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Semantic fluency is associated with reduced temporal discounting☆

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A R T I C L E I N F O

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A B S T R A C T

People vary in their *temporal discounting,* the tendency to prefer smaller, sooner rewards over larger, later rewards. Higher temporal discounting (i.e., more impatience) is associated with detrimental behaviors, such as substance abuse and physical inactivity. Therefore, understanding the cognitive capacities underlying individual differences in temporal discounting is important. Previous research has suggested that episodic memory supports future-oriented decision making by facilitating prospection, but an association between episodic memory abilities and temporal discounting has not yet been established in a cognitively normal population. One potential reason for this lack of an association is that *semantic* memory, not episodic memory, underlies reduced temporal discounting. After all, semantic memory provides the conceptual "scaffolding" for imagining the future. Here we tested the hypothesis that semantic memory is negatively associated with temporal discounting in an online study of 203 adults. We assessed semantic memory function in two ways: a semantic fluency task and a Deese-Roediger-McDermott (DRM) false memory recognition task. The semantic fluency task measures voluntary semantic memory retrieval, while the false memory paradigm assesses the extent to which semantic information biases episodic retrieval. We found that better semantic fluency was associated with reduced temporal discounting, even after controlling for letter fluency, age, gender, education, and socioeconomic status. However, false memory rate was not a significant predictor of temporal discounting. These findings provide novel evidence that semantic memory retrieval abilities may support future-oriented decisions.

People often have to make decisions that involve tradeoffs between smaller, sooner rewards and larger, later rewards. These decisions range from the mundane (e.g., whether to pay more for shipping to receive items sooner) to the consequential (e.g., whether to pay a penalty to withdraw funds from a retirement account early). In these intertemporal choices, people tend to display temporal discounting. That is, they devalue potential rewards as the delay to receiving them increases. People vary substantially in the extent to which they devalue delayed rewards (Keidel et al., 2021; Peters & Büchel, 2011), however, and people with better cognitive function show less temporal discounting (Keidel et al., 2021), or a stronger preference for larger, later rewards over smaller, sooner ones. The precise cognitive capacities that facilitate future-oriented choice are still unknown, though. Recent research has pointed to a link between better declarative memory and reduced temporal discounting (Bulley & Schacter, 2023; Lempert, MacNear, et al., 2020; Lempert, Mechanic-Hamilton, et al., 2020), but this work has focused primarily on episodic memory. Here we tested the novel hypothesis that better semantic memory ability is associated with lower temporal discounting.

Temporal discounting is typically measured by having participants make a series of choices between smaller, sooner monetary rewards (e.g., "$10 today") and larger, later monetary rewards (e.g., "$25 in 14 days"). From these choices, a discount rate can be derived. Higher discount rates reflect a tendency to choose immediate rewards at one's long-term expense, whereas lower discount rates reflect more patience. Discount rates measured in the laboratory are associated with many real-world behaviors that have delayed consequences (Bartels et al., 2023; Bradford et al., 2017; Chabris et al., 2008). For example, people with higher discount rates are more likely to smoke (Bickel et al., 1999), use alcohol (Bradford et al., 2017; Vuchinich & Simpson, 1998), buy unhealthy foods (Appelhans et al., 2019), gamble (Dixon et al., 2006), have credit card debt (Meier & Sprenger, 2012), and exercise less (Bradford et al., 2017). Temporal discounting is also reliably higher in some forms of psychopathology, such as substance use disorder (Amlung et al., 2017, 2019; MacKillop et al., 2011). Understanding the cognitive processes underlying individual differences in temporal discounting will

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not only help elucidate the mechanisms by which intertemporal choices are made; this knowledge can also help us develop interventions for reducing discounting.

The notion that long-term, declarative memory plays a key role in temporal discounting is inspired by research showing that the neural mechanisms of thinking about the future overlap with the neural mechanisms of episodic memory retrieval (Bulley & Schacter, 2023; Schacter et al., 2007). Moreover, people who are better able to recollect the past in detail (i.e., those who have better episodic memory retrieval ability) have also been shown to imagine the future in more detail (Addis et al., 2011; Hassabis et al., 2007). Imagining future outcomes more vividly can enhance the value of those outcomes, perhaps by making them seem more proximal and concrete (Rick & Loewenstein, 2008; Trope & Liberman, 2010). Indeed, just having people engage in episodic future thinking before they make intertemporal choices has been shown to reduce temporal discounting (Benoit et al., 2011; Peters & Büchel, 2010). This effect has been replicated many times (Rösch et al., 2022), and other manipulations of temporal discounting have generally been less successful (Lempert & Phelps, 2016; Rung & Madden, 2018).

