LONG-TERM EPISODIC MEMORY, EXECUTIVE FUNCTIONING, AND THE AGE-HINDSIGHT BIAS RELATIONSHIP

by

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Abstract

Previous predictions about an event are often influenced by outcome knowledge of that event. Older adults tend to show more of this hindsight bias effect than younger adults. The present study investigated whether long-term episodic memory and aspects of executive functioning mediated or moderated the relationship between age and hindsight bias. Sixty-four younger adults and 60 healthy, community-living older adults completed a cognitive battery and a memory design hindsight bias task. Older adults showed hindsight bias more often than younger adults. Moreover, poorer long-term episodic memory and inhibition were associated with an increased probability of showing hindsight bias, after controlling for age. Both inhibition and long-term episodic memory independently mediated the age-hindsight bias relationship. Inhibition also moderated this relationship. By identifying the basic mental abilities contributing to age differences in hindsight bias, the present study's findings extend prior work in the hindsight bias and cognitive aging literatures.

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Dedication

To my parents, sister, and grandmother for their encouragement and support.

To my boyfriend, Brant, for his inspiration, patience and belief in my abilities.

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Introduction

Hindsight bias, also referred to as the "I knew it along effect" (Fischhoff, 1975), is a general inclination to perceive past events as predictable or inevitable. It emerges when new knowledge interferes with recall of a past event. For example, on June 15, 2011 a riot broke out in the city of Vancouver following the loss by the Vancouver Canucks to the Boston Bruins in Game Seven of the Stanley Cup Final. In the days following the riot, people recalled feeling that the riot was predictable and even inevitable. For example, a security expert stated, "given the size and emotion of the crowd, and the sheer number of innocent bystanders… a large scale riot would have happened in Vancouver after Game Seven, no matter how many police officers were on hand" (CKNW News, 2011). This statement neglects the uncertainties people had prior to the event given the city's complacent behaviour during prior playoff games and in the Olympics, and is an instance of the "I knew it all along" effect. This effect has also been implicated in social and moral judgments, such as legal decisions (Harley, 2007), and in academic (Hinds, 1999) and medical settings (Arkes, Wortman, Saville, & Harkness, 1980). Thus, erroneous judgments and biased decision-making in important life situations may occur due to hindsight bias.

Although many studies have demonstrated a robust hindsight bias effect in young adults (see Birch & Bernstein, 2007 for a review), only two have investigated whether the propensity to exhibit hindsight bias changes as we age (Bayen, Erdfelder, Bearden, & Lozito, 2006; Bernstein, Erdfelder, Meltzoff, Perria, & Loftus, 2011). Their findings revealed an increased susceptibility to hindsight

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bias in older as compared to younger adults. Some have suggested that age differences in hindsight bias are due to age-related declines in episodic memory and executive functioning (e.g., Bayen, Pohl, Erdfelder, & Auer, 2007); however, nobody to date has investigated this theory systematically. The primary objective of the present study was to determine whether long-term episodic memory and aspects of executive functioning underlie age differences in hindsight bias. Specifically, we tested whether these aspects of cognition mediated or moderated the age-hindsight bias relationship.

Age Differences in Hindsight Bias and Cognitive Functioning

Bayen et al. (2006) and Bernstein et al. (2011) investigated age differences in hindsight bias in younger and older adults using a memory design task (Hertwig, Gigerenzer, & Hoffrage, 1997). This is an established measure of hindsight bias that requires participants to estimate the answers to difficult general knowledge questions with a numerical response. Approximately 90 min later, participants recall their original estimates to the questions. They learn the correct answers to half the questions (experimental items), but not the other half (control items), and attempt to recall their original estimates to all questions. Hindsight bias occurs when participants' recalled estimates are closer to the correct answers in the experimental condition than the control condition (Pohl, 2007).

Bayen et al. (2006) found that older adults showed more hindsight bias than younger adults. However, there were no age differences in hindsight bias when the correct answers were not in sight or directly accessible during recall

(see Experiment 3). This suggests that hindsight bias in older adults results from outcome knowledge interfering with memory for one's original estimates. Bernstein et al. (2011) extended these findings by measuring hindsight bias across the lifespan (ages 3 to 95). While all age groups exhibited hindsight bias, the magnitude of the bias followed a U-shaped curve, declining from early childhood to young adulthood, and then increasing from young to older adulthood. The authors concluded that older adults' enhanced hindsight bias resulted from forgetting a greater number of their original predictions, and a tendency to use available outcome information to reconstruct their forgotten estimates.

Although the above findings suggest that older adults' hindsight bias results from a reconstructive error, the basic cognitive abilities underlying this error are unclear. Some of the proposed abilities that have been implicated in hindsight bias include inhibition, working memory, retroactive interference, and long-term episodic memory (see Bayen et al., 2006, 2007; Bernstein et al., 2007; Blank & Nestler, 2007). Notably, these are higher-order cognitive processes that are vulnerable to declines associated with aging (Ebert & Anderson, 2009; Hedden & Gabrieli, 2004; Zelazo, Craig, & Booth, 2004). One proposed mechanism (e.g., Bayen et al., 2007) is that older adults are more prone to retroactive interference (new information interfering with the recall of prior information; Postman, 1971) than younger adults (Delis et al., 2000), and thus, their increased hindsight bias is due to a poorer ability to inhibit outcome knowledge. This relates to Hasher & Zacks' (1988) inhibitory-deficit theory of

aging. According to this theory, if the access function of inhibition is impaired, then task-irrelevant information enters working memory. If the suppression function is also impaired this information is not inhibited, and thus interferes with memory of task-relevant information. In terms of the memory design task, this theory would predict that when the correct answer (irrelevant information) is presented (and thus in working memory during recall), age-related declines in the suppression function would result in older adults being more biased by this information than younger adults.

Bayen and her colleagues (2006) used this theory to interpret their results and found evidence that the suppression function of inhibition contributes to age differences in hindsight bias, but not the access function. When the correct answer was not available or accessible during recall (Experiment 3) no age differences were observed, suggesting that older adults are as capable of inhibiting the correct answer from entering working memory as younger adults (intact access function). However, when the correct answer was available (Experiment 1) or accessible in working memory (Experiment 2), older adults exhibited greater hindsight bias than younger adults. That is, older adults had greater difficulty suppressing this information, only when it was in working memory.

Although Bayen et al.'s (2006) finding implicates working memory in the hindsight bias process, the standard memory design task displays the correct answer throughout recall, and thus working memory is not required. However, working memory may play a different role in the hindsight bias process. For

example, in the recall phase, individuals must keep multiple pieces of information in mind (i.e., the task demands, the correct answer, and their original estimate, if accessible), and retrieve their original estimate from long-term memory storage. Both of these processes rely on working memory (De Neys, Schaeken, & d'Ydewalle, 2005; Muller, Miller, Michalczyk, & Karapinka, 2007). Based on this, and research indicating age-related declines in working memory (e.g., Mayr, Spieler, & Kliegl, 2001), less efficient working memory may contribute to older adults' increased susceptibility to hindsight bias.

Finally, long-term episodic memory (memory of specific information and events; Robertson & Kohler, 2007) has been implicated in cognitive process theories of hindsight bias (see Blank & Nestler, 2007). For example, the Selective Activation and Reconstructive Anchoring (SARA; Pohl, Eisenhauer, & Hardt, 2003) model emphasizes the role of traditional memory principles, such as strengthening of associations in long-term memory and subsequent changes of information accessibility, in the production of hindsight bias (Blank & Nestler, 2007). The model assumes that individuals activate question-relevant items from their knowledge base and integrate them to form their original judgment (Blank & Nestler, 2007). For instance, when first answering the question, "In what year was slavery abolished in the United States?" an individual may access knowledge about the Civil War occurring in the mid-1800s, but also recall information about slaves being freed in Virginia in the 1770s. Because each item would result in a different numerical estimate to the question, potential responses to both items are integrated into a single numerical estimate (Blank & Nestler,

2007). After learning the correct answer, the image within one's knowledge base that is most consistent with the correct answer (i.e., knowledge of the Civil War) is strengthened, causing a biased reconstruction of the original judgment (Blank & Nestler, 2007). Multinomial processing tree studies (Bayen et al., 2006; Bernstein et al., 2011; Erdfelder & Brandt, 2007) have also implicated long-term memory in hindsight bias. Their findings suggest that one mechanism underlying hindsight bias is a failure to retrieve one's original estimates from long-term memory, and that recollection rates decline through adulthood. In summary, older adults with less efficient memory recall may be more susceptible to hindsight bias, possibly because they more frequently have to use outcome knowledge to reconstruct their forgotten original estimates.

