger adults. We also conducted planned exploratory analyses to test the prediction that older adults would rely more on semantic memory to make decisions, even when relevant episodic memories were available.

Method

Transparency and Openness

All hypotheses, methods, and analyses for this study were preregistered. We report how we determined our sample size, and describe all data exclusions, manipulations, and all measures in the study. All data, analysis code, and research materials are available.

Participants

Participants included 40 younger adults (n = 26 women; n = 14 men; age range = 18–24; racial/ethnic background = 70% Asian, 17.5% Caucasian, 7.5% Middle Eastern, 5% Latinx, 2.5% African Canadian; preferred time of day = 59.56% neither morning nor evening, 35.73% evening type, 4.7% morning type) from the Introduction to Psychology Subject Pool at the University of Toronto and 47 older adults (n = 31 women; n = 14 men; n = 2 other; age range = 61–75; racial/ethnic background = 85% Caucasian, 6% African Canadian, 4% Asian, 2.5% Aboriginal/First Nations, 2.5% other; preferred time of day = 61.7% morning type, 36.2% neither morning nor evening, 2.1% evening type) from the Adult Volunteer Pool at the University of Toronto, which consists of adults from the Greater Toronto Area community. The gender of participants did not differ according to age group ($\chi^2 = 1.89$, $p = .39$). There was a significant association between age group and preferred time of day ($\chi^2 = 35.65$, $p < .001$), which was expected based on prior research showing that older adults are more likely to be morning types than younger adults (May & Hasher, 1998; Mecacci et al., 1986). Note also that all participants were able to select their session's time of, with ample morning sessions available to accommodate these well-documented chronotype differences. Older adults in our final sample also had better performance on the Shipley-2 vocabulary subtest (Shipley et al., 2009) than younger adults, $t(55.99) = -7.51$, $p < .001$, consistent with well-established increases in vocabulary with aging (Verhaeghen, 2003).

However, we also found some unanticipated differences between our age groups. There was a significant association between age group and race ($\chi^2 = 122.25$, $p < .001$), such that our younger adult (YA) group was predominantly Asian while our older adult (OA) group was predominantly Caucasian. There is robust evidence for differences in cognition between Eastern and Western participants (Chua et al., 2005; Millar et al., 2013; Nisbett & Masuda, 2003). Accordingly, we conducted control analyses to probe possible differences between Asian and non-Asian young adults in episodic (see Supplemental Equation 6) and semantic memory use (see Supplemental Equation 10) on our task. The details and results of these analyses are included in Online Supplemental Material and addressed in our Discussion section. Our final older adult sample also had more years of education than the younger adults, $t(53.18) = -6.45$, $p < .001$. Though note that older adults' years of education did not correlate with their semantic memory use in our task (r = 0.04, p = .79), suggesting that this difference in education does not contribute to the age differences that we report below.

Participants gave written informed consent, and all procedures were in accordance with the Research Ethics Board at the University of Toronto. Younger adults received one credit toward their final grade and older adults received \$16 per hour as compensation. For both younger and older adults, the inclusion criteria were as follows: no self-reported history of psychiatric disorders; no self-reported history of attention deficit and hyperactivity disorder or other learning disorders; no self-reported history of neurological disorders; and no self-reported history of having lost consciousness for more than a few seconds. To limit the enrolment of those at risk for mild cognitive impairment in the older adult sample, a score below 26/30 on the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005) was also an exclusion criterion for older adults, resulting in the exclusion of seven participants from analyses for a total of 40 participants per group. We determined that two younger and two older adults did not comply with task instructions following data collection (i.e., were more likely to choose a card with lower compared to higher point values), suggesting that the majority of participants in both age groups correctly interpreted our instructions. In line with preregistered exclusion criteria, we excluded these individuals from analyses for a final sample of 38 participants per age group. We reasoned that age differences in associative memory in our task would be most similar to age differences in source memory, which have been shown to be moderate in effect size (lower bound $d = 0.64$; Old & Naveh-Benjamin, 2008b). To achieve 80% power at an α of 0.05, an a priori power analysis determined that we needed 39 participants per group; however, we still achieved 79% power with a final sample of 38 participants in each group.

Materials

Stimuli

Stimuli consisted of 278 images of colored, nonemotional objects (i.e., safety pin, camera), presented on computer generated rectangles designed to look like playing cards (2.86 in. wide × 3.35 in. high) and randomly selected on each experimental run from a larger pool of 416 images, with sets selected yoked between pairs of younger and older adults. Object images were collected from online sources using internet searches. On the back of each object card was an associated point value that remained constant throughout the experiment (e.g., the safety pin could be assigned a value of 75 points). Point values ranged from 0 to 100 points in 25-point increments which were randomly assigned to objects at the beginning of the experiment. All objects were presented on an iMac with a 21.5-in. screen using the Psychtoolbox-3 for MATLAB (Brainard, 1997).

Objects were chosen to vary continuously in their real-world dollar value; some objects had a lower real-world value (e.g., safety pin, with an average normed value of $0.71) and others had a higher real-world value (e.g., camera, with an average normed value of $351.13). We used this variability to assess how participants' choices were biased by their semantic knowledge of these values, despite experimental instructions (see below) to only use the arbitrary object-point associations. We focused on this real-world dollar value, rather than other values like utility, because it is structurally similar to the point value system used in the card game and, thus, would be most likely to influence choice. We quantified the semantic value of each object through a norming experiment conducted online using Inquisit 5 (*Inquisit 5 [Computer Software]*, 2016), with the experiment made available to the English-speaking, North American participant pool on Amazon's Mechanical Turk (Buhrmester et al., 2011). No age range was selected as an inclusion criterion because we wanted to obtain semantic values for each object that were applicable regardless of age.

