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RAPID COMMUNICATION

Future Decision-Making Without Episodic Mental Time Travel

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ABSTRACT: Deficits in episodic memory are associated with deficits in the ability to imagine future experiences (i.e., mental time travel). We show that K.C., a person with episodic amnesia and an inability to imagine future experiences, nonetheless systematically discounts the value of future rewards, and his discounting is within the range of controls in terms of both rate and consistency. Because K.C. is neither able to imagine personal uses for the rewards nor provide a rationale for selecting larger future rewards over smaller current rewards, this study demonstrates a dissociation between imagining and making decisions involving the future. Thus, although those capable of mental time travel may use it in making decisions about future rewards, these results demonstrate that it is not required for such decisions. © 2011 Wiley Periodicals, Inc.

KEY WORDS: hippocampus; episodic memory; future imagining; delay discounting; patient K.C.

Much of the richness in human mental life derives from mental time travel, the ability to remember our personal pasts and imagine our personal futures. These abilities are entwined: People with hippocampal damage and corresponding episodic memory impairment also have an impaired ability to imagine the future (Tulving, 1985; Klein et al., 2002; Rosenbaum et al., 2005; see Addis et al., 2007 for neuroimaging evidence; Kwan et al., 2010). Some propose that hippocampally mediated episodic memory is part of a system that subserves future-oriented decision-making in general (Bar, 2009, 2010; Suddendorf and Corballis, 2007; Gupta et al., 2009; Buckner, 2010; Szpunar, 2010). A novel way to test this supposition is to examine how neurocognitive memory disorders, such as amnesia, affect such decision-making. The ability to choose between smaller, immediate rewards and larger, later rewards is a fundamental aspect of future-oriented decision-making, and one that is plausibly influenced by the ability to imagine one's possible future (Atance and O'Neil, 2001; Tulving, 2002; Boyer, 2008; Liberman and Trope, 2008; Atance and Jackson, 2009; Peters and Büchel, 2010; Benoit et al., 2011).

Imagining future episodes requires one to both orient oneself to a future time and construct a narrative of an event at that time. A recent study of patients with hippocampal amnesia revealed a deficit in event construction, although the task did not require temporal orientation (Hassabis et al., 2007). It remains to be determined whether such individuals are able to perform a task that requires temporal orientation but not necessarily event construction. The distinction between temporal orientation and event construction could be important because the two might be independent processes. Indeed, an imaging study with healthy individuals suggests that the hippocampus may be selectively activated for the latter but not the former (Nyberg et al., 2010).

The well-documented tendency to discount the value of future rewards requires future-orientation but need not involve event construction, although some researchers believe it plays an important role (Berns et al., 2007; Boyer, 2009; Luhmann, 2009). Thus, it is of considerable interest how someone with extensive bilateral hippocampal damage, who is unable to construct details of future events, performs on a task that requires only valuation of future rewards. Is such an individual also unable to find value in future rewards or alternatively, does he systematically discount the value of future rewards as a function of the delay until their receipt, as do nonamnesic individuals? To answer this question, we tested K.C., a well-characterized amnesic individual. K.C. sustained bilateral hippocampal damage in a 1981 motorcycle accident and as a result, is unable to recall any past personal event or to imagine any future personal event (Rosenbaum et al., 2005).

Berns et al. (2007) have emphasized the role of anticipation of future events in making choices whose consequences play out over time. Different predictions emerge, however, depending on what aspects of future events are anticipated. For example, Boyer (2008) has hypothesized that the capacity to imagine future rewards has the evolutionary function of counteracting the tendency to discount future rewards. If so, then when K.C. is given a choice between a smaller, immediate reward and a larger, delayed reward, he (unlike the controls) should devalue the future and exhibit a selective bias toward only choosing the immediate reward given that he is unable to imagine the future. Alternatively, Luhmann and colleagues (Luhmann et al., 2008; Luhmann, 2009) have argued that people imagine the wait period itself and that the anticipated

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unpleasantness of waiting for a delayed reward biases subjects toward immediate rewards. According to this view, K.C. (unlike controls) should not exhibit a bias toward choosing a smaller, immediate reward and instead, should always choose the larger amount. Thus, based on either Boyer's hypothesis or that of Luhmann, one would expect K.C. to show a nontemporal strategy in his decision-making. That is, he should either always choose the smaller, immediate reward according to the first account, or always choose the larger, later reward according to the second account; in either case, there should be no systematic effect of delay on K.C.'s choices.

K.C. was 58 years old at the time of testing. He is right-handed and has 15 years of formal education. His MRI scans reveal extensive volume loss in medial temporal lobe structures, most notably the hippocampal formation and surrounding parahippocampal gyrus, bilaterally. Additional affected areas include the septal area, posterior thalamus, and caudate nucleus, bilaterally, as well as his left amygdala, mammillary bodies, and anterior thalamus.