The Present Study

Several models have implicated various cognitive operations in hindsight bias; however, nobody to date has conducted a systematic examination of associations between hindsight bias and the proposed underlying cognitive functions in adults. Thus, the aim of the present study was to examine whether long-term episodic memory, retroactive interference, inhibition, and/or working memory contribute to age differences in hindsight bias. Specifically, we investigated whether these aspects of cognition mediated or moderated the relationship between age and hindsight bias in younger adults and healthy, community-living older adults. Three primary hypotheses guided our investigation. First, consistent with previous work, we predicted that older adults would show a greater susceptibility to hindsight bias than younger adults.

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Second, we expected that poorer cognitive functioning would be associated with greater hindsight bias, even after accounting for age. Lastly, we expected that the association between age and hindsight bias measured in past studies could at least partially be accounted for by age-related declines in aspects of cognitive functioning.

Methods

Participants

Sixty-four younger and 60 older adults completed the study. Younger adults were introductory psychology students at Simon Fraser University and received course credit for participating. Community-living adults were recruited through newspaper advertisements and flyers in the metro Vancouver area, the Simon Fraser University staff union e-mail list, and academic aging seminars. They received payment for their participation. All participants met the following inclusion criteria: (a) English fluency, (b) a minimum of grade 7 education, (b) no major visual (corrected vision ≤ 20/50) or hearing impairments, (c) absence of major psychotic illness, concurrent acute illness that may affect testing, neurological disorder, major organ failure, severe traumatic head injury, and history of a stroke that affected daily living activities, (d) no history of self-reported diagnosis of dementia by a physician, and (e) alcohol consumption of less than 3 ounces/day. No participants received a score less than 24 on the Mini Mental Status Examination (Folstein, Folstein, & McHugh, 1975).

Measures

Participants completed a two-hr cognitive battery of paper and pencil tests to assess long-term episodic memory, retroactive interference, inhibition, working memory, and hindsight bias. Trained research assistants individually administered the following measures at the Simon Fraser University Cognitive Aging Laboratory.

Hindsight bias. Hindsight bias was assessed using a memory design task (see Appendix A). Participants completed the following two questionnaires:

The Original Judgment (OJ) questionnaire. Participants completed the OJ questionnaire at the start of the study, which involved answering 54 questions requiring a numerical response[1]. The questions encompass general knowledge topics that participants should be familiar with, but not know the correct answer to (e.g., "How high is the statue of liberty including its base?"). Thirty-six of the questions were adopted from Bayen et al.'s (2006) measure[2], and 18 from Hardt and Pohl's (2003). The units of responding (i.e., meters, kilometers, etc.) were based on the metric system and provided to participants. The order of the questions was randomized, and then presented in a fixed order.

The Recall of the Original Judgment (ROJ) questionnaire. After completion of the OJ questionnaire, participants completed a 90-min cognitive test battery followed by the ROJ questionnaire. This questionnaire required participants to recall their original answers to all 54 questions. The questions were divided into two sets of 27. One set of questions provided the correct answers (experimental items) and the other set did not (control items). To counterbalance the control and experimental items we randomly assigned participants to one of two versions. The first version presented the set of experimental items prior to the control set, and vice versa for the second version.

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[1] One question (When was Socrates born?") was dropped because some participants were responding in B.C. and others in A.D., which prohibited the aggregation of responses across participants.
[2] The remaining questions from Bayen et al.'s (2006) measure were not used because they were not relevant to the Canadian culture (e.g., What year was Daniel Boone born?) or may have produced a truncated range of responses (e.g., the answer to "How old was Mahatma Gandhi when he died?" would likely be between 70 and 100).

The questions appeared in the same order as the OJ questionnaire. Participants were informed that they would learn the correct answers to half of the questions, and were asked to recall their original answers to all of them. These instructions were also printed on the top of the questionnaire. There was no time limit, and participants took approximately 10-20 min to complete each questionnaire.

  Cognitive functioning. We assessed long-term episodic memory and the following aspects of executive functioning: inhibition, working memory, and retroactive interference. Performance on the long-delay free recall (number of words recalled) and long-delay retention (long-delay free recall vs. trial 5: Percent change) trials of the California Verbal Learning Test-2 (CVLT-II; Delis et al., 2000) were used to assess long-term episodic memory and retroactive interference, respectively. Inhibition was measured using the Colour-Word Interference test from the Delis-Kaplan Executive Function System (D-KEFS; Delis, Kaplan, & Kramer, 2001). The outcome measure was the raw score (latency in s) obtained on condition 3. Working memory was measured using the raw scores obtained on the Letter-Number Sequencing and Backward Digit Span tests of the Wechsler Adult Intelligence Scale-III (WAIS-III; Wechsler, 1997).

Statistical Analyses

We examined demographic characteristics and mean scores on the cognitive variables across age groups (see Table 1 and 2). Outliers on cognitive variables (> 3 standard deviations from the mean of their respective age group) were altered to less extreme values by adding one unit to the highest non-outlying score to maintain rank order of the data (Tabachnick & Fidell, 2007). Group differences were analyzed using independent samples t-tests for continuous variables and chi-square tests for categorical variables.

Measuring Hindsight Bias

Both continuous and categorical methods of quantifying the magnitude of the hindsight bias effect have been used in the literature. While continuous indices have been used in experiments with continuous feedback values, such as Pohl's (1992) Δz index, multinomial processing tree models use a categorical approach (see Erdfelder & Buchner, 1998). Both approaches capture hindsight bias as instances where the recalled estimate deviates from the original estimate in the direction of the correct answer. The degree of the deviation is lost when data are categorized, but the loss of information is small because the deviations are measured in arbitrary units (i.e., Celsius, kilometers, etc.; Erdfelder & Buchner, 1998). We examined hindsight bias using both continuous and categorical approaches; however, we chose a categorical variable in our analyses because the data followed a natural dichotomy. We also ran our mediation and moderation analyses using linear multiple regression analyses and Pohl's continuous hindsight bias index. The results of these analyses were the

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Table 1.   Demographic Variables.

Participant Characteristics	Younger (participants = 64)	Older (participants = 60)	*p*
Age (*M* ± *SD*)	20.05 ± 1.85	72.50 ± 4.87	< .001
Female (*n*; *%*)	47 (73%)	35 (58%)	ns
Ethnicity			
Caucasian (*n*; *%*)	32 (50.0%)	51 (85.0%)	< .001
Asian (*n*; *%*)	18 (28.1%)	3 (5.0%)	< .001
Other (*n*; *%*)	14 (21.9%)	6 (10.0%)	ns
Education (*M* ± *SD*)	13.38 ± 1.24	14.28 ± 2.96	< .05

Table 2.   Performance on Cognitive Measures.

Cognitive Measures	Younger (participants = 64) (*M* ± *SD*)	Older (participants = 60) (*M* ± *SD*)	*p*
CVLT-II – Long-Delay Free Recall (Long-Term Memory)[a]	12.81 ± 2.44	8.63 ± 3.35	< .001
CVLT-II – Short-Delay Retention (Retroactive Interference)[b]	-7.51 ± 14.86	-21.69 ± 22.09	< .001
Colour/Word Interference (Inhibition)[b]	43.98 ± 9.25	64.82 ± 14.16	< .001
WAIS-III Backward Digit Span (Working Memory)[a]	86.90 ± 13.97	6.93 ± 2.26	< .001
WAIS-III Letter-Number Sequencing (Working Memory)[a]	11.73 ± 2.53	9.22 ± 3.09	< .001
Hindsight Bias[b]	0.457 ± .498	0.551 ± .498	< .001

[a] Higher scores reflect better performance. [b] Lower scores reflect better performance.

same as those from the logistic regression analyses presented in this paper (See

Appendix B).

We measured hindsight bias continuously using Pohl's Δ*z* index (see Pohl,

1992). This index measures the absolute difference between two discrepancies,

namely, the distance between the original judgment (OJ) and the correct

judgment (CJ) and the difference between the recalled original judgment (ROJ)

and the correct judgment (CJ). To allow for a sensible comparison of data across

items that have different "natural scales" (e.g., Celsius, kilometers, etc.), the data is standardized by dividing each item by the standard deviation of responses for that item. This allows the magnitude of hindsight bias to be expressed in standard deviation units (Pohl, 2004). According to Pohl (2004), an index value of 0 indicates the absence of hindsight, and any positive value indicates its existence. The according index is formally defined as (Pohl, 1992):

$$\Delta z = |z_{OJ} - z_{CJ}| - |z_{ROJ} - z_{CJ}|$$

Rather than averaging indices across items, we analyzed each of the 27 hindsight bias index scores for each participant. By not aggregating the index scores across items, we increased the number of hindsight bias observations from 124 (one mean index score per participant) to 3267 ((27 hindsight bias observations x 124 participants) – 81 missing data points[3]), maximizing our statistical power. As can be seen in Figure 1, approximately half of the Δz index scores were positive (i.e., hindsight bias), and half were either negative or 0 (i.e., absence of hindsight bias; see Table 3). Based on the natural dichotomy of hindsight bias responses in the sample, we dichotomized the data by coding each item observation (27 per participant) as a 1 if the recalled judgment was closer to the correct judgment than the original judgment (positive Δz index) and 0 if the recalled judgment was equal to the original judgment (Δz index = 0) or was further from the correct judgment than the original judgment (negative Δz

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[3] 62 (1.9%) observations were excluded because one of the hindsight bias items on the second version was not used due to a scaling problem (see p. 10). The remaining 19 (0.006%) observations were excluded because the responses were missing or invalid. A response was considered invalid if it was a range of numbers (i.e., 100-200) or an inexact number (i.e. 1800s) because the discrepancy scores between the original estimate, recalled estimate, and correct judgment could not be calculated.