Object stimuli were split into four groups of 104 objects each, to which participants ($N = 39$, 15 women, median age = 35 years, SD = 13.21 years, range = 19–70 years) were randomly assigned. They were asked to input the approximate, real-world dollar value of each object. To assess the relative agreement about the value of objects, we median split participants in each group by subject number and correlated the median dollar value for each object across groups. Responses were significantly correlated with each other, $r(414) = 0.92$, $p < .0001$. To ensure that ratings did not differ by age, we also median split participants in each group by age and correlated the median dollar value for each object across groups. Again, responses were significantly correlated with each other, $r(414) = 0.90$, $p < .0001$. Nevertheless, to reduce the influence of extreme values, we winsorized the top and bottom percentile of object dollar values and then log transformed all values. We also removed objects that did not receive reliable value ratings (discrepancy across a split sample greater than 2.5 standard deviations above the mean discrepancy). All analyses which interrogate the use of semantic object value use these transformed, normative estimates of real-world object value. Objects with high versus low semantic values were assigned each of the five episodic point values with equal frequency ($\chi^2 = 4.92$, $p = .30$).

Procedure

Prior to beginning the study, all participants completed demographics forms. Older adult participants additionally completed the MoCA, a neuropsychological assessment to test for mild cognitive impairment.

To investigate how younger and older adults use episodic memory to make decisions, participants played a computerized card game in which they could use their memories of point values to maximize their final score (Figure 1A). On each trial, participants saw a pair of cards with different objects on them. The participant's job was to select one of the cards within 2.5 s, a longer time window than typically used in tasks of this kind (Duncan et al., 2019; Duncan & Shohamy, 2016), in consideration of older adults' reduced processing and response times (RTs; Bashore et al., 2014; Tun & Lachman, 2008). The selected (and only the selected) card then flipped over to reveal its point value for 2 s. The object-point associations were randomized across participants, with each value occurring equally often. On critical *old* trials (which appeared approximately 47% of the time), an object card, selected 5–20 trials earlier, was presented alongside a new card. On *new* trials (approximately 53% of trials), two new cards were dealt, giving participants the opportunity to learn new card values. The game was divided into two separate test blocks of 90 trials each with a break in the middle, for an approximate total time of 20 min.

Participants were instructed to "play a card game" whose "goal was to win as many points as possible." They were further told that

> there is a trick to earning more points: Each card has a different object on it. Cards with a specific object will always be worth the same number of points. For example, if you get 100 points for picking the balloon card, it will be worth 100 points the next time you see it.

Thus, participants could use their knowledge of object-point associations to maximize their points whenever an old card repeated. Although we explicitly told participants to maximize their points and that earlier trials were relevant for later ones, we did not use the word "memory" in our task instructions to reduce the degree to which older adults felt like their memory was being tested. Participants were asked to make their response within the 2.5 s response window but were not instructed to make responses as quickly as possible as we were primarily interested in how likely people were to make memory-guided as opposed to semantic knowledge decisions when allotted sufficient time.

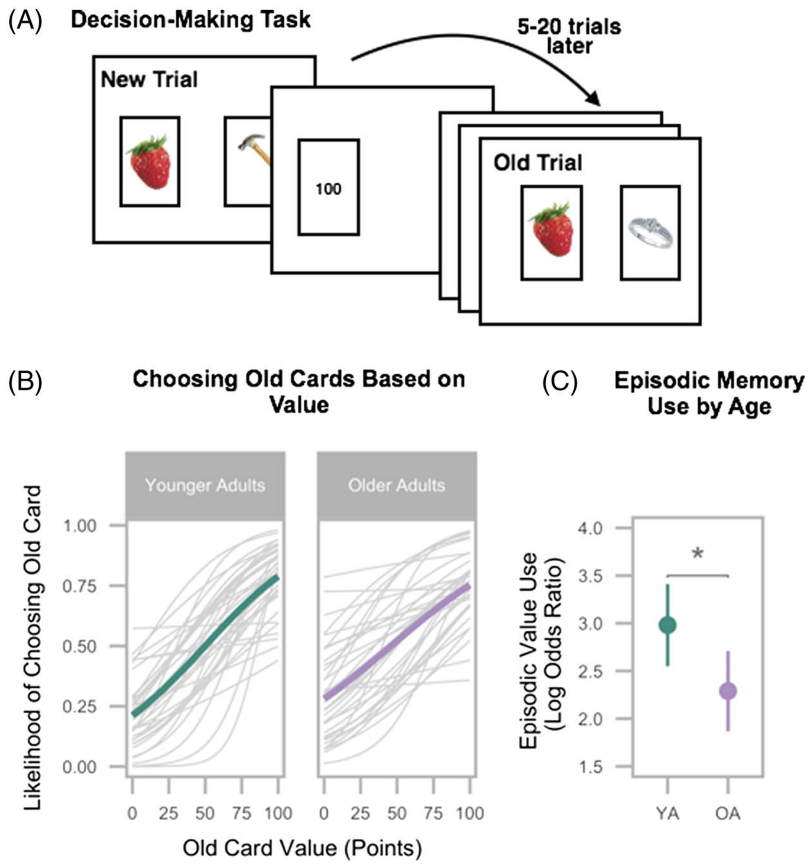
Following the card game, all participants completed the Shipley-2 vocabulary subtest (Shipley et al., 2009), and the Morningness Eveningness Questionnaire (Horne & Ostberg, 1976), which provided a measure of each participants' chronotype or preferred time of day (see Table 1). As we did not systematically manipulate the time of day at which participants performed the experiment, we do not include time of day compatibility in any of the analyses reported in the current article.