If imagining the future can attenuate temporal discounting, and if people with better episodic memory are better at imagining the future, then perhaps individual differences in temporal discounting are driven by individual differences in episodic memory. There is not much evidence for an association between episodic memory and temporal discounting, though. Two studies showed no relationship between episodic memory and temporal discounting in cognitively normal older adults (Boyle et al., 2012; Seinstra et al., 2015). Another study found that standard neuropsychological measures of delayed episodic recall were associated with temporal discounting in older adults, but this relationship was driven by the subset of participants who were diagnosed with mild cognitive impairment (Lempert, Mechanic-Hamilton, et al., 2020). Two studies using Human Connectome Project data (>1000 adult participants) did not find significant correlations between episodic memory scores and temporal discounting (Garzón et al., 2023; Yeh et al., 2021). Finally, although people with amnesia due to hippocampal damage show severe episodic memory deficits (Rosenbaum et al., 2005), their discount rates are no different from those of healthy controls (Craver et al., 2014; Kwan et al., 2012). It is difficult to argue that episodic memory is critical for choosing delayed rewards, when people who cannot form new episodic memories are still capable of choosing delayed rewards.

One explanation for these null results is that *semantic* memory, which remains unimpaired in people with damage restricted to the hippocampus, is sufficient for considering the future in decision making. Semantic memory is not entirely distinct from episodic memory; episodic memories become "semanticized" over time (Renoult et al., 2019; Sekeres et al., 2018). Semantic memories can be distinguished from episodic memories, though, because they are not confined to a single time and place (Tulving, 1987). Rather, semantic memory comprises categories, concepts, and schemas that are learned over time. Schemas stored in semantic memory provide the scaffolding for episodic future thinking (Irish et al., 2012), since imagined future events, no matter how vividly they can be conjured, lack specific time and place details by definition. Therefore, if someone is able to draw on semantic knowledge – that is, knowledge of how things *usually are* – then they may be able to make decisions in their long-term best interest, even if they cannot envision future events in detail.

The strongest evidence for the idea that future-oriented choice depends on semantic memory comes from the neuroscience literature. The brain region that is most crucial for semantic memory is the anterior temporal lobe (Lambon Ralph et al., 2012). The anterior temporal lobe is also the region where cortical thickness is most robustly and uniquely associated with temporal discounting (Garzón et al., 2023): people with more intact anterior temporal lobes have lower discount rates. Furthermore, people who are known to have extensive damage to the anterior temporal lobe, such as those with semantic variant primary progressive aphasia (svPPA), do show steep discounting, both compared to healthy controls and to people with other neurodegenerative diseases (Beagle et al., 2020; Chiong et al., 2016). The defining feature of svPPA is a loss of semantic knowledge, but patients with this disorder also have a severe deficit in prospection (Irish et al., 2012; Irish & Piolino, 2016), because they lack the schemas needed to imagine events that haven't occurred yet. Therefore, it is possible that what enables future-oriented decision making is conceptual information that is stored in semantic memory.

To our knowledge, no study has directly examined semantic memory and temporal discounting in the same set of participants in order to see if they are associated. We used two measures to assess different aspects of semantic memory: semantic fluency and the Deese-Roediger-McDermott (DRM) false memory paradigm. Semantic fluency is a semantic memory retrieval task that is known to engage the anterior temporal lobe (Baldo et al., 2006; Poch et al., 2021). In the semantic fluency task (Morris et al., 1989), participants name as many exemplars as they can from a category that is provided to them (e.g., animals) in a short amount of time. The number of unique exemplars named in that time is a measure of semantic retrieval ability. Of course, semantic fluency is also shaped by other cognitive processes, such as inhibition, working memory, verbal ability, and processing speed (Unsworth et al., 2011), so finding a relationship between semantic fluency and temporal discounting does not provide conclusive evidence that semantic retrieval underlies future-oriented choice. For that reason, we also included a measure of letter fluency as a control task. In letter fluency, participants name as many words beginning with a certain letter (e.g., "L") as they can. Letter fluency and semantic fluency are highly correlated with each other, and they both rely on executive functions (Unsworth et al., 2011), but only semantic fluency *requires* that participants retrieve meanings of words, since letter fluency can be performed using phonological cues alone. Moreover, semantic fluency requires the temporal lobe, while letter fluency does not (Baldo et al., 2010; Gourovitch et al., 2000; Henry & Crawford, 2004), and semantic memory retrieval is associated with semantic fluency performance, but not letter fluency performance (Stolwyk et al., 2015). Therefore, we hypothesized that better semantic fluency would be associated with lower temporal discounting, even after controlling for letter fluency.

Semantic fluency is a measure of *voluntary* semantic retrieval; we sought convergent evidence for the relationship between semantic memory and temporal discounting by also examining a measure of involuntary semantic retrieval: the DRM false memory paradigm. In the DRM false memory paradigm (Roediger & McDermott, 1995), participants are first asked to encode a list of words that are drawn from a small number of categories. Later, they are asked whether they recognize: (1) previously seen words, (2) words that were strong semantic associates of the previously seen words, but were not seen at encoding (critical words), and (3) new words that were unrelated to the encoded words (distractor words). In this task, people often falsely remember seeing new words that are strong semantic associates of previously seen words (Gallo, 2010; Pardilla-Delgado & Payne, 2017). This modulation of episodic memory by semantic knowledge depends on the anterior temporal lobe (Gallate et al., 2009), and people with better semantic memory abilities tend to show more false memories for critical lures (Gatti et al., 2024). Thus, our second measure of semantic memory was the critical word false alarm rate in the DRM task. If we were to find that both semantic fluency and the critical word false alarm rate are associated with temporal discounting, then that would suggest that the association between semantic memory and temporal discounting generalizes across tasks, and does not depend on semantic retrieval being voluntary. Since episodic memory ability can also influence the critical word false alarm rate, here we calculated and controlled for d' in our analysis. We also controlled for the criterion, a response bias toward endorsing words as familiar. We hypothesized that a higher critical word false alarm rate would be associated with lower temporal discounting, even after controlling for d' and criterion.