Figure 1. **Scatterplot of Pohl's (1992) *Δz* index scores across the entire sample.**
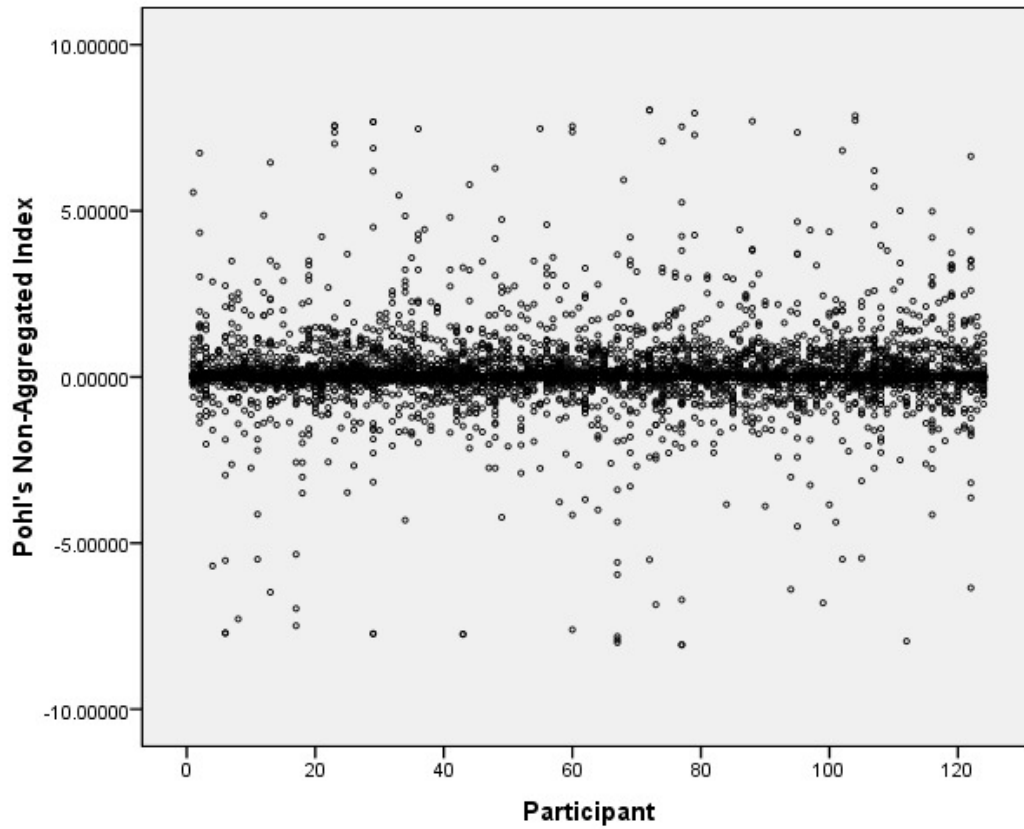
Table 3. **Breakdown of Positive, Negative, and Zero Hindsight Bias Scores Using Pohl's (1992) Δz Index.**

Hindsight Bias (*Δz*)	Entire Sample	Younger Adults	Older Adults
Positive	50.2%	45.6%	55.1%
Zero	26.7%	32.2%	20.9%
Negative	23.0%	22.2%	24.0%

index). Using this method resulted in 3267 observations, of which 49.8% were coded as 0 (23% negative; 26.8% were exactly 0), and 50.2% as 1.

Because the aim of our study was to identify the neuropsychological variables associated with the occurrence hindsight bias, it was sufficient to dichotomize responses into two categories, one representing the presence of hindsight bias and one representing the absence of hindsight bias. For example, differentiation of perfect recollections from other non-hindsight bias observations (i.e., negative indices) was not required for us to determine if memory is associated with the occurrence of hindsight bias. Additionally, we ran a multinomial logistic regression where we distinguished perfect recollections from reverse hindsight bias (i.e., the original estimate is closer to the correct judgment than the recalled estimate; negative index value) and true hindsight bias observations. The effect of the covariates on the probability of showing hindsight bias was the same as when two categories were used. Furthermore, there were no significant effects of the covariates on the probability of showing reverse hindsight bias as opposed to perfect recollections. Thus, distinguishing between the absence and presence of hindsight bias is sufficient to answer our question regarding the association between neuropsychological functioning and hindsight bias.

The data were fully utilized by employing standard panel data analysis techniques. The dependent variable was constructed by stacking participants' responses on the 27 hindsight bias items into a single variable (of length = 3267). Independent variables were constant within observations for each participant, but

varied across participants. To control for response bias, a variable was constructed using the 27 control items. These were coded as 0 and 1 in the same manner as the hindsight bias items, and the proportion of 1's for each participant was included in as a covariate in subsequent analyses[4].

Regression Analyses

Prior to conducting logistic regression analyses, correlations between hindsight bias, cognitive variables, and demographic variables were conducted to determine their inclusion as potential covariates in the model (see Table 4). To reduce the possibility of capitalizing on chance associations, variables that were significantly associated with hindsight bias at $p < .01$ were entered as covariates in the final regression analyses. All of the cognitive variables and age met this criterion. Because we had two highly correlated measures of working memory (Letter-Number Sequencing and Backward Digit Span, $r = .60$, $p < .001$), the data on both variables were converted to z-scores and then summed to create a working memory composite z-score (Edgington, 1995) that was included as a covariate in subsequent analyses.

We used a series of logistic regression analyses to test the following research questions: (1) Do older adults exhibit more hindsight bias compared to younger adults? (2) Do long-term episodic memory, retroactive interference,

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[4] In contrast, Pohl's proximity index directly subtracts the median value of the control responses. Our method is equivalent to moving this control to the right hand side of the equation and multiplying it by an estimated coefficient. It is important to include the control as a covariate because prior work (see Erdfelder & Buchner, 1998) has shown individuals sometimes show a positive response bias on control items (i.e., recalled estimates are closer to the correct answer than original estimates). Thus, a hindsight bias value that is larger than 0 is not sufficient to establish a hindsight bias effect. Rather hindsight bias can only be determined when the hindsight bias value for experimental items exceeds that of the control items.

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Table 4.   Intercorrelations Between Cognitive and Demographic Variables Across All Participants.

Variables	1	2	3	4[a]	5[a]	6	7	8
1. Age	--							
2. Gender	-.16***	--						
3. Education	.20***	.02	--					
4. BDS	-.24***	-.07**	-.15***	--				
5. LNS[a]	-.41***	-.04*	.13***	.60***	--			
6. Long-Term Memory	-.59***	.31***	.04*	.16***	.41***	--		
7. Inhibition	.66***	-.15***	-.05**	-.33***	-.53***	-.60***	--	
8. RA	-.36***	.11***	.13***	.13***	.18***	.60***	-.32***	--
9. Hindsight Bias	.07***	-.02	-.01	-.06**	-.06***	-.10***	.10***	-.05**

Note: BDS = Backward Digit Span; LNS = Letter-Number Sequencing; RA = Retroactive Interference. [a] Measure of working memory. All correlations with the hindsight bias variable are partial correlations controlling for the response bias control variable.
* $p < .05$. **$p < .01$. ***$p < .001$.

Inhibition, and/or working memory significantly predict hindsight bias above and beyond age? (3) Do long-term episodic memory, retroactive interference, inhibition, and/or working memory mediate and/or moderate the relationship between age and hindsight bias. Regression analyses were performed to ensure that the conditions for mediation were met (Baron & Kenny, 1986). To quantify the degree of mediation associated with a given variable we conducted a Sobel's (1982) test. Because some steps in the mediation analysis used logistic regression, and some linear, the coefficients were on different scales. Thus, the standard errors of the coefficients were rescaled to make them comparable (see MacKinnon & Dwyer, 1993). For moderation analyses, continuous predictors were centred to reduce nonessential collinearity (Cohen, Cohen, West, & Aiken, 2003). All analyses were conducted using SPSS 17 software (SPSS Inc. Chicago, Il).