Analysis

All analyses were completed using the R programming language (Version 3.6.1; R Core Team, 2021). Our primary dependent variable was the likelihood of selecting an old card. Generalized mixed effects models (GMMs, glmer function in the *lme4* package; Bates et al., 2015) were used in analyses with multiple observations per participant per condition (e.g., choice on each trial). All models included random slopes for all within-subject variables, grouped by participant. See Supplemental Material, for the details of each model and analysis scripts at https://osf.io/84nrm/. We also estimated the linear trends and calculated pair-wise contrasts with Tukey-adjusted p values for our GMM models (emtrends function in the *emmeans* package; Lenth, 2020). Confidence intervals for models were derived from the confint function (*lme4 package*; Bates et al., 2015). Independent sample t tests or Wilcoxon Sign Rank tests

Figure 1

Decision-Making Task, Likelihood of Choosing an Old Card, and Episodic Memory Use



Note. (A) Decision-making task. Participants were presented with two object cards. They selected one card which flipped to reveal how many points they received on that trial. Point values varied between 0 and 100 at 25-point intervals. Five to 20 trials later, participants were presented with a previously selected card alongside a new card. Critically, on these old trials, participants had the opportunity to use their episodic memory of the previously learned object-point association to make decisions. (B) Likelihood of choosing an old card based on its learned value. Younger adults' responses plotted on the left and older adults' response on the right. Each participant's likelihood of choosing the old card on an old trial based on its previously experienced point value is plotted in gray lines. Colored lines indicate the population mean for younger (green) and older (purple) adults, respectively. Steeper slopes are indicative of greater episodic memory use. (C) Episodic Memory Use by Age. Younger adults (green) use their episodic memory of the object-point association significantly more than older adults (purple). The graph plots mean β estimates of memory use; error bars reflect standard error of the mean. See the online article for the color version of this figure.

were used to compare groups in analyses with single indices per participant (e.g., episodic RT effect), depending on whether the indices passed the Shapiro test for normality (*t*.test, Wilcox.test, and Shapiro.test functions in the *stats* package; R Core Team, 2021).

Results

Episodic Memory Use

Episodic memory use within and between age groups was assessed with a GMM predicting the likelihood of choosing an old card from age group, the previously experienced card value, and their interaction (see Supplemental Equation 1). Both age groups were more likely to choose old cards that had a higher as compared to lower point value, indicating that they successfully used episodic memory to make decisions (YA: $\beta = 2.98$, 95% CI [2.55, 3.41], $z = 13.55$, $p < .001$; OA: $\beta = 2.29$, 95% CI [1.87, 2.71], $z = 10.63$ $p < .001$; Figure 1B). As predicted, though, younger adults did use their episodic memory more reliably than older adults ($\beta = -0.69$, 95% CI [−1.29, −0.09], $z = 2.26$, $p = .024$; Figure 1C). This difference in memory use was reflected in older adults earning fewer points on

Table 1
Demographic Information for Older and Younger Adult Participants

Age group	M_{age} (*SD*)	Age range	Distribution of gender	Education	Shipley	MoCA	MoCA memory	Distribution of race/ethnicity	MEQ category
Younger adults	18.90 (1.36)	18–24	65% women, 35% men	12.92 *(1.36)*	28.13 *(5.3)*	NA	NA	17.5% Caucasian, 70% Asian, 2.5% African Canadian, 5% Latinx, 7.5% Middle Eastern	4.7% morning type, 35.73% evening type, 59.56% neither type
Older adults	69.02 (4.02)	61–75	66% women, 29.8% men, 4.25% other	17.31 *(4.62)*	35.16 *(2.78)*	27.71 *(1.27)*	4.24 *(0.98)*	85% Caucasian, 4% Asian, 6% African Canadian, 2.5% Aboriginal/First Nations, 2.5% Other	61.7% morning type, 2.1% evening type, 36.2% neither type

Note. Italicized values indicate the standard deviation from the mean. MoCA = Montreal Cognitive Assessment; MEQ = Morningness Eveningness Questionnaire; NA = not applicable.

average than their younger counterparts, $t(72.25) = 2.40$, $p = .019$; YA: $M = 95{,}710$, $SD = 4{,}140$; OA: $M = 93{,}450$, $SD = 3{,}550$. Notably, when we added experiment block as a predictor in this model (see Supplemental Equation 2), there was no evidence of a decline in point outcome use across the two blocks ($\beta = -0.07$, 95% CI [−0.42, 0.27], $z = -0.43$, $p = .66$). This suggests that older adults' reduced use of episodic memories did not reflect a buildup of interference, but rather a consistent reduced tendency to use single past experiences to guide simple choices.