K.C.'s injury left him with a unique neuropsychological profile. A formal test of mental time travel using a modified version of the Autobiographical Interview with Galton-Crovtiz cuing (Addis et al., 2008; Kwan et al., 2010) revealed that his performance was at floor, with a total of only three episodic details generated for five past events and none generated for five future events. K.C.'s performance represents a striking deficit, and differs considerably from what is observed even in patients with probable Alzheimer's disease (Addis et al., 2009).

Despite such severe impairment in episodic thought and construction, K.C. has retained facts about himself and the world. He also functions well in many other cognitive domains, including correct assessment of other people's current mental states (Rosenbaum et al., 2007). Detailed neuropsychological assessment shows that this pattern of preserved semantic and impaired episodic memory abilities has remained stable since the time of his accident. K.C. continues to demonstrate average IQ and relatively preserved cognitive functioning outside of his episodic memory impairment and a conservative response bias with no evidence of confabulation (Rosenbaum et al., 2005, 2009).

For this study, K.C. and 18 healthy, male, right-handed controls completed a computerized version of an established measure of delay discounting (Green and Myerson, 2004). Even though the discounting task on which K.C. was tested involved hypothetical rewards, it has been shown that healthy individuals' choices regarding hypothetical rewards are highly correlated with their choices regarding real rewards (e.g., Johnson and Bickel, 2002; Madden et al., 2003). Controls were matched for age (M = 56.6, SD = 6. 24) and education (M = 16.19, SD = 2.28), as well as for other factors known to influence delay discounting, including history of gambling and use of alcohol, cigarettes, and recreational drugs. For the delay discounting task, participants made a series of choices between hypothetical monetary offers—a smaller, immediate amount and a larger, future amount. They were told that the task assesses their preferences and that there are no correct or incorrect choices. Participants were tested on multiple occasions to assess the consistency of K.C.'s performance relative to controls.

For each of two future amounts ($100 and $2,000), participants made six choices for each of seven delays (1 week, 1 month, 3 months, 6 months, 1 yr, 3 yr, and 10 yr), presented in random order. The first choice at each delay was between the delayed amount and an immediate amount that was equal to half of the delayed amount (e.g., $100 in 1 month or $50 now). For each of the subsequent choices at that delay, the amount of the immediate reward was adjusted based on the participant's previous choice. If the participant chose the immediate reward, then its amount was decreased on the following trial; if the participant chose the larger, delayed reward, then the amount of the immediate reward on the next trial was increased. The size of the adjustment to the immediate reward after the first choice was half of the smaller amount. Subsequently, the size of the adjustment to the immediate reward decreased with each successive choice and was always equal to half of the previous adjustment, rounded to the nearest dollar. This iterative procedure converged rapidly on an estimate of the amount of an immediate reward corresponding to the subjective value of the delayed reward (Estle et al., 2006).

The 18 control participants completed the discounting task three times: twice on the first testing day (~ 1 h apart) and a third time ~ 1 week later. Participants committed to two sessions but were unaware that they would be retested on the same task. On each retest, participants were instructed to make their choices based on their current preferences and not to try to replicate their previous performance. K.C. was tested six times over the span of ~ 1 month and was never able to explicitly recall previous testing sessions.

As may be seen in Figure 1, the subjective value that K.C. placed on a future reward decreased systematically with the delay until the receipt of that reward. K.C. exhibited clear discounting of both the $100 and $2,000 delayed amounts (see left panels) and although his rate of discounting is relatively steep at the longest delay, it is still within the range of the controls (see right panels).

In addition to examining each participant's discounting curve (i.e., subjective value as a function of delay), we calculated the areas under the curve (AuCs) for each testing session for each participant. The AuCs measure represents the area under the observed subjective values and provides a single, theoretically neutral measure of the degree of discounting. Both subjective value and delay are normalized for purposes of calculating the AuCs measure (Myerson et al., 2001) which, as a result, ranges between 0.0 (maximally steep discounting) and 1.0 (no discounting). As may be seen in Figure 2, which shows the frequency distributions of the mean AuCs for K.C. and the controls (see left panels), K.C.'s AuCs for both the $100 and $2,000 rewards are close to the median values for the controls.

It is important to note that K.C. showed a magnitude effect (i.e., shallower discounting of the larger delayed amount), a standard finding in the human delay discounting literature