Assumptions of Logistic Regression and Observation-to-Predictor Ratio

Logistic regression has one primary assumption, that the dichotomous outcome variable follows a binomial distribution (Peng, Lee, & Ingersoll, 2002). This implies that the same probability of the outcome occurring is maintained across the range of predictor values. In samples that are random, the binomial assumption may be taken to be robust, and the observations can be considered independent from each other (Peng et al., 2002). Because the present study's sample was random, the binomial assumption appeared to be robust underlying all logistic analyses conducted. To determine whether the degree of mulitcollinearity between predictor variables was problematic Variable Inflation Indices (VIF) and tolerance values were examined. None of the VIF or tolerance statistics indicated a high level of multicollinearity between predictor variables in an equation.

In terms of adequacy of sample size, there are no published guidelines applicable to logistic regression (Peng et al., 2002). However, several authors of multivariate statistics (e.g., Marascuilo & Levin, 1983; Tabachnick & Fidell, 2007) have recommended a minimum ratio of 10 to 1, with a minimum sample size of 100. The logistic regression analyses conducted in the present study had a maximum of six predictor variables and a total of 3267 observations. A sample of this size exceeds the above recommendation ((6 predictors x 10) + 100 = 160 required observations), indicating that the reported results are stable.

Results

Logistic Regression Analysis Assessing Age and Aspects of Cognitive Functioning as Predictors of Hindsight Bias

To address our first two research questions, we conducted a sequential logistic regression analysis (see Table 5). The overall multivariate model was significant (χ^2 (6, N = 3267) = 66.74, $p < .001$). The response bias control was a significant predictor of hindsight bias in Step 1 (odds ratio [OR] = 6.08, d = 1.00, $p < .001$). Specifically, individuals with a positive average response bias on the control items (i.e., recalled estimates were closer to the correct answer than original estimates) had an increased probability of showing hindsight bias on the experimental items. As we expected, age was a significant predictor of hindsight bias in Step 2. Examination of this effect revealed that the odds of an older adult showing hindsight bias were 1.34 times higher than those of a younger adult (d = 0.16). In regards to our second question, we found that inhibition and long-term episodic memory individually significantly predicted hindsight bias even after controlling for age. Specifically, a 10-sec increase in completion time of the colour/word inhibition test increased the odds of showing hindsight bias by 1.08 times (d = 0.04), and a one-word reduction in the number of words recalled on the delayed recall trial of the CVLT-II increased the odds bias by 1.03 times (d = 0.02). The other cognitive variables did not significantly predict hindsight bias, and thus were not considered in subsequent analyses. The addition of the cognitive variables to the model significantly improved its predictive power (χ^2 (4, N = 3267) = 24.11, $p < .001$).

Table 5.   Sequential Logistic Regression: Predictors of Hindsight Bias.

Predictor	β	SE β	Wald's χ^2	df	p	e^β (odds ratio)	95% CI Lower	95% CI Upper
Step 1								
Response Bias Control	1.805	0.352	26.339	1	<.001	6.082	3.052	12.118
Step 2								
Response Bias Control	1.357	0.369	13.528	1	<.001	3.886	1.885	8.010
Age	0.295	0.074	15.955	1	<.001	1.343	1.162	1.553
Step 3								
Response Bias Control	1.153	0.376	9.395	1	.002	3.167	1.515	6.617
Age	-0.031	0.101	0.097	1	.756	0.969	0.795	1.181
Inhibition	0.007	0.003	4.862	1	.027	1.008	1.001	1.014
Long-Term Memory	-0.033	0.015	4.708	1	.030	0.968	0.940	0.997
Retroactive Interference	0.000	0.002	0.099	1	.753	0.999	0.995	1.004
Working Memory	-0.030	0.023	1.769	1	.184	0.970	0.928	1.014

Test	χ^2	df	p
Overall Model Evaluation			
Likelihood Ratio Test	66.740	6	<.001

Although the odds ratios for inhibition and long-term episodic memory were close to 1.0, when the scale of these variables is considered they are still meaningful. For example, the odds ratio reported for inhibition is associated with a 10-sec increase in completion time of the task; however, if the data are split at the mean into a poor inhibition group and a good inhibition group, the difference in average completion times between these groups is 26.81 s. A 26.81 s increase in completion time leads to an increase in the odds ratio of 1.21. Similarly, the odds ratio reported for memory is associated with a one-word decrease in the total words recalled; however, if the data are split at the mean into a poor memory group and a good memory group, the difference in the average number of words recalled between these two groups is 5.76. A 5.76 reduction in the number of words recalled leads to an increase in the odds ratio of 1.21. Thus, individuals with poor inhibition and memory recall are 21% more likely to show hindsight bias than those with good inhibition and memory, indicating that these cognitive variables are meaningful predictors of hindsight bias.

The Mediating Role of Inhibition and Long-Term Episodic Memory in the Age-Hindsight Bias Relationship

To examine the potential mediating roles of inhibition and long-term episodic memory, we conducted sequential logistic regression analyses (see Table 6). For the first analysis examining inhibition as a potential mediator, we found that poorer inhibition significantly predicted hindsight bias even after controlling for age ($OR = 1.01$, $p < .001$). Furthermore, the relationship between age and hindsight bias was reduced after controlling for inhibition, indicating that

Table 6.   Mediation Models with Inhibition/Long-Term Episodic Memory as the Mediating Variable.

Predictor	β	SE β	Wald's χ^2	df	p	e^β (odds ratio)	95% CI Lower	Upper
Step 1								
Response Bias Control	1.805	0.352	26.339	1	<.001	6.082	3.052	12.118
Step 2								
Response Bias Control	1.357	0.369	13.528	1	<.001	3.886	1.885	8.010
Age	0.295	0.074	15.955	1	<.001	1.343	1.162	1.553
Step 3 (Inhibition)								
Response Bias Control	1.301	0.370	12.331	1	<.001	3.672	1.777	7.590
Age	0.058	0.096	0.368	1	.544	1.060	0.878	1.280
Inhibition	0.012	0.003	14.729	1	<.001	1.012	1.006	1.018
Step 3 (Long-Term Memory)								
Response Bias Control	1.225	0.371	10.888	1	.001	3.404	1.644	7.048
Age	0.108	0.089	1.475	1	.225	1.114	0.936	1.325
Long-Term Memory	-0.047	0.012	14.615	1	<.001	0.954	0.931	0.977

mediation was established ($\Delta\beta = .07$, Sobel's $Z = 3.99$, $p < .001$). The potential

mediating effect of long-term episodic memory was examined similarly in a

subsequent model. Poorer memory recall significantly predicted hindsight bias

even after controlling for age ($OR = 0.95$, $p < .001$). Furthermore, the

relationship between age and hindsight bias was reduced after controlling for

long-term episodic memory, indicating that mediation was established ($\Delta\beta = .05$,

Sobel's $Z = 3.90$, $p < .001$). In summary, both inhibition and long-term episodic

memory independently mediated the relationship between age and hindsight bias

(see Figure 2).

The Moderating Role of Inhibition and Long-Term Episodic Memory in the Age-Hindsight Bias Relationship

To examine the potential moderating role of inhibition and long-term

episodic memory, we included the interaction terms of these variables with age

(see Table 7 and 8). For the first analysis examining the interaction between age

and inhibition, the interaction term was a significant predictor of hindsight bias

($OR = 1.01$, $p = .04$). Thus, the effect of inhibition on hindsight bias varied across

younger and older adults, such that inhibition in younger adults had a minimal

effect on hindsight bias, while poorer inhibition in older adults was associated

with an increased probability of hindsight bias (see Figure 3). The interaction

between age and long-term episodic memory was similarly examined in a

subsequent model. Although poorer memory recall remained a significant

predictor of hindsight bias ($OR = 0.96$, $p = .003$), the interaction term was not

significant.