Apart from this reduced use of episodic memory, older adults' memory-guided decisions were similar to younger adults'. We first investigated whether older adults displayed an overall bias toward either familiar or novel cards. Age groups did not differ in how often they chose old compared to new cards, suggesting older adults were no more or less likely to prefer familiar cards than younger adults ($\beta = 0.11$, 95% CI [−0.22, 0.44], $z = 0.66$ $p = .51$). In addition, an exploratory analysis calculating the point of subjective equality (PSE) to determine the point at which younger and older adults were equally likely to pick the old or new card, revealed no difference between age groups (PSE: YA = 51.04; OA = 46.29; $W = 769$, $z = -0.48$, $p = .63$), suggesting that aging is not related to a systematic preference for either novelty or familiarity in this task. However, this lack of difference in an overall bias may reflect individual differences in preferences for either familiarity or novelty. To address this, we conducted an exploratory analysis probing age-related differences in decision biases by calculating the absolute value of how much participants' rate of selecting old objects deviated from 50% (absolute bias). Although older adults were quantitatively more likely to exhibit a bias toward either preferring familiar or novel options (YA = 10.7%; OA = 13.4%), this group difference was not statistically significant ($W = 571$, $z = -1.56$, $p = .12$).

Lastly, we assessed how aging influenced the use of different types of point outcomes. First, we asked in an exploratory analysis whether older adults relied more on gist-based representations of good versus bad cards—making them just as likely to select a 75 as compared to 100 point card—or if they showed similar sensitivities to increments within these categories as younger adults. To this end, we ran two GMMs predicting the of likelihood of choosing an old card from age group, the previously experienced card value, and their interaction, restricting trials to those with either high value (75 and 100 points; see Supplemental Equation 3) or low value (0 and 25 points; see Supplemental Equation 4) old cards. In both analyses, we found that older and younger adults were sensitive to these increments (*high values:* $\beta = 1.03$, 95% CI [0.71, 1.3], $z = 6.40$, $p < .001$; *low values:* $\beta = 0.85$, 95% CI [0.57, 1.13], $z = 5.95$, $p < .001$), and that groups did not reliably differ in their discrimination of specific values (age by value interaction for *high values:* $\beta = -0.11$, 95% CI [−0.54, 0.32], $z = 0.50$, $p = .62$; *low values:* $\beta = -0.085$, 95% CI [−0.47, 0.30], $z = 0.43$, $p = .67$). Second, we assessed whether aging resulted in a positivity bias, manifested as higher sensitivity to increments within the high as compared to low point outcomes. Specifically, we used a GMM to predict the likelihood of choosing an old card from age group, high or low prior value (i.e., 0 and 25 points coded as low; 75 and 100 points coded as high), and relative prior value (i.e., 0 and 75 points coded as low; 25 and 100 points coded as high; see Supplemental Equation 5). It did not reveal any age group differences in their sensitivity to point increments within high as compared to within low point values (β = −0.01, 95% CI [−0.27, 0.26], $z = -0.51$, $p = .96$; Figure 1B).

Together these results suggest that older adults are less likely to use episodic memories to guide their choices as compared to younger adults (Figure 1C), but when they do, they use these memories in very similar ways.

Impact of Episodic Memory Use on RT

Older adults took more time to select cards than younger adults across all choices ($W = 885$, $z = -7.38$, $p < .001$; YA mean = 1120.65 ms; OA mean = 1350.95 ms; Figure 2A). To assess age differences in RT distributions, we ran exploratory analyses in which we fit each participant's RTs with an ex-Gaussian model (using the *gamlss* function; see Supplemental Equation 7) which models both Gaussian and exponential components to capture long tails. Four older and two younger adults were removed from this analysis because the models could not converge. We compared age groups using a separate linear regression for each parameter. We confirmed that the mean of the Gaussian distribution underlying older adults' RTs was indeed much larger than for younger adults' (β = 329.28, $SE = 53.24$, $t = 6.19$, $p < 10^{-8}$; Table 2). Likewise, we found that the variance of this distribution was robustly broader in older compared to younger adults (β = 0.33, $SE = 0.09$, $t = 3.74$, $p = .0004$; Table 2), reflecting more variability in older adults' memory and decision-making times. Younger adults' RTs also had a somewhat longer tail than older adults (β = −0.45, $SE = 0.22$, $t = -2.05$, $p = .04$; Table 2). Interestingly, individual difference in this long tail parameter were not reliably correlated with object point use in younger, $r(35) = -.17$, $p = .29$, or older, $r(32) = 0.06$, $p = .72$, adults, suggesting that they do not reflect a task relevant process, like recollection.

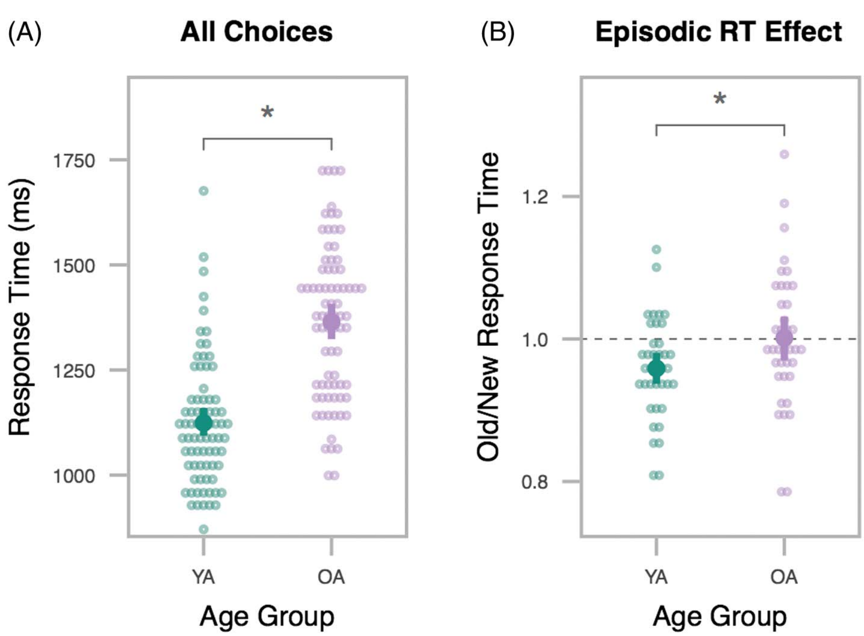
To investigate whether the speed of older and younger adults' responses was differently affected by the presence of an old card, we calculated an *episodic RT effect* (Figure 2B) as the ratio of RT on old trials (when episodic memories can be used) to new trials (with no relevant episodic memory). Younger adults' decisions were disproportionately faster than older adults' when relevant episodic memories were available to support their arbitration, $t(67.65) = -2.21$, $p = .031$; YA mean = 0.96; OA mean = 1.00; Figure 2B. This age difference may reflect younger adults' faster access to relevant episodic memories when dealt old cards. Alternatively, younger adults may be more likely to strategically slow down to exhaustively search for a relevant memory when dealt only new cards.