Just as we included control measures for semantic fluency and false memory rate in our study, we also included a control decision-making task, to ensure that any relationships that we found were specific to intertemporal preferences. Therefore, we also assessed risk tolerance, by having participants make a series of choices between smaller, certain and larger, probabilistic rewards (Levy et al., 2010). Risk tolerance reflects the extent to which people devalue rewards that are uncertain, rather than delayed. Since we expect that semantic memory is involved specifically in considering delayed outcomes, we did not expect to see any significant relationships between our semantic memory measures and risk tolerance.

In sum, here we examined semantic memory and decision making in an online community sample. We hypothesized that better semantic memory would be associated with reduced temporal discounting.

Method

Participants

Participants were recruited online via Prolific. A recent *meta*-analysis of individual differences research found that a typical correlation effect size in this literature is about $r = 0.2$ (Gignac & Szodorai, 2016). To achieve 80% power to detect a correlation of that size (at $\alpha = 0.05$), 191 participants are required. To account for exclusions, we adhered to a data collection stopping rule of 230 participants. To be included, participants had to be at least eighteen years of age, fluent in English, and currently residing in the United States. They were also required to complete the survey on either their laptops or desktop computers (no mobile devices). No other inclusion criteria were used. The survey should have taken approximately 30 min to complete, so participants were excluded if they took less than 15 min ($n = 1$) or more than 50 min ($n = 20$) to complete it. We excluded participants at these extremes because we wanted to make sure that the delay time between encoding and retrieval was similar for all participants. Participants were also excluded if they failed at least two of four attention check questions in the decision-making tasks ($n = 2$ additional participants) or if they did not follow instructions in the fluency tasks ($n = 3$). Two of those three participants attempted to write down words from the encoding list instead of listing exemplars from categories; the remaining participant provided a numbered list of more exemplars than it would be possible to type in just one minute (50, 50, 100, and 98 in each of the four categories). We decided that this participant must have copy and pasted this word list from another source (e.g., artificial intelligence). Finally, one participant was excluded for admitting that they wrote down the words from the encoding list to study them.

Therefore, a total of 203 participants were included in the study (114 F, 84 M, 3 non-binary, 2 not reported; mean age = 37.2; SD = 12.4; range: 19–76; 134 White Non-Hispanic, 15 White Hispanic, 9 Asian Non-Hispanic, 1 Asian Hispanic, 28 Black Non-Hispanic, 2 Black Hispanic, 1 American Indian or Alaska Native Hispanic, 4 Other/Mixed Race Hispanic, 2 Other/Mixed race non-Hispanic, and 7 Not Reported). Participants were paid \$5 for completing the study (~\$10.46 / hour). In addition, one participant per data collection day (five participants total) received a bonus based on their choices in the decision-making tasks (see below for details). All participants gave informed consent, and approval was obtained from Adelphi University's Institutional Review Board (protocol #060323). The research was conducted in accordance with the Declaration of Helsinki.

Procedure

Participants performed a series of tasks and surveys in the following order: Deese-Roediger-McDermott (DRM) encoding task, temporal discounting task, risk tolerance task, semantic fluency, letter fluency, demographic and survey measures, and, finally, a DRM recognition memory task (Fig. 1). The average time it took to complete the study was 28.68 min (SD = 8.03 min). The study was presented in Qualtrics (Provo, UT).

DRM encoding task

Participants viewed a list of 54 words for three seconds each. They were told ahead of time that they would be tested for their memory of those words later in the study. These words were drawn from the DRM lists (Roediger & McDermott, 1995). There were nine words drawn from six semantic categories (i.e., masculine traits, sleep, sweets, emotions, insects, and colors; see Supplementary Tables 1 and 2 for full word lists). After three seconds passed, the next word appeared automatically. The encoding task was split into three blocks of eighteen words each, so that participants could have a thirty second break between blocks.

Temporal discounting task

Next, participants completed two decision-making tasks. Before the tasks began, participants were given the following instructions: "Later today, we will be holding a lottery, which will randomly select one participant out of every 50 participants and award them with one of the options they have chosen in one of the two tasks. Each choice has an equal chance of being selected, so you should respond on each choice as if it were the one that was going to be paid." Right before the temporal discounting task, we added the following: "If, on the choice selected, you chose money today, you will get that money today as a bonus in Prolific. If, on the choice selected, you chose a delayed amount of money, you will get that amount of money as a bonus in Prolific, after the delay has passed." In the temporal discounting task (Lempert, Mechanic-Hamilton, et al., 2020; Senecal et al., 2012), participants made 53 decisions. Each question required the participant to choose between two options: one was an amount of money that the participant could receive immediately, and the other was an amount of money the participant could receive after a delay (e.g., \$24 now or \$25 in 166 days; see