Figure 2. **Model of the relationships among age, cognitive functioning, and hindsight bias.**
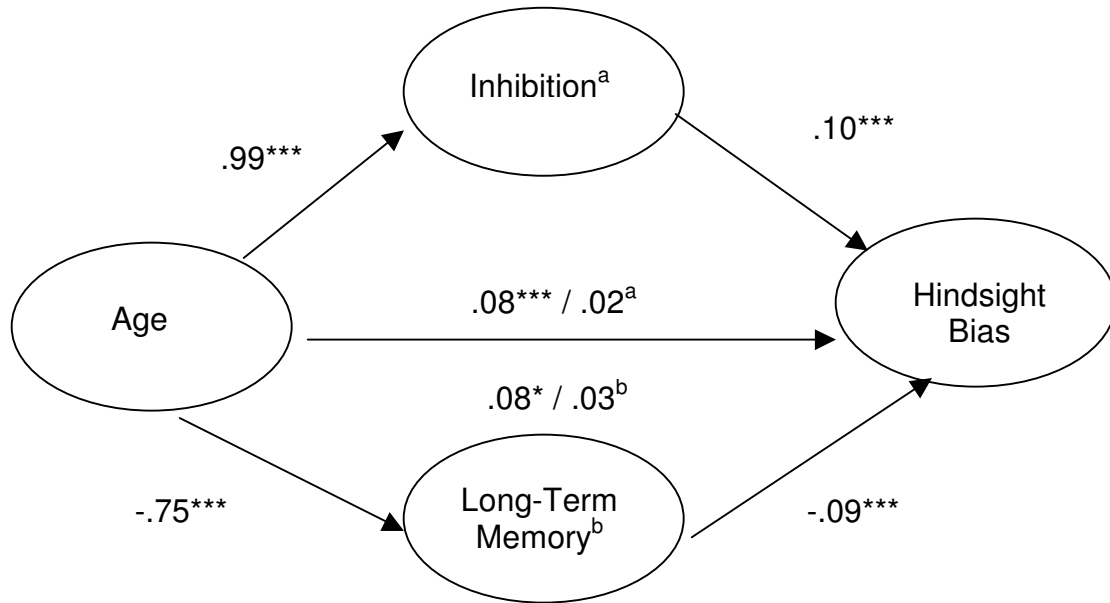
Note: Numbers represent the rescaled beta coefficients. The coefficient after the slash reflects weight after the inclusion of the specified mediator ([a] = inhibition; [b] = long-term memory). *$p < .05$; ** $p < .01$; *** $p < .001$.

Table 7.   Moderation Model with Inhibition as the Moderating Variable.

Predictor	β	SE β	Wald's χ^2	df	p	e^β (odds ratio)	95% CI Lower	95% CI Upper
Step 1								
Response Bias Control	1.805	0.352	26.339	1	<.001	6.082	3.052	12.118
Step 2								
Response Bias Control	1.301	0.370	12.331	1	<.001	3.672	1.777	7.590
Age	0.058	0.096	0.368	1	.544	1.060	0.878	1.280
Inhibition	0.012	0.003	14.729	1	<.001	1.012	1.006	1.018
Step 3								
Response Bias Control	1.179	0.375	9.888	1	.002	3.252	1.559	6.782
Age	0.110	0.100	1.230	1	.267	1.117	0.919	1.357
Inhibition	0.003	0.005	0.223	1	.637	1.003	0.992	1.013
Age*Inhibition	0.014	0.007	4.280	1	.039	1.014	1.001	1.027

Table 8.   Moderation Model with Long-Term Memory as the Moderating Variable.

Predictor	β	SE β	Wald's χ^2	df	p	e^β (odds ratio)	95% CI Lower	Upper
Step 1								
Response Bias Control	1.805	0.352	26.339	1	<.001	6.082	3.052	12.118
Step 2								
Response Bias Control	1.225	0.371	10.888	1	.001	3.404	1.644	7.048
Age	0.108	0.089	1.475	1	.225	1.114	0.936	1.325
Long-Term Memory	-0.047	0.012	14.615	1	<.001	0.954	0.931	0.977
Step 3								
Response Bias Control	1.190	0.372	10.218	1	.001	3.288	1.585	6.820
Age	0.107	0.089	1.445	1	.229	1.112	0.935	1.324
Long-Term Memory	-0.040	0.014	8.531	1	.003	0.961	0.936	0.987
Age*Long-Term Memory	<0.001	0.001	1.686	1	.194	0.999	0.998	1.000

Figure 3.   The moderating effect of age and inhibition on hindsight bias.
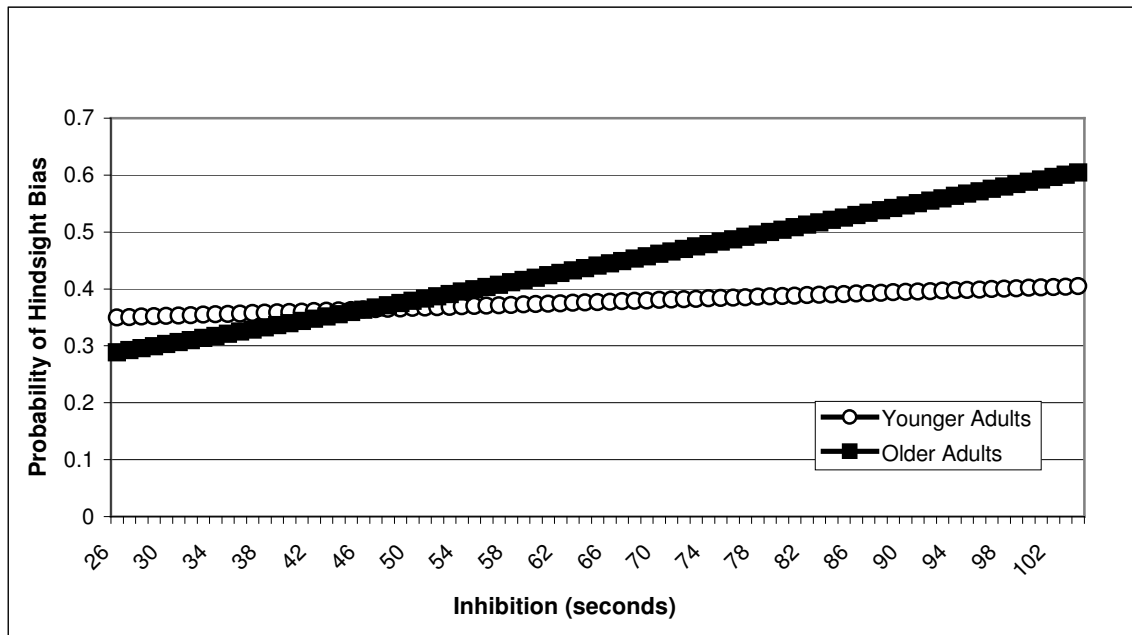
Note: Higher inhibition and hindsight bias scores indicate worse performance.

Discussion

We used a memory design task to investigate age differences in hindsight bias in younger and older adults. The present study had three main aims: (1) to replicate the finding of an increased susceptibility to hindsight bias in older compared to younger adults, (2) to extend this finding by identifying the cognitive abilities associated with hindsight bias, and (3) to determine whether age-related changes in specific aspects of cognitive functioning underlie age differences in hindsight bias. Our findings contribute to the existing hindsight bias and cognitive aging literatures in several ways. We replicated prior work by showing that older adults were more susceptible to hindsight bias than younger adults (Bayen et al., 2006; Bernstein et al., 2011), and extended this work by showing that age-related declines in inhibition and long-term episodic memory underlie these age differences. While poorer long-term episodic memory contributed to hindsight bias in both younger and older adults, poorer inhibition was associated with greater susceptibility to hindsight bias in older adults only.

We found that older adults were 1.34 times more likely to show hindsight bias than younger adults. Thus, our study demonstrated that the association between age and hindsight bias measured in past studies is robust. We also extended this finding by identifying the cognitive mechanisms underlying this relationship. Although past researchers have implicated various aspects of cognitive functioning in hindsight bias, the current study is the first to examine this relationship in adults using standard neuropsychological measures. Our findings revealed that the relationship between age and hindsight bias could be

at least partially accounted for by age-related changes in long-term episodic memory and inhibition. Thus, we have provided experimental evidence for the hypothesis that cognitive functioning is implicated in the age-hindsight bias relationship.

Our finding that inhibition mediated and moderated the age-hindsight bias relationship supports the hypothesis that age differences in hindsight bias can be explained by variation in inhibitory functioning (Hasher & Zacks, 1988). Specifically, we found that older adults' increased susceptibility to hindsight bias was more pronounced among those demonstrating poorer inhibition. In contrast, inhibition was only weakly related to hindsight bias in younger adults, suggesting that the importance of inhibition in hindsight bias varies at different stages in the lifespan. This finding may be due to the lack of variability in inhibition in younger compared to older adults. While the majority of younger adults have overall strong inhibitory processes, inhibition is more variable and generally poorer in older adults. Perhaps there is a threshold effect, such that a specific level of inhibition is required to suppress outcome knowledge. While the majority of younger adults may meet this threshold, a greater proportion of older adults may not. This could be further investigated by studying a sample of adults across a broader age range (i.e., age 40 to 90) that encompasses a wider range of inhibitory functioning.