Semantic Memory Use and Suppression

Semantic memory use within and between age groups was assessed with a GMM predicting the likelihood of choosing a card from semantic value, trial type, age group, and the interaction (see Supplemental Equation 8) between these variables suggest that younger adults were more likely to strategically suppress their use of semantic memories as compared to older adults depending on the trial

Figure 2

Effect of Age on Response Time and on Episodic Reaction Time Effect



Note. (A) Effect of age on response time (RT). Older adults (purple) were significantly slower to respond than younger adults (green) when making decisions across all trials. (B) Effect of age on episodic RT effect (old trial RT/new trial RT). A value of 1 indicates similar choice time on old and new trials. Younger adults (green) responded more quickly on old trials, but there was no difference between old and new trials in older adults (purple). See the online article for the color version of this figure.
* $p < .05$.

Table 2
Mean and Standard Deviation of the μ, Variance, and Tail of Individual Subjects' Reaction Time Distributions in Younger and Older Adults

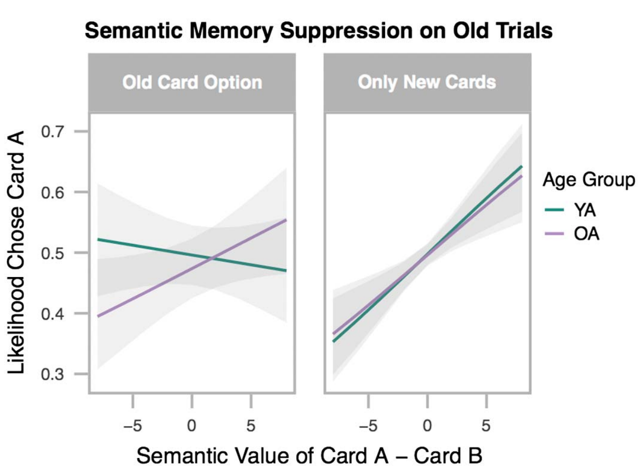
Age group	μ (*SD*)	Variance (*SD*)	Tail (*SD*)
Younger adults	824 (183)	5.08 (0.36)	5.39 (0.76)
Older adults	1,145 (260)	5.39 (0.37)	4.96 (1.06)

type (β = −0.061, 95% CI [−0.12, 0.0006], z = −1.98, p = .048; Figure 3). Specifically, when dealt two new cards, both younger and older adults were more likely to select the cards marked with objects that have greater real-world values (YA: β = 0.075, 95% CI [0.037, 0.11], z = 3.89, p < .001; OA: β = 0.067, 95% CI [0.029, 0.10], z = 3.47, p < .001), and age groups did not differ in this tendency (β = 0.008, 95% CI [0.05, 0.006], z = 0.29, p = .99), reflecting the uninstructed recruitment of semantic information to aid their choice. But younger adults stopped using this semantic value information when dealt an old card (β = −0.013, 95% CI [−0.051, 0.025], z = −0.66 p = .51), allowing them to shift toward the more relevant episodic information. This was not the case for older adults, who continued to use semantic memories on old trials (β = 0.040, 95% CI [0.001, 0.08], z = 2.01, p = .045). However, older adults greater use of semantic memory on old card trials did not reach statistical significance (β = −0.053, 95% CI [−0.13, 0.019], z = −1.90, p = .23).

We ran two exploratory control analyses to better understand why older and younger adults used semantic values so differently, both targeting the hypothesis that older adults' continued use of semantic memories on old trials may be a byproduct of their poorer episodic memories, rather than a failure in strategic suppression. If the latter were the case, age differences should disappear when episodic memory use is equated across groups. Accordingly, we dropped data from older adults whose episodic memory was in the bottom quartile and repeated the semantic memory analysis. We reran the GMM (see Supplemental Equation 7) in this subset with roughly equated episodic memory use (mean YA = 3.28, mean OA = 2.97, β = −0.30, p = .47). Even with a smaller older adult sample, reducing our power, we still saw a trend toward this three-way interaction (β = −0.062, 95% CI [−0.13, −0.003], z = −1.86, p = .063), with age differences suggesting that even when episodic memory is similar, older—but not younger—adults continue to rely on semantic knowledge when it would be more strategic to use episodically learned values.