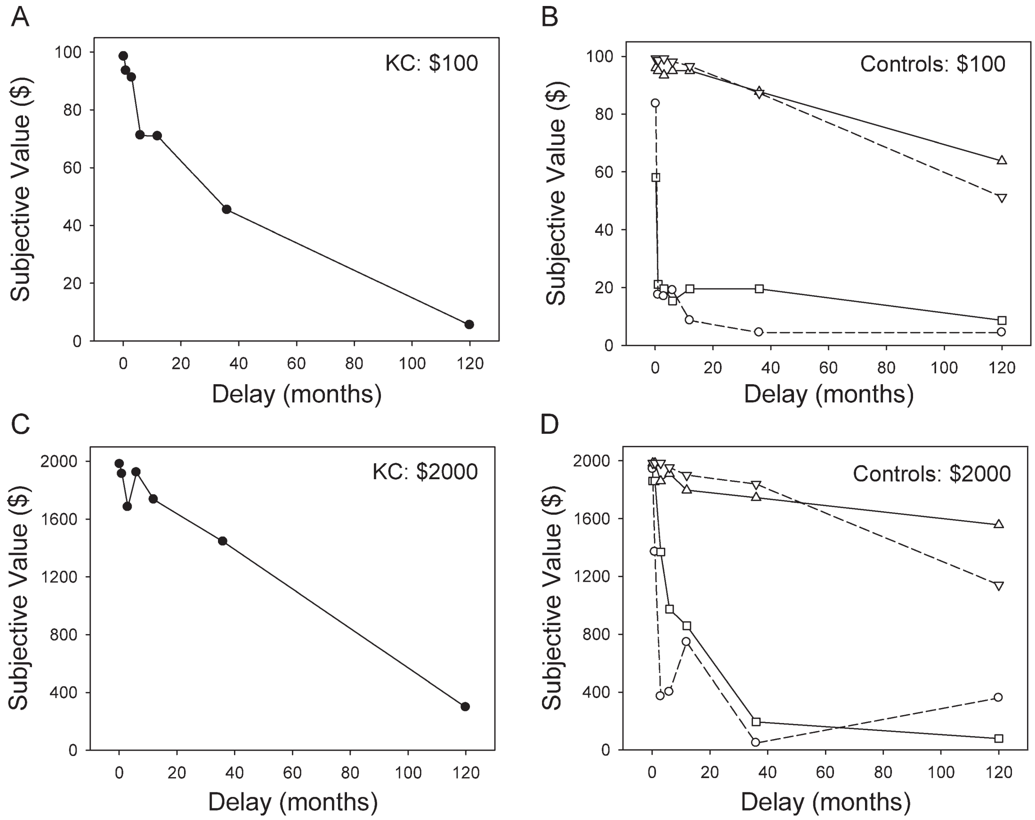

FIGURE 1. Discounting of $100 and $2,000 delayed rewards. (A) Mean subjective values at each delay to the $100 reward for K.C. (B) Mean subjective values at each delay to the $100 reward for the two control participants who showed the steepest and the two who showed the shallowest discounting. (C) Mean subjective values at each delay to the $2,000 reward for K.C. (D) Mean subjective values at each delay to the $2,000 reward for the two control participants who showed the steepest and the two who showed the shallowest discounting.

(Green and Myerson, 2004): The mean areas under K.C.'s normalized discounting curves were 0.371 (SD = 0.177) for the smaller amount and 0.553 (SD = 0.103) for the larger amount. The corresponding overall means (and SDs) for the control group were 0.437 (0.254) and 0.502 (0.259). A modified t-test designed to compare performance of individual patients with a small control group (Crawford and Howell, 1998) failed to reveal a significant difference between K.C.'s AuC and that of controls for either the $100 amount, $t(17) = 0.253$, $P = 0.804$, or the $2,000 amount $t(17) = 0.193$, $P = 0.849$. Crawford and Howell's modified t-test also provides estimates of the percentage of the normal population falling below a patient's score. K.C.'s performance variability was at the 40.18 percentile and 57.55 percentile for the $100 and $2,000 amounts, respectively.

We also compared the variability of K.C.'s discounting across repeated testing sessions with that of the controls. As can be seen in the right-hand panels of Figure 2, K.C.'s intra-subject variability, although relatively high for the $100 amount, was within the range for the controls for both reward amounts. Crawford and Howell's (1998) modified t-test failed to reveal a significant difference between K.C.'s variability and that of controls for either the $100 amount, $t(17) = 1.533$, $P = 0.144$, or the $2,000 amount $t(17) = 0.397$, $P = 0.696$. K.C.'s performance variability was at the 92nd percentile and 65th percentile for the $100 and $2,000 amounts, respectively.

Taken together, these findings demonstrate that K.C., a person with extensive hippocampal damage and resulting episodic amnesia, still values future rewards despite being unable to construct the details of either past or future events. The results contribute to two separate literatures: First, the finding that K.C. can perform a task that requires future orientation but not event construction supports theoretical accounts of amnesia as primarily a deficit in construction (Hassabis et al, 2007; Rosenbaum et al., 2009; Schacter and Addis, 2009). Second, the finding that K.C. systematically discounted the value of future rewards is inconsistent with the predictions of accounts that emphasize the critical role of imagining future events in making choices when the decisions involve future outcomes (Boyer, 2008; Luhmann et al., 2008). K.C. did discount delayed rewards relatively steeply, however, and this may reflect the damage to his hippocampus. Indeed, nonhuman animals with hippocampal lesions tend to be more impulsive than controls (Cheung and Cardinal, 2005; Mariano et al., 2009). Nevertheless, it is unclear whether animals and humans engage in the same underlying