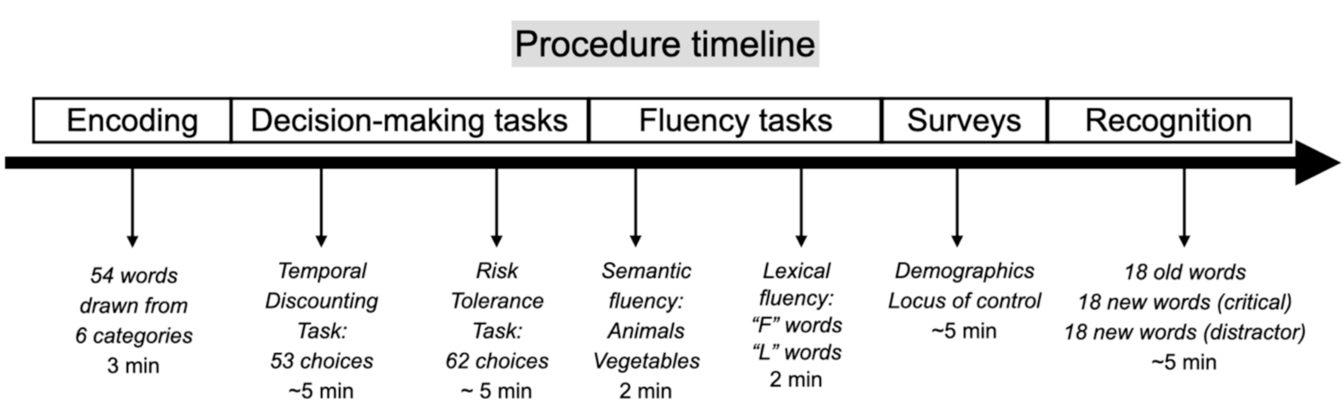

Fig. 1. Procedure timeline. The study was presented in five parts in Qualtrics, and it took about 30 min total.

Supplementary Tables 3 and 4 for full list of choices from both decision-making tasks). The task has 51 choices, designed to capture a range of discount rates. We included an additional two "catch" trials in which we asked participants whether they wanted more money now or less money later ("$10 now or $9 in 180 days?" and "$28 now or $26 in 100 days?"). On these trials, any participant who is paying attention should select the immediate option since it dominates the delayed option on both attributes – amount and delay.

Risk tolerance task

Right before the risk tolerance task, participants were once again reminded about the lottery. The following language was added before this block: "If, on the choice selected, you chose money for sure, you will get that money today as a bonus in Prolific. If, on the choice selected, you chose a gamble option, we will flip a coin to see if you get that amount of money that you gambled for, or if you get $0. That amount would also be sent to you today as a bonus in Prolific." During the risk tolerance task, participants made 62 choices. On each trial, one option was an amount of money that the participant could receive for sure (i.e., with a 100% chance), and the other option was an amount of money they could receive with a 50% chance (i.e., the gamble option). If the gamble option was selected, the participant would have a 50% chance of getting that amount of money; otherwise, they would receive $0. Two "catch" trials were included that asked if participants preferred more money for sure or less money with a 50 % chance ("$13 for sure or $10 with a 50% chance?" and "$21 for sure or $20 with a 50% chance?"). On these trials, since the lower monetary value was also more uncertain, any participant who is trying to maximize potential earnings should select the higher value. Any participants who failed to select the higher value on two or more of these catch trials – across both decision-making tasks – was excluded.

Fluency tasks

Next, participants did four fluency tasks. In each task, they were asked to name as many exemplars from a category as they could in 60 s (the task would automatically end after 60 s). The first two tasks were semantic fluency tasks; participants were asked to name as many animals as they could, and then as many vegetables as they could. The next two were letter fluency tasks; participants were asked to name as many words beginning with the letter "F," as they could, and then as many "L" words as they could. The number of unique exemplars that fit into the category was taken as a measure of fluency. Plural forms of nouns and different conjugations of verbs were accepted, however. Misspellings were allowed as long as the meaning of the word was clear. The number of animals and vegetables named were added together to create a semantic fluency score, and the number of F-words and L-words were summed to determine the letter fluency score.

Demographic and survey measures

Participants were next asked about their age, religion, race, ethnicity, occupation, place of residence, socioeconomic status, income, and political orientation. Income took on one of three values: 1 (corresponding to $<$ \$52k/year), 2 (corresponding to $>$\$52k/year, but $<$\$156k/year, or middle-class), or 3 (corresponding to $>$\$156k/year). Participants were also asked to report their "subjective" socioeconomic status, by rating where they stood on a metaphorical ladder. This measure is known as the MacArthur Scale of Subjective Social Status (Adler et al., 2000). Participants were instructed as follows: "Imagine that this ladder is a representation of how the United States of America is set up. At the top of the ladder are the people who are the best off, those who have the most money, most education, and best jobs. At the bottom are the people who are the worst off, those who have the least money, least education, worst jobs, or no job." Participants then entered a numerical value ranging from 1 (top of the ladder) to 10 (bottom of the ladder).

After the MacArthur Scale of Subjective Social Status, participants did the Rotter Locus of Control questionnaire. This questionnaire aims to understand the extent to which people feel like events are within their control (internal locus of control) or outside of their control (external locus of control; Rotter, 1966). This questionnaire was included to test a separate research question, and so, we will not discuss the results further.