The second analysis investigated how trial-by-trial fluctuations in episodic memory accessibility influence the use of task-irrelevant semantic memories. We used the delay between the initial selection of a card and its next presentation as a proxy for memory accessibility, reasoning that older adults would be more likely to use semantic memories after long delays if their use reflects poor episodic memory access. Surprisingly, we found the opposite pattern. Specifically, we reran our GMM (restricted to old card trials) including delay since the old card was selected (normalized number of trials) and its interaction with age group and semantic value (see Supplemental Equation 9). We found a significant three-way interaction (β = −0.05, 95% CI [−0.097, 0.003], z = −2.09, p = .037), which reflected that older (but not younger) adults tended to use semantic memories more often when delays were shorter (YA: β = −0.03, p = .14, OA: β = 0.07, p = .004). These two exploratory control analyses (along with individual differences analyses reported below) suggest that age-related differences in semantic memory use do not stem from changes in episodic memory accessibility.

Figure 3
Effect of Age on Semantic Memory Suppression on Old as Compared to New Trials



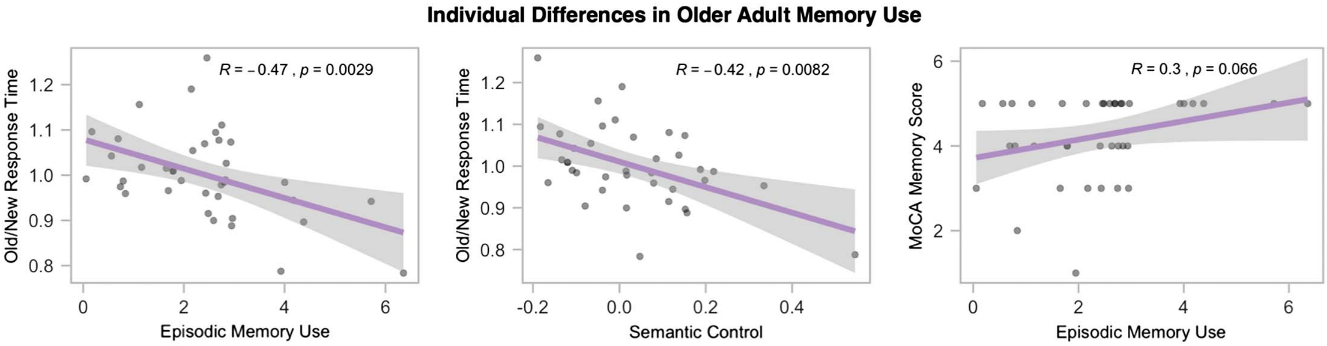
Note. Younger adults (green) suppressed semantic memory use on old trials (when competing episodic memories are available), but older adults (purple) used semantic memory regardless of whether or not episodic memories were available. See the online article for the color version of this figure.

Individual Differences

In younger adults, episodic memory use, the episodic RT effect, and the suppression of semantic memory on old compared to new trials were not reliably correlated with each other (all absolute r values less than or equal to r = 0.21, p = .21). By contrast, these different aspects of memory-guided decisions were correlated within the older adult group (Figure 4). Specifically, episodic memory use was correlated with the episodic RT effect (r = −0.47, p = .0029), suggesting that the older adults who were most adept at using episodic memories in the game were faster at picking cards when an episodic memory could be used—much like their younger counterparts. This episodic RT effect was also correlated with the reduced use of semantic memory on old trials in older adults (r = −0.42, p = .0082), perhaps because both effects are partially related to the strategic use of memory in decision-making. The use of episodic memory, however, was not reliably correlated with the suppression of semantic memory in older adults (r = 0.12, p = .47), further suggesting that older adults did not fall back on semantic memories when they struggled to find episodic ones. Lastly, we found a trending correlation between scores on the memory portion of the MoCA and episodic memory use in older adults (r = 0.30, p = .066), suggesting that the use of memories in the context of this card game was related to a standardized neuropsychological assessment of older adults' underlying memory abilities.

Figure 4

Relationship Between Memory Use Correlated With the Episodic RT Effect in Older Adults



Note. MoCA = Montreal Cognitive Assessment; RT = response time. There was a negative correlation between episodic memory use and the episodic RT effect on all trials in older adults. There was also a negative correlation between semantic memory suppression and the episodic RT effect on all trials in older adults. This indicates that older adults who performed like younger adults in memory use also showed a similar episodic RT effect as younger adults. There was a marginally positive correlation between MoCA memory score and episodic memory use in older adults. All statistics reflect Spearman correlations to reduce influence of outlying data points. See the online article for the color version of this figure.

Discussion

Although age-related differences in memory systems have been well characterized (but see Amer et al., 2022), their implications for episodic memory-guided decision-making remain understudied. In the present study, older and younger adults completed a value-based decision-making task in which episodic memory could be used to maximize points. We found that older adults used episodic memory to guide their decisions but did so reliably less than younger adults. Moreover, when given the chance to use episodic memories, older adults instead tended to also use the task-irrelevant semantic information to make their decisions. In comparison, younger adults strategically used the semantic value of the card, suppressing their use when a relevant episodic memory could be used. Taken together, our findings suggest that age-related memory differences shape experience-guided decisions, an effect which may stem from impaired arbitration between conflicting information that arises from intact semantic and weakened access to episodic memory.