Our finding that long-term episodic memory mediated the relationship between age and hindsight bias is consistent with cognitive process theories and findings from multinomial processing tree analyses (e.g., Bernstein et al., 2011;

Blank & Nestler, 2007). A potential mechanism may be that age-related memory declines in older adults contribute to greater hindsight bias by making their original estimates inaccessible. Research has demonstrated that when unable to recall previously learned material, older adults are more likely than younger adults to make a biased guess using easily accessible information (see Jacoby, 1999). Thus, older adults are not only required to reconstruct a greater number of their original estimates, but they are also more likely to be biased by the correct answer when making their reconstructions. This explanation supports multinomial processing tree models of hindsight bias, which have shown that older adults' increased hindsight bias is the result of poorer recall of their original predictions (poorer recollection) combined with a tendency to use outcome information to reconstruct their forgotten estimates (increased reconstruction bias; Bernstein et al., 2011).

We did not replicate the finding that working memory is related to hindsight bias (Bayen et al., 2006). We measured working memory using standard neuropsychological tests that assess the ability to retain and manipulate information on-line. In contrast, Bayen and colleagues implicated working memory in hindsight bias by manipulating the memory design task. Specifically, they showed that older adults have greater hindsight bias than younger adults when the correct judgments are presented (i.e., standard memory design task) or accessible in working memory, but not when this information is inaccessible. Because the present study did not manipulate the accessibility of the correct judgments (i.e., correct judgments were available throughout recall), working

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memory was not required to keep this information in mind. Thus, susceptibility to interference effects from the correct judgments was not dependent on participants' working memory. Though older adults may have relied on the available outcome information to reconstruct their original estimates to a greater extent than younger adults, this reconstructive error was not due to differences in the accessibility of the correct judgments.

Limitations, Future Directions, and Implications

Converging evidence suggests that older adults are more susceptible to hindsight bias; however, the age at which susceptibility increases remains unknown because hindsight bias in middle-aged adult has not been investigated. Interestingly, certain aspects of cognitive functioning may improve from young to middle adulthood, followed by a decline in late adulthood (Thornton & Dumke, 2005). Future studies that broaden the age range of the sample to include middle-aged adults are needed to determine whether a similar relationship occurs with hindsight bias. This research would complete the field's understanding of the developmental changes in hindsight bias across adulthood and would have implications for identifying the age at which susceptibility to hindsight bias increases.

Given the present study's correlational approach, we could not determine where in the hindsight bias process long-term episodic memory and inhibition were influential. Rather, we were limited to concluding that individuals with poorer functioning in these areas are more likely to exhibit the hindsight bias effect. An important step in advancing this literature would be to determine at

what stage in the hindsight bias process these abilities are important. For example, one may speculate that long-term episodic memory would be involved in the retrieval of one's original prediction from long-term memory storage, while inhibition would be involved in the suppression of the correct judgment during recall so that an unbiased reconstruction of one's original estimate is made. This research would help us understand how poorer inhibition and long-term episodic memory lead to an increased susceptibility to hindsight bias, and would have important practical implications for developing strategies or interventions to reduce or eliminate the hindsight bias effect.

Finally, given that individuals over the age of 65 comprise an increasing proportion of the world's population, it will be imperative for future work to identify the extent to which hindsight bias and other judgment biases affect everyday decisions encountered in later life. Peters, Hess, Vastfjall, and Auman (2007) further highlight the importance of this research by acknowledging a social trend towards maintaining independence as we age, and being responsible for making decisions for a greater number of years. However, researchers have found evidence of older adults being more susceptible to making errors in real-world decision-making tasks, particularly when faced with complex tasks that involves multiple choice options (e.g., Medicare plans; Wood et al., 2011). In addition, Peters et al. (2007) note that the elderly may be more vulnerable to incurring adverse consequences from poor decisions due to their lack of physical resiliency and time to cope with the associated negative outcomes. Given the large number of complex and risky financial (e.g., investment and retirement),

health (e.g., medical plans), housing (e.g., assistant living options), and safety (e.g., con artists and scams; Hanoch, Wood, & Rice, 2007) decisions encountered in later life, it is imperative to (1) determine the extent to which hindsight bias affects real-word life decisions, (2) further understand the mechanisms underlying hindsight bias so that we can intervene in the process or at least predict situations in which older adults may be prone to hindsight bias, and (3) propose strategies or resources (i.e., financial or medical advisors or aids) to minimize hindsight bias and ensure sound, unbiased decisions are made.

Along these lines, a study by Renner (2003) directly implicated hindsight bias in self-relevant health risk assessments. In this study, participants (M_{age} = 42 years) estimated their expected cholesterol levels, received a cholesterol-screening test, and then recalled their original estimate immediately after receiving their test results and again several weeks later. Participants with unexpected negative cholesterol results showed hindsight bias (i.e., recalled estimate was closer to their actual cholesterol reading) immediately after feedback was given, but not several weeks later. Renner proposed that while hindsight bias may help people regain a sense of control and predictability over their health (e.g., they "knew all along" their cholesterol would be high because of a recent weight gain), it could interfere with adaptive health behaviours. Because cholesterol and other health problems are more prevalent in the elderly, further investigation of the impact of hindsight bias in these situations is vital.

In summary, the present study confirmed age differences in hindsight bias, and extended this finding by identifying the associated cognitive abilities, and the

mediating and moderating role of these factors in the age-hindsight bias relationship. Our findings suggest that older adults with poor memory and inhibitory processes will be more susceptible to hindsight bias. However, there are likely many other factors that underlie age differences in hindsight bias (e.g., source monitoring, perceived plausibility, and notions of surprise; Birch & Bernstein, 2007; affective information processing; Peters et al., 2007), and these warrant further investigation. This study provides a strong foundation for a more detailed investigation of the developmental changes in hindsight bias across adulthood and the mechanisms underlying these changes. Our findings also motivate future studies to investigate how poorer inhibition and long-term episodic memory lead to increased hindsight bias, and the functional implications of hindsight bias in the elderly. A better understanding of hindsight bias in the elderly would ultimately allow us to design cognitive strategies and environments to improve real world decision-making.

Appendices

Appendix A: Memory Design Task

Original Judgment (OJ) Questionnaire

Below are some questions about science, nature, and other general topics. I would like you to answer each question to the best of your knowledge, giving your best estimate if necessary. Where necessary, the units in which your responses are required are presented below each question.

1. At what temperature does copper melt?

_____Celsius

2. How high is the Statue of Liberty including its base?

_____meters

3. What year did the mutiny on the Bounty occur?

_____

4. What is the distance between New York and Los Angeles (by road)?

_____kilometers

5. In what year was the monkey wrench invented?

_____

6. In what year was the harmonica invented?

_____

7. How long is the Rhine River?

_____ kilometers

8. What year did the Hundred Years' War begin?

_____

9. What year was the lightning rod invented?

_____

10. How long is the Great Wall of China?

_____kilometers

11. What year were X-rays discovered?

_____

12. At what speed must wind blow to be classified as a Moderate Gale Force?

_____kilometers per hour

13. What is the average depth of the Pacific Ocean?

_____meters

14. At what temperature does tin melt?

_____Celsius

15. On average, how many days is a female elephant pregnancy?

_____days

16. How long is the Amazon River?

_____ kilometers

17. How long is the Mississippi River?

_____kilometers

18. What year did William Herschel discover the planet Uranus?

_____

19. In what year was Jane Austin's "Pride and Prejudice" first published?

_____

20. What is the average temperature of the Antarctic winter?

_____ Celsius

21. What is the highest temperature ever measured on Earth?

_____Celsius

22. What percentage of the world's population was under the age of five in 1995?

_____%

23. What year was Leonardo da Vinci born?

_____

24. How long is the world's longest bridge?

_____kilometers

25. What year did Sir James Dewar, an English chemist, invent the thermos

flask?

_____

26. When was the first reflecting telescope developed?

_____

27. How many carats is the world's largest reported diamond?

_____carats

28. What is the official land speed record for a land vehicle?

_____kilometers per hour

29. How many days does the planet Mercury take to make one trip around the

sun?

_____days

30. How long is an international nautical mile?

_____ meters

31. What percentage of the world's population lived in Africa in 1994?

_____%

32. How many plays did William Shakespeare write?

_____plays

33. When travelling 97 kilometers per hour in a car, how much room should you

allow yourself to brake?