DRM recognition memory task

Finally, participants were tested on their memory for the words that they saw in the encoding task. They were provided with a list of 54 words, one at a time, and asked whether they recognized each word from the earlier list. Participants were presented with four options on each trial: "definitely old," "probably old," "definitely new," and "probably new." There was no time constraint given, and participants would move on to the next trial automatically, as soon as they responded. Of the 54 words on the list, 18 of those words were from the original encoding list ("old" words), 18 were not on the list, but were drawn from the same semantic categories as the words on the encoding list ("critical" words), and 18 were novel words that were unrelated to any of the words in the encoding list ("distractor" words).

At the very end of the procedure, participants were asked to indicate whether or not they had written the words from the encoding list down. We excluded anyone who admitted to doing so.

Analysis

Decision-making tasks

Participants' individual choice data for the temporal discounting and risk tolerance tasks were fit with the following logistic function using maximum likelihood estimation in MATLAB:

$$P_1 = \frac{1}{1 + e^{-\beta(SV1 - SV2)}}, P_2 = 1 - P_1 \tag{1}$$

Here P_1 refers to the probability that the participant chose option 1, and P_2 refers to the probability that the participant chose option 2. SV_1 and SV_2 refer to the participant's estimated subjective value of option 1 and option 2 respectively. The scaling factor β was fitted for each individual task.

In the temporal discounting task, P_1 was the probability of choosing the delayed option, and the subjective values of the options were estimated using a hyperbolic discounting function (Green & Myerson, 2004; Kable & Glimcher, 2007; Mazur, 1987):

$$SV = \frac{A}{1 + kD} \tag{2}$$

Here A is the amount received, D is the delay until receipt (for immediate rewards, $D = 0$), and k is a discount rate parameter that varies across subjects. Higher k indicates higher discounting (more impatience). Since k is not normally distributed, these values were natural log-transformed before statistical analyses were conducted. The log-transformed discount rate parameter k was our measure of temporal discounting.

In the risk tolerance task, P_1 was the probability of choosing the risky option. SV_1 and SV_2 (for the risky option and safe option, respectively) were estimated using a power utility function:

$$SV = p^* A^\alpha \tag{3}$$

Here A is the amount that could be received, p is the probability of receipt ($p = .5$ for the risky option, $p = 1$ for the certain option), and α is a risk tolerance parameter that varies across subjects. Higher α indicates greater risk tolerance (less risk aversion). The values of α were also natural log-transformed before statistical analyses were conducted.

Fluency analyses

We took a hierarchical regression approach to analyze our data, with the log-transformed discount rate as the dependent variable. In the first step, we entered demographic variables which may have an impact on temporal discounting: age, gender, years of education, income level, and subjective socioeconomic status. Gender and income level were entered as factor variables, rather than continuous variables, with three levels each. For gender, the levels were male, female, and other; the "other" category comprised individuals who identified as non-binary or third gender ($n = 3$), or who did not report their gender ($n = 2$; note that we did not have enough power to investigate these categories separately). For income level, the three levels were: <$52,000/year, between $52,000 and $156,000/year, and >$156,000/year. In the second step, we entered letter fluency (sum of F-words and L-words), thus controlling for any effects of processing speed, executive function, or verbal ability on temporal discounting. Finally, the semantic fluency score (sum of animals and vegetables named) was entered in the third step. We hypothesized that better semantic fluency would be associated with lower temporal discounting. To ensure that this relationship, if significant, was specific to temporal discounting, we re-ran this regression with risk tolerance as the dependent variable.

False memory analyses

For the analysis of the recognition memory task, all responses of either "definitely old" or "probably old" were labeled as "yes" responses, and all responses of either "definitely new" or "probably new" were considered "no" responses. If a word had appeared in the encoding task, and the participant indicated that they saw it, that trial was labeled as a "hit," and the participant's hit rate was defined as the percentage of times that they answered "yes," to seeing a word from the encoding task. The novel words were divided into those that were strong semantic associates of words that appeared in the encoding task ("critical words") and those that were drawn from categories that never appeared in the encoding task ("distractor words"). If a participant responded that they saw one of the novel words before, then that was considered a false alarm. False alarm rates were computed separately for the critical words and the distractor words. We conducted a paired-samples *t*-test to compare each participant's distractor word false alarm rate to their critical word false alarm rate. We expected that the false alarm rate would be higher for the critical words compared to the distractor words, in line with previous research.

The critical word false alarm rate was our measure of semantic memory from this task. Of course, the critical word false alarm rate may also reflect episodic memory ability. Therefore, we planned to include a d' measure as a covariate. The d′ measure was calculated as z-score (hit rate) – z-score (distractor word false alarm rate). We implemented standard correction procedures to account for hit rates of 1 and false alarm rates of 0, by adjusting extreme values by 1/2N, where N is the number of old words for hit rates and the number of novel foils for false alarms. We ensured that participants performed above chance on the episodic memory task, by conducting a one-sample *t*-test to compare d' to 0. In addition to calculating d', we also calculated the criterion, as defined by −.5*(z-score (hit rate) + z-score (distractor word false alarm rate). Controlling for this measure of response bias is important, since the extent to which someone is biased toward endorsing a word as "old" can also impact the false memory rate.