While older adults used their episodic memory less than younger adults in our study, the deficit was not as large as is commonly observed in the aging and episodic memory literature (present study: Cohen's $d = .51$; Old & Naveh-Benjamin, 2008b: Cohen's $d = 0.73$ [0.64–0.82]). This may be due to the somewhat more realistic nature of our card game task. Indeed, previous studies have found that grounded, meaningful tasks ameliorate age-related memory differences (Amer et al., 2018; Castel, 2005; Rahhal et al., 2002). By contrast, many laboratory tasks investigating associative memory in aging have participants encode associations between neutral, unrelated stimuli (Old & Naveh-Benjamin, 2008b). These tasks typically yield poor episodic memory in older adults (Bastin & Van der Linden, 2006; Chalfonte & Johnson, 1996; Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2003, 2004). By assessing memory in a motivated, and familiar card-game context—as well as providing all participants with ample time to respond, in consideration of age-related differences in processing and RT (Bashore et al., 2014; Tun & Lachman, 2008)—we may have more accurately assessed older adult's real-world memory potential, despite the use of arbitrary point associations. Alternatively, our clear and explicit instructions to use previously experienced object-point values may have ensured that older and younger adults used similar strategies, providing the type of environmental support that can reduce age-differences in episodic memory performance (Fu et al., 2016). Regardless of the cause, our results demonstrate that the use of episodic memory in decision-making may not be as restricted in healthy aging as one might expect from past work investigating age-related associative memory deficits (Chalfonte & Johnson, 1996; Lyle et al., 2006; Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2003, 2004; Old & Naveh-Benjamin, 2008b).

In contrast to how aging simply shifted the degree of episodic memory use, it qualitatively changed how people used task-irrelevant semantic values. While both age groups robustly used real-world object values when selecting between two new cards, only younger adults stopped using this task-irrelevant knowledge when an episodic memory could be used. This greater reliance on semantic memory in older adults is particularly striking, considering that our normative real-world object values were obtained from a random sample that was skewed toward younger and middle-aged adults. There are two candidate explanations for this pattern of semantic memory use. First, perhaps shifts in the relative balance of memory systems with age (Nyberg et al., 2003, but see Murphy & Castel, 2020) cause older adults to rely more on compensatory strategies to support their decision-making (Healey & Hasher, 2009; Yoon et al., 2009). Indeed, the deficit attenuation hypothesis posits that stronger, more accessible semantic memories may increasingly guide decisions in the face of failing episodic memory (Yoon et al., 2009). From this perspective, older adults may have continued to rely on real-world values when dealt an old card because they struggled to either recognize the old object or access its point value. Or, perhaps, even when they could have accessed the memory they preferred using their comparatively robust semantic memories (Brashier et al., 2017), despite being instructed to focus on object-point associations. By contrast, with their stronger abilities to rapidly recall the pertinent episodic memory, younger adults may not have needed to fall back on this task-irrelevant semantic knowledge.

A second possibility is that declining inhibitory control (Amer et al., 2016; Campbell et al., 2020; Christ et al., 2001; Hasher & Zacks, 1988) contributes to older adults' bias toward (task irrelevant) semantic memory use. Semantic processing has been argued to occur automatically (Hohlfeld et al., 2015; Vachon et al., 2019), whereas episodic memory is thought to be a slower, conscious process (Yonelinas, 2002). So, while the automaticity of accessing real-world dollar values is not known, they could conceivably become available before task relevant point-values are retrieved, or perhaps even before objects are recognized as old. Thus, maximizing points could involve suppressing the use of this real-world knowledge, particularly when task-relevant point-values could be used. In line with age-related impairments in suppressing competing information when forming and retrieving memories (Campbell et al., 2010; Dey et al., 2017; Healey et al., 2013; Weeks & Hasher, 2017), older adults may struggle more with this strategic suppression than their younger counterparts.

While age-related shifts in memory systems and inhibitory control may both contribute to the pattern of semantic memory use, the bulk of our results better align with the inhibitory control explanation. For instance, if older adult's continued use of semantic memories on old card trials reflected their episodic memory impairments, one would expect that the older adults with strongest episodic memory abilities would also show the strongest strategic semantic suppression. But we did not find evidence for this relationship, either when correlating individual differences or subsetting our sample to equate episodic memory use. Instead, we found that the strategic use of semantic memory correlated with older adults' tendencies to make slower decisions when dealt only new cards—a pattern expressed by younger adults, which may reflect the controlled, exhaustive search for relevant memories. Lastly, older adults were surprisingly more likely to use semantic values when dealt cards that should be easier to recognize, namely those that they selected only a few trials ago, perhaps because they so recently accessed that object's real-world value. Thus, older adults' continued use of semantic memory when making decisions about old cards is not obviously related to accessing episodic memories; it may rather reflect a failure in inhibitory control. However, future work should more directly arbitrate between these possibilities. The role of episodic memory accessibility could be more directly assessed by manipulating, for example, the number of exposures to specific object-point associations. Conversely, the role of inhibitory control could be more directly assessed by, for example, reducing decision time or adding a secondary task.

A final possibility is that differences in the racial and ethnic backgrounds of participants across age groups (Table 1) influenced their semantic memory use on the task. Our younger adult sample was primarily Asian, whereas our older sample was primarily Caucasian—a consequence of the participant pools from which they were recruited. Prior research has shown that Asian individuals are more likely than Caucasians to attend to incidental contextual information (Chua et al., 2005; Nisbett & Masuda, 2003) and incorporate these contexts into their memory (Millar et al., 2013). The biased racial and ethnic compositions of our age groups could, thus, result in the younger adult sample using more incidental contextual information to choose cards than our older adult sample. In fact, we did investigate this possibility (see Supplemental Equation 10) and confirm that Asian younger adults were less likely than non-Asian younger adults to strategically suppress semantic information. Notably, though, this bias would reduce—not drive—the observed age-related differences in semantic memory use. Future research should explore this possibility directly by comparing samples of older and younger adults from a range of cultural backgrounds, as the present study did not have sufficient power to investigate this question in older adults, nor were there an equal number of Asian and non-Asian participants in either of our age groups.