_____meters

34. What is the distance between Tokyo and Chicago (by air)?

_____kilometers

35. What year was the parking meter invented?

_____

36. What year was radiotelegraphy invented?

_____

37. What year did Leonardo da Vinci create "Mona Lisa"?

_____

38. In what year was Harvard University founded?

_____

39. What year did the Franz Joseph I, the emperor of Austria, die?

_____

40. What year did Albert Einstein formulate the theory of relativity?

_____

41. What is the diameter of the planet Mars?

_____kilometers

42. How high is the highest point on Mount Kilimanjaro?

_____meters

43. What year were the first modern-day Olympic games celebrated?

_____

44. What percentage of the world's population lived in Europe in 1994?

_____%

45. How many muscles does the human body have?

_____muscles

46. What percentage of the human body is composed of nitrogen?

_____%

47. What year was the first mailbox invented?

_____

48. When was slavery officially abolished in the United States?

_____

49. How many films did Alfred Hitchcock direct?

_____films

50. In what year was William Shakespeare's "The Tragedy of King Lear" first published?

_____

51. In what year was Socrates born?

_____

52. In what year was Daniel Defoe's "Robinson Crusoe" first published?

_____

53. What year was the mechanical loom invented?

_____

54. How many detective books did Agatha Christie write?

_____books

Recall of the Original Judgment (ROJ) Questionnaire[5]

These are the same questions that you completed at the very start of the study today. We are interested in how well people remember their own answers to earlier questions. **Please try to answer the questions with the same answers you gave the first time you answered them.** Some of the questions have the correct answer below them, but we are interested in how well you remember 'your' answers. Thus, the best answers on this questionnaire are those that are exactly the same as (or very close to) the answers you gave earlier regardless of what the correct answer is.

---

1. At what temperature does copper melt?

Copper melts at 2415 degrees Celsius.

What was your original answer?

_____Celsius

2. How high is the Statue of Liberty including its base?

The Statue of Liberty is 93 meters high.

What was your original answer?

_____meters

3. What year did the mutiny on the Bounty occur?

The mutiny on the Bounty occurred in 1790.

What was your original answer?

_____

4. What is the distance between New York and Los Angeles (by road)?

The distance between New York and Los Angeles (by road) is 4546 kilometers.

What was your original answer?

_____kilometers

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[5] A second version of the recall of the original judgment questionnaire, in which the correct answers were presented for the second half of the questions only, were given to half of the participants.

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5. In what year was the monkey wrench invented?

The monkey wrench was invented in 1841.

What was your original answer?

_____

6. In what year was the harmonica invented?

The harmonica was invented in 1821.

What was your original answer?

_____

7. How long is the Rhine River?

The Rhine River is 1320 kilometers.

What was your original answer?

_____ kilometers

8. What year did the Hundred Years' War begin?

The Hundred Years' War began in 1339.

What was your original answer?

_____

9. What year was the lightning rod invented?

The lightning rod was invented in 1752.

What was your original answer?

_____

10. How long is the Great Wall of China?

The Great Wall of China is 3460 kilometers long.

What was your original answer?

_____kilometers

11. What year were X-rays discovered?

X-rays were discovered in 1895.

What was your original answer?

_____

12. At what speed must wind blow to be classified as a Moderate Gale Force?

Wind must blow 51 kilometers per hour to be classified as a Moderate Gale

Force

What was your original answer?

_____kilometers per hour

13. What is the average depth of the Pacific Ocean?

The average depth of the Pacific Ocean is 3940 meters.

What was your original answer?

_____meters

14. At what temperature does tin melt?

Tin melts at 2930 degrees Celsius.

What was your original answer?

_____Celsius

15. On average, how many days is a female elephant pregnancy?

On average a female elephant's pregnancy is 631 days.

What was your original answer?

_____days

16. How long is the Amazon River?

The Amazon River is 6556 kilometers long.

What was your original answer?

_____ kilometers

17. How long is the Mississippi River?

The Mississippi River is 3779 kilometers long.

What was your original answer?

_____kilometers

18. What year did William Herschel discover the planet Uranus?

William Herschel discovered the planet Uranus in 1781.

What was your original answer?

_____

19. In what year was Jane Austin's "Pride and Prejudice" first published?

Jane Austin's "Pride and Prejudice" was first published in 1813.

What was your original answer?

_____

20. What is the average temperature of the Antarctic winter?

The average temperature of the Antarctic winter is -68 degrees Celsius.

What was your original answer?

_____ Celsius

21. What is the highest temperature ever measured on Earth?

The highest temperature ever measured on Earth is 57 degrees Celsius.

What was your original answer?

_____Celsius

22. What percentage of the world's population was under the age of five in 1995?

7.7% of the world's population was under the age of five in 1995.

What was your original answer?

_____%

23. What year was Leonardo da Vinci born?

Leonardo da Vinci was born in 1452.

What was your original answer?

_____

24. How long is the world's longest bridge?

The world's longest bridge is 38.42 kilometers long

What was your original answer?

_____kilometers

25. What year did Sir James Dewar, an English chemist, invent the thermos flask?

The thermos flask was invented by Sir James Dewar in 1873.

What was your original answer?

_____

26. When was the first reflecting telescope developed?

The first reflecting telescope was built in 1671.

What was your original answer?

_____

27. How many carats is the world's largest reported diamond?

The world's largest reported diamond is 3106 carats.

What was your original answer?

_____carats

28. What is the official land speed record for a land vehicle?

What was your original answer?

_____kilometers per hour

29. How many days does the planet Mercury take to make one trip around the sun?

What was your original answer?

_____days

30. How long is an international nautical mile?

What was your original answer?

_____ meters

31. What percentage of the world's population lived in Africa in 1994?

What was your original answer?

_____%

32. How many plays did William Shakespeare write?

What was your original answer?

_____plays

33. When travelling 97 kilometers per hour in a car, how much room should you

allow yourself to brake?

What was your original answer?

_____meters

34. What is the distance between Tokyo and Chicago (by air)?

What was your original answer?

_____kilometers

35. What year was the parking meter invented?

What was your original answer?

_____

36. What year was radiotelegraphy invented?

What was your original answer?

_____

37. What year did Leonardo da Vinci create "Mona Lisa"?

What was your original answer?

_____

38. In what year was Harvard University founded?

What was your original answer?

_____

39. What year did the Franz Joseph I, the emperor of Austria, die?

What was your original answer?

_____

40. What year did Albert Einstein formulate the theory of relativity?

What was your original answer?

_____

41. What is the diameter of the planet Mars?

What was your original answer?

_____kilometers

42. How high is the highest point on Mount Kilimanjaro?

What was your original answer?

_____meters

43. What year were the first modern-day Olympic games celebrated?

What was your original answer?

_____

44. What percentage of the world's population lived in Europe in 1994?

What was your original answer?

_____%

45. How many muscles does the human body have?

What was your original answer?

_____muscles

46. What percentage of the human body is composed of nitrogen?

What was your original answer?

_____%

47. What year was the first mailbox invented?

What was your original answer?

_____

48. When was slavery officially abolished in the United States?

What was your original answer?

_____

49. How many films did Alfred Hitchcock direct?

What was your original answer?

_____films

50. In what year was William Shakespeare's "The Tragedy of King Lear" first

published?

What was your original answer?

_____

51. In what year was Socrates born?

What was your original answer?

_____

52. In what year was Daniel Defoe's "Robinson Crusoe" first published?

What was your original answer?

_____

53. What year was the mechanical loom invented?

What was your original answer?

_____

54. How many detective books did Agatha Christie write?

What was your original answer?

_____books

Appendix B: Linear Regression Analyses Using Pohl's Continuous Hindsight Bias Index

Correlational Analyses

Prior to the main multiple linear regression analyses, bivariate correlations between hindsight bias, cognitive variables, and demographic variables of interest were conducted (see Table A1). Increasing age was associated with poorer performance on all of the cognitive variables, including hindsight bias, thus, this variable was included in further analyses. Poorer performances on all of the cognitive variables were associated with greater hindsight bias. To reduce the possibility of capitalizing on chance associations, the cognitive variables that were examined in further analyses were those that explained at least 10% of the variance in hindsight bias. Two cognitive measures met this criterion: long-term episodic memory ($r^2 = .35$) and colour/word interference (inhibition; $r^2 = .44$).

Hierarchical Multiple Regression Analysis Assessing Age, Long-Term Episodic Memory, Inhibition, and Hindsight Bias

To address our first two research questions, a hierarchal multiple regression analysis was performed (see Table A2). As we expected, age was a significant predictor of hindsight bias in Step 1 ($p = .01$). Examination of this effect revealed that increased age was associated with greater hindsight bias. Specifically, being old, as opposed to young, was associated with a statistically significant 0.019 increase in the hindsight bias index (Sample $M = .022$, $SD = .043$, $Range = -.023$ to .25). In regards to our second question, the addition of inhibition and long-term episodic memory significantly increased the explained

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Table A1.   Intercorrelations Between Cognitive and Demographic Variables Across All Participants.