We took a similar hierarchical regression approach to examine the relationship between false memory rate and temporal discounting. In the first step, we entered age, gender, years of education, income level, and subjective socioeconomic status. In the second step, we entered d', criterion, and the total task duration in seconds. These variables represent non-semantic influences on false memory: d' and criterion are measures of episodic memory accuracy and response bias, respectively, and task duration is a proxy for the time delay that separated the encoding task and the recognition memory task. While the delay was set to be approximately 20 min for all participants, it did vary somewhat between subjects since the decision-making tasks and demographic surveys were self-paced. Since the encoding task was the same length for all participants, the total task duration was directly proportional to the length of the delay between encoding and retrieval. Finally, the critical word false alarm rate was entered in the third step. We expected that the critical word false alarm rate would be negatively associated with temporal discounting. We also ran this regression again with risk tolerance score as the dependent variable, to verify that any relationships we found were specific to temporal discounting. We set an α level of 0.05 for significance testing for all analyses.

Results

Descriptive statistics and inter-item reliability estimates for all measures are shown in Table 1, and bivariate Pearson correlations among our measures are shown in Table 2.

In line with our first hypothesis, semantic fluency was negatively associated with temporal discounting. Semantic fluency significantly predicted temporal discounting above and beyond the effects of age, gender, education, income, subjective socioeconomic status, and letter fluency (standardized $\beta = -0.269$; 95 % CI: $-0.440 - -0.096$; $p = 0.002$; $R^2 = 0.107$; $\Delta R^2 = 0.044$; Table 3). That is, participants who named more unique animals and vegetables when prompted to do so were more likely to select larger, later rewards over smaller, sooner ones. A scatterplot illustrating the bivariate correlation between semantic fluency and temporal discounting is shown in Fig. 2. Demonstrating the specificity of this association to intertemporal decision making, semantic fluency was not associated with risk tolerance (standardized $\beta = -0.064$; 95 % CI: $-0.239 - 0.112$; $p = 0.477$; $R^2 = 0.068$; $\Delta R^2 = 0.002$; Supplementary Table 5).

Turning to the recognition task results, participants performed significantly above chance on the DRM task (mean d' = 2.04; SD = 1.23; $t_{202} = 23.7$; $p < 0.001$; Cohen's $d = 1.66$). They falsely recalled the critical words (i.e., strong associates of the encoded words) at a rate of 46.8 % on average. Unsurprisingly, given the large literature on false memory in the DRM paradigm, people were more likely to mistakenly recognize a critical word rather than a distractor word ($t_{202} = 20.1$; $p < 0.001$; Cohen's $d_z = 1.41$).

Contrary to our second hypothesis, however, the critical word false alarm rate was not associated with temporal discounting (standardized $\beta = -0.053$; 95 % CI: $-0.225 - 0.118$; $p = 0.543$; $R^2 = 0.096$; $\Delta R^2 = 0.002$; Table 4). Therefore, the extent to which semantic knowledge influences episodic memory retrieval in the DRM task does not predict people's intertemporal preferences. False memory rate was also not associated with risk tolerance (standardized $\beta = 0.035$; 95 % CI: $-0.134 - 0.205$; $p = 0.680$; $R^2 = 0.119$; $\Delta R^2 = 0.0008$; Supplementary Table 6).

Discussion

Here, in an online sample of 203 adults recruited through Prolific, we

Table 1
Descriptive statistics and reliability estimates for measures of interest.

Measure	M	SD	Skew	Kurtosis	Cronbach's α
Discount rate (log-k)	−3.89	1.65	−0.599	−0.089	0.959
Risk tolerance (log-alpha)	−0.434	0.593	−0.119	−0.424	0.969
Semantic fluency	25.9	7.96	−0.064	−0.232	0.711
Letter fluency	30.5	9.53	0.365	0.982	0.831
DRM hit rate	0.778	0.186	−0.926	0.589	0.773
DRM critical word FA rate	0.468	0.201	−0.091	−0.268	0.727
DRM distractor word FA rate	0.172	0.199	1.61	2.53	0.853
DRM d'	2.04	1.23	−0.757	0.813	n/a
DRM criterion	0.111	0.368	−0.081	−0.010	n/a

Note. DRM = Deese-Roediger-McDermott paradigm. FA = false alarm. SD = standard deviation. Hit rate and distractor word false alarm rates are included in the table since inter-item reliability estimates were not available for d' and criterion, but only d' and criterion were used in analyses.

Table 2
Correlation matrix for measures of interest.

Measure	1.	2.	3.	4.	5.	6.	7.
1. Discount rate (log-k)	—						
2. Risk tolerance (log-alpha)	−0.125	—					
3. Semantic fluency	−0.217**	−0.008	—				
4. Letter fluency	−0.083	0.044	0.577***	—			
5. DRM critical word FA rate	0.087	0.014	−0.110	−0.007	—		
6. DRM d'	−0.115	−0.131	0.285***	0.287***	−0.282***	—	
7. DRM criterion	−0.131	0.058	0.014	−0.083	−0.502***	0.105	—

Note: DRM = Deese-Roediger-McDermott paradigm. FA = false alarm. **$p < 0.01$, ***$p < 0.001$.