Age-related differences in other cognitive processes, such as attention, may have also interfered with older adults' ability to learn the episodic object-point associations. Attentional broadening with age results in an encoding phenomenon known as hyperbinding, whereby older adults implicitly form powerful memories for task-irrelevant information that can be retrieved on subsequent tasks—an effect not observed for younger adults (Campbell et al., 2010, 2014; Campbell & Hasher, 2018; Weeks et al., 2016; Weeks & Hasher, 2018). The explicit instructions to use object-point associations in the present study may have prevented this implicit learning, exacerbating age differences in performance. It is possible that older adults' comparative task performance would have increased had they been told to ignore this information, as has been observed in previous work (Weeks et al., 2016).

The possibility still remains that older adults used something other than specific, episodic memories to guide their decisions. Recent work has found that older adults' memories for value-based information tends to be generalized and valenced (i.e., whether an object is "good" or "bad"; Flores et al., 2017) and that this kind of knowledge may be employed in lieu of specific retrieved associations (i.e., whether an object was worth 100 or 0 points) during decision-making (Castel et al., 2007; Mather & Johnson, 2003). However, we do have reason to believe that older (and younger) adults were using episodic associations on this task. Specifically, the decisions made by both age groups similarly reflected the specific points associated with the object card (e.g., selecting 100 point cards more often that 75 point ones, Figure 1). Moreover, in tasks similar to ours, episodic memories of associations were shown to be instrumental when decisions are guided by the outcome of a single experience (Murty et al., 2016). Performance on this card game has also been found to increase following manipulations linked to conscious episodic retrieval (Duncan & Shohamy, 2016; Patil & Duncan, 2018), an effect later shown to be specific to the use of single episodes and not other forms of reinforcement learning (Duncan et al., 2019). Thus, our findings, coupled with the fact that our task targets episodic memory, suggests that older adults were using their episodic memories, albeit to a lesser degree than younger adults.

We add to an emerging body of work suggesting that episodic memory plays an important role in making even simple value-based choices (Biderman et al., 2020). Our understanding of how people use learned values to make choices is anchored within a reinforcement learning perspective, in which value associations are incrementally accumulated across multiple experiences to inform future decisions, via procedural learning (Knowlton et al., 1996; Lee et al., 2012). Accordingly, age-related decrements in reinforcement learning have largely been attributed to changes to the procedural learning system (Chowdhury et al., 2013; Eppinger et al., 2011, 2013). Recently, however, a significant role for episodic memory in probabilistic reinforcement learning (Gershman & Daw, 2017; Lengyel & Dayan, 2008) and experience-driven decisions more broadly (Biderman et al., 2020; Bornstein et al., 2017; Murty et al.,

2016) has emerged. Indeed, memories of single events are readily used to make value-based choices (Duncan & Shohamy, 2016; Murty et al., 2016; Wimmer & Büchel, 2016), even in tasks generally thought to be supported by incremental, procedural value learning (Bornstein et al., 2017). As the relationship between episodic memory and reinforcement learning is only beginning to be appreciated, it follows that age-related differences in this relationship remain underexplored (Del Missier et al., 2015; Healey & Hasher, 2009; Sparrow & Spaniol, 2016). We add to this body of work by showing that aging reduces our use of one-shot episodic learning in a simple reinforcement learning task.

Broadly, there may be costs and benefits associated with a shift away from using episodic and toward semantic memory as we age. On one hand, by imbuing decisions with the vivid, contextual details of our experiences, episodic memories improve choices (Biderman et al., 2020). When choosing a movie to watch based on the recommendation of a friend, for instance, remembering *which* friend recommended the movie allows us to take the trustworthiness of the source into account. Relying on single past experiences may also be advantageous when we have limited data about a situation (Gershman & Daw, 2017; Lengyel & Dayan, 2008) and, thus, lack relevant knowledge. Accordingly, the one-shot learning provided by episodic memory could bolster decision-making in less well-established contexts. For example, relying on a single movie recommendation from a friend may introduce you to a new, entertaining, genre. Alternatively, a shift toward stable semantic memories, which reflect robust relationships in the environment rather than anecdotal evidence supplied by episodic memories (Tulving, 1972), may lead to more stable decisions over time (Gershman & Daw, 2017). The benefit of relying on a genre preference stems from the robust evidence supplied by having viewed so many films within it. Indeed, previous work has identified advantages for older adults in a number of more complex decision-making scenarios than considered in the present study, particularly in the wisdom and problem-solving literature (Del Missier et al., 2013; Fisk & Rogers, 2000; Hess et al., 1998; Masunaga & Horn, 2001; Worthy et al., 2011). Thus, a shift away from episodic memories with age may change the outcomes of decisions but could confer benefits in circumstances where aggregating across a long life's worth of experience is most relevant. By focusing on simple choices, our results extend on more well-researched changes to complex decision-making to improve our understanding of the full spectrum of decision-making across the lifespan.

Given the emerging appreciation for the influence of multiple memory systems in reinforcement learning and decision-making, our findings validate the importance of incorporating episodic memory into decision-making research by showing how decisions change in a group with episodic memory deficits. Further, by showing that age-related memory differences influence decisions, we provide new insight into the dimensions of cognition that are altered during healthy aging. Thus, age-related memory differences extend beyond reflection on the past and can permeate other consequential aspects of our lives.

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