Variables	1	2	3	4^a	5^a	6	7	8
1. Age	—							
2. Gender	-.16***	—						
3. Education	.20***	.02	—					
4. Backward Digit Span^a	-.24***	-.07**	-.15***	—				
5. Letter-Number Sequencing^a	-.41***	-.04*	.13***	.60***	—			
6. Long-Term Memory	-.59***	.31***	.04*	.16***	.41***	—		
7. Inhibition	.66***	-.15***	-.05**	-.33***	-.53***	-.60***	—	
8. Retroactive Interference	-.36***	.11***	.13***	.13***	.18***	.60***	-.32***	—
9. Hindsight Bias	.22*	-.04	-.10	-.12	-.15	-.32***	.34***	-.22*

^{a} Measure of working memory; *$p < .05$. **$p < .01$. ***$p < .001$

Table A2.   Hierarchical Multiple Regression Examining Age and Cognitive Functioning as Predictors of Hindsight Bias.

	Hindsight Bias							
	Step 1				Step 2			
Predictor	B	SE	β	t	B	SE	β	T
Age	.019	.008	.224	.541*	-.006	.010	-.067	-.561
Long-Term Memory					-.003	-.001	-.205	-1.847
Inhibition					<.001	<.001	-.258	2.151*
F-value	6.455*				6.353***			
ΔF					6.035**			
R^2	.050*				.137**			
ΔR^2					.087**			

Note. F-values represent the ANOVA for the full model. ΔF indicates the contribution of the second step (i.e., the variables added in Step 2); *$p < .05$. **$p < .01$. ***$p < .001$.

variance in hindsight bias ($p = .003$) After controlling for age, inhibition was a significant predictor of hindsight bias ($p = .03$). Specifically, a 10-sec increase in completion time of the inhibition test was associated with a statistically significant 0.0071 increase in the hindsight bias index. Poorer memory recall was a marginally significant predictor of greater hindsight bias ($p = .07$). The full model accounted for 14% of the variance in hindsight bias.

The Mediating and Moderating Role of Long-Term Episodic Memory and Inhibition in the Age-Hindsight Bias Relationship

For the first analysis examining inhibition as a potential mediator, we found that poorer inhibition significantly predicted increased hindsight bias even after controlling for age ($\Delta R^2 = .06$, $F(1, 121) = 8.49$, $p = .004$). Furthermore, the relationship between age and hindsight bias was reduced after controlling for inhibition ($\Delta \beta = .24$, Sobel's $Z = 2.84$, $p = .005$), indicating that mediation was established. The potential mediating effect of long-term episodic memory was examined similarly in a subsequent model. Poorer long-term episodic memory significantly predicted increased hindsight bias even after controlling for age ($\Delta R^2 = .05$, $F(1, 121) = 7.23$, $p = .008$). Furthermore, the relationship between age and hindsight bias was reduced after controlling for long-term episodic memory ($\Delta \beta = .18$, Sobel's $Z = 2.81$, $p = .005$). The above analyses revealed that both inhibition and long-term episodic memory independently mediated the relationship between age and hindsight bias (see Figure A1).

Next, we considered the possibility that inhibition and long-term episodic memory were moderators of the relationship between age and hindsight bias. The first moderation model examined the predictive utility of age (Step 1), inhibition (Step 2) and their interaction (Step 3) in accounting for hindsight bias performance. The interaction between age and inhibition was a significant predictor of hindsight bias ($t(120) = 2.29$, $p = .02$). Thus, the effect of inhibition on hindsight bias varied across younger and older adults, such that inhibition in younger adults had a minimal effect on hindsight bias, while poorer inhibition in

Figure A1. **Model of the relationships among age, cognitive functioning, and hindsight bias.**
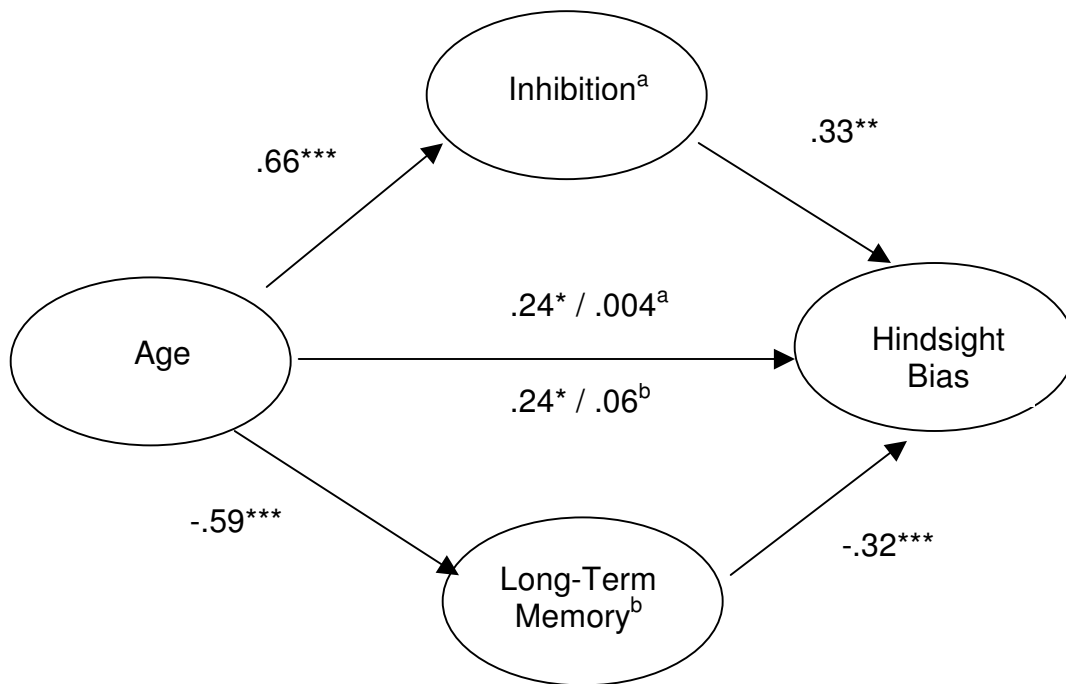
Note: Numbers represent the standardized beta coefficients. The standardized coefficient after the slash reflects weight after the inclusion of the specified mediator. [a] = inhibition; [b] = long-term memory; *$p < .05$; ** $p < .01$; *** $p < .001$.

older adults was associated with an increased probability of hindsight bias (see

Figure A2). The second moderation model examined the predictive utility of age

(Step 1), long-term episodic memory (Step 2), and their interaction (Step 3) in

accounting for hindsight bias. Although long-term episodic memory remained a

significant predictor of hindsight bias (t (120) = -2.22, p = .03), the interaction

term was not significant.

Figure A2.   Scatterplot illustrating the interaction effects of age and inhibition on hindsight bias.
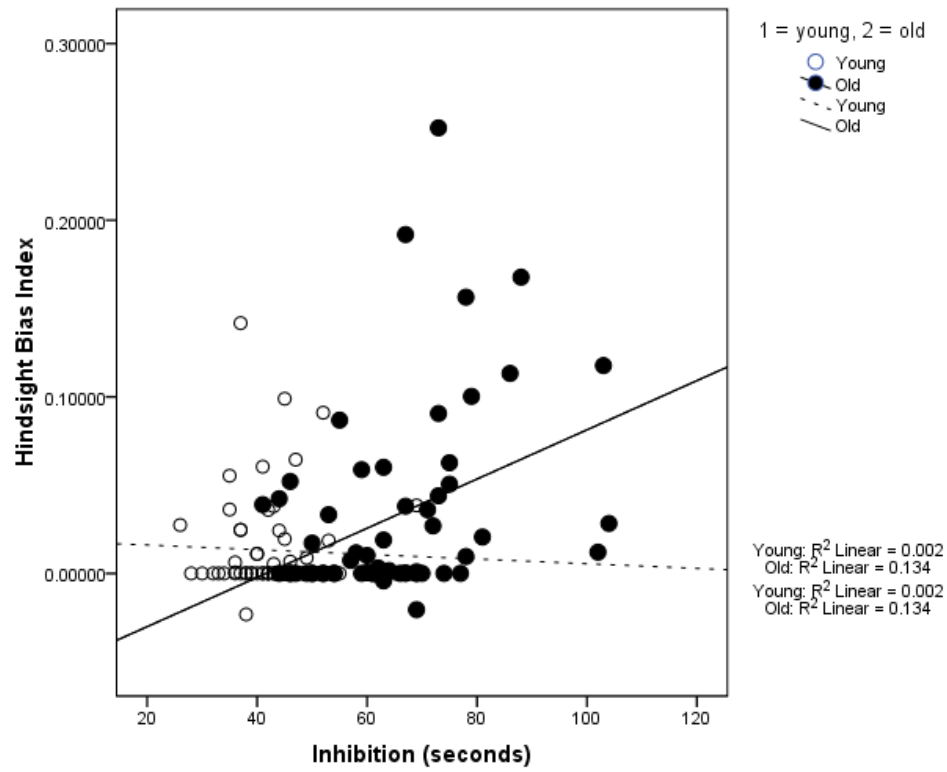
Note: Higher inhibitory control and hindsight bias indicates worse performance.

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