Table 3
Hierarchical regression results for semantic fluency predicting discount rate.

Predictor	Model 1		Model 2		Model 3	
	Stand. β	Stand. 95 % CI	Stand. β	Stand. 95 % CI	Stand. β	Stand. 95 % CI
Age	−0.092	[-0.231, 0.048]	−0.103	[-0.243, 0.037]	−0.124	[-0.261, 0.014]
Gender†:						
Male − Female	−0.098	[-0.380, 0.184]	−0.132	[-0.418, 0.155]	−0.224	[-0.510, 0.063]
Other − Female	−0.337	[-1.260, 0.586]	−0.333	[-1.255, 0.588]	−0.193	[-1.099, 0.714]
Income‡:						
Middle − Low	0.213	[-0.105, 0.531]	0.217	[-0.101, 0.534]	0.190	[-0.121, 0.501]
High − Low	0.020	[-0.473, 0.514]	0.045	[-0.449, 0.539]	−0.017	[-0.502, 0.468]
MacArthur SSS	0.030	[-0.121, 0.180]	0.018	[-0.134, 0.169]	0.020	[-0.129, 0.168]
Education	−0.199**	[-0.345, −0.053]	−0.197**	[-0.343, −0.051]	−0.172*	[-0.315, −0.028]
Letter fluency			−0.092	[-0.235, 0.050]	0.052	[-0.116, 0.220]
Semantic fluency					−0.268**	[-0.440, −0.096]
R^2	0.055		0.063		0.107	

Note. Discount rate was log-transformed prior to analysis. SSS = Subjective Social Status. CI = Confidence Interval. †Reference level is Female. ‡Reference level is low income, < \$52k/year. Middle income = between \$52k/year and \$156k/year. High income = >\$156k/year. *$p < 0.05$, **$p < 0.01$.

Table 4
Hierarchical regression results for false memory rate predicting discount rate.

Predictor	Model 1		Model 2		Model 3	
	Stand. β	Stand. 95 % CI	Stand. β	Stand. 95 % CI	Stand. β	Stand. 95 % CI
Age	−0.092	[-0.231, 0.048]	−0.064	[-0.203, 0.075]	−0.069	[-0.209, 0.071]
Gender†:						
Male − Female	−0.098	[-0.380, 0.184]	−0.155	[-0.437, 0.127]	−0.152	[-0.435, 0.131]
Other − Female	−0.337	[-1.260, 0.586]	−0.286	[-1.198, 0.626]	−0.293	[-1.206, 0.621]
Income‡:						
Middle − Low	0.213	[-0.105, 0.531]	0.237	[-0.080, 0.554]	0.256	[-0.067, 0.578]
High − Low	0.020	[-0.473, 0.514]	0.036	[-0.451, 0.524]	0.064	[-0.432, 0.561]
MacArthur SSS	0.030	[-0.121, 0.180]	0.049	[-0.101, 0.199]	0.051	[-0.099, 0.201]
Education	−0.199**	[-0.345, −0.053]	−0.206**	[-0.351, −0.061]	−0.209**	[-0.354, −0.063]
Task duration			−0.117	[-0.255, 0.022]	−0.125	[-0.116, 0.220]
D'			−0.113	[-0.252, 0.026]	−0.125	[-0.268, 0.019]
Criterion			−0.091	[-0.230, 0.047]	−0.115	[-0.273, 0.044]
Critical word FA rate					−0.053	[-0.225, 0.118]
R^2	0.055		0.094		0.096	

Note. Discount rate was log-transformed prior to analysis. SSS = Subjective Social Status. FA = false alarm. CI = Confidence Interval. †Reference level is Female. ‡Reference level is low income, < \$52k/year. Middle income = between \$52k/year and \$156k/year. High income = >\$156k/year. **$p < 0.01$.

tested the novel hypothesis that semantic memory abilities are associated with reduced temporal discounting. To this end, we examined individual differences in semantic fluency and DRM false memory rate and related them to individual differences in temporal discounting. We found that semantic fluency, a measure of voluntary semantic memory retrieval, was negatively associated with temporal discounting. Specifically, participants who generated more category exemplars in the semantic fluency task were more likely to select larger, later rewards over smaller, sooner rewards. In contrast, the false memory rate, which measures the extent to which semantic knowledge incidentally biases episodic memory, was not associated with temporal discounting.

This study has a few noteworthy limitations. First of all, we used a correlational design. Therefore, we do not know whether semantic memory influences temporal discounting, or *vice versa*. It is also possible that a third, latent variable is related to both constructs. Nevertheless, demonstrating this association is an important step in understanding the cognitive mechanisms underlying temporal discounting. Another limitation is that our study was done online, which gave us less experimental

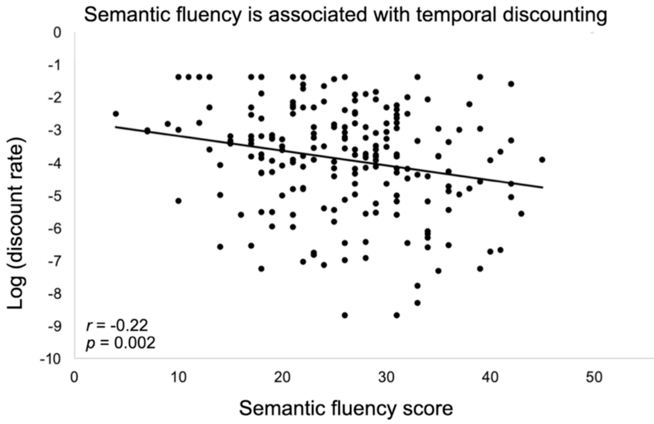

Fig. 2. Scatterplot illustrating significant Pearson correlation between semantic fluency and temporal discounting. Note that the primary analysis was a hierarchical regression in which demographic variables were controlled for in a first step, and letter fluency was controlled for in a second step. Semantic fluency was quantified as the total number of animal and vegetable exemplars provided in the semantic fluency tasks. Discount rates were log-transformed prior to analysis.

control. We excluded people who showed evidence of cheating on the tasks, but some participants who used artificial intelligence or other aids might have escaped detection. There was also some variability between participants in how long the delay between encoding and retrieval was, although we did try to control for that in our models. A strength of our online study is that it allowed us to collect a large sample size, which was necessary, given that most effect sizes from individual differences analyses are small (Gignac & Szodorai, 2016). It also allowed us to collect a sample that was diverse with respect to age, geographical location, income, and education. Still, we hope that future research will replicate this effect in different samples and settings. Finally, it is a limitation that we did not pre-register the hypotheses and analyses used in this study. However, we have been transparent here about our hypotheses, and we did establish our exclusion criteria and stopping rule for data collection before we collected data.

To our knowledge, this is the first study to show that semantic memory abilities are associated with temporal discounting in a general population. Episodic future thinking has been shown to reduce temporal discounting (Rösch et al., 2022). This discovery prompted several previous studies to examine the links between episodic memory – a key contributor to episodic future thinking – and temporal discounting, but these studies have been inconclusive (Boyle et al., 2012; Garzón et al., 2023; Lempert, MacNear, et al., 2020; Lempert, Mechanic-Hamilton, et al., 2020; Seinstra et al., 2015). Imagining the future and making decisions about it may actually depend more on *semantic* memory than on episodic memory, though. Semantic memory provides the "scaffolding" for prospection (Irish et al., 2012), since it is where schemas and scripts are drawn from. Indeed, previous neuroscience research has shown that semantic memory deficits and atrophy in the temporal lobe are associated with increased temporal discounting (Beagle et al., 2020; Chiong et al., 2016; Garzón et al., 2023; Owens et al., 2017).

Although our study was correlational, the semantic fluency result suggests that individual differences in temporal discounting may emerge from individual differences in the ability to retrieve conceptual information, including conceptual information about the future. This putative mechanism is further supported by the specificity of the association that we found. First of all, semantic fluency was not related to risk preferences, in line with the idea that semantic memory is involved specifically in deciding about *future* rewards. Second, semantic fluency predicted significant variance in temporal discounting even after accounting for effects of letter fluency. In fact, letter fluency alone did not significantly predict temporal discounting. Letter fluency and semantic fluency both assess executive functions, such as processing speed, working memory, and cognitive flexibility (Unsworth et al., 2011), but semantic fluency relies on semantic memory much more than letter fluency does (Stolwyk et al., 2015). If we had found a significant association between *both* types of fluency and temporal discounting, then we would not have known which of the many cognitive processes captured by both tasks is associated with temporal discounting. That relationship might have been driven by executive function, conscientiousness, attention, or even just general intelligence. The dissociation between letter fluency and semantic fluency thus strengthens our conclusions vis-à-vis semantic memory and temporal discounting.

On the other hand, a different measure of semantic memory – the false memory rate from the DRM paradigm (Roediger & McDermott, 1995) – was not associated with temporal discounting. One possible explanation for this null result is that only *voluntary* semantic memory retrieval – which is assessed by the semantic fluency task but not by the DRM paradigm – is important for intertemporal decision making. In our sample, the critical word false alarm rate was not even associated with semantic fluency ($r = -0.11$; $p = 0.118$), so despite the fact that semantic processes are involved in both tasks, the tasks are clearly not measuring the same construct. Future studies using additional semantic memory tasks (e.g., semantic priming; Gatti et al., 2024) are needed to further understand the precise mechanism by which semantic memory supports future-oriented choice.

In sum, here we directly tested whether measures of semantic memory are associated with temporal discounting. Semantic fluency, a measure of voluntary semantic memory retrieval, was associated with more future-oriented choice. The DRM false memory rate, a measure of the extent to which semantic knowledge incidentally biases episodic memory, was not. Semantic memory is necessary for imagining the future (Irish et al., 2012; Irish & Piolino, 2016); our finding suggests that it may be critical for the valuation of future rewards as well.

CRediT authorship contribution statement

Danielle Akilov: Writing – review & editing, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Karolina M. Lempert:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Software, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jml.2025.104616.

Data availability

Data and materials from this study have been shared publicly via the Open Science Framework (https://osf.io/dnsha/).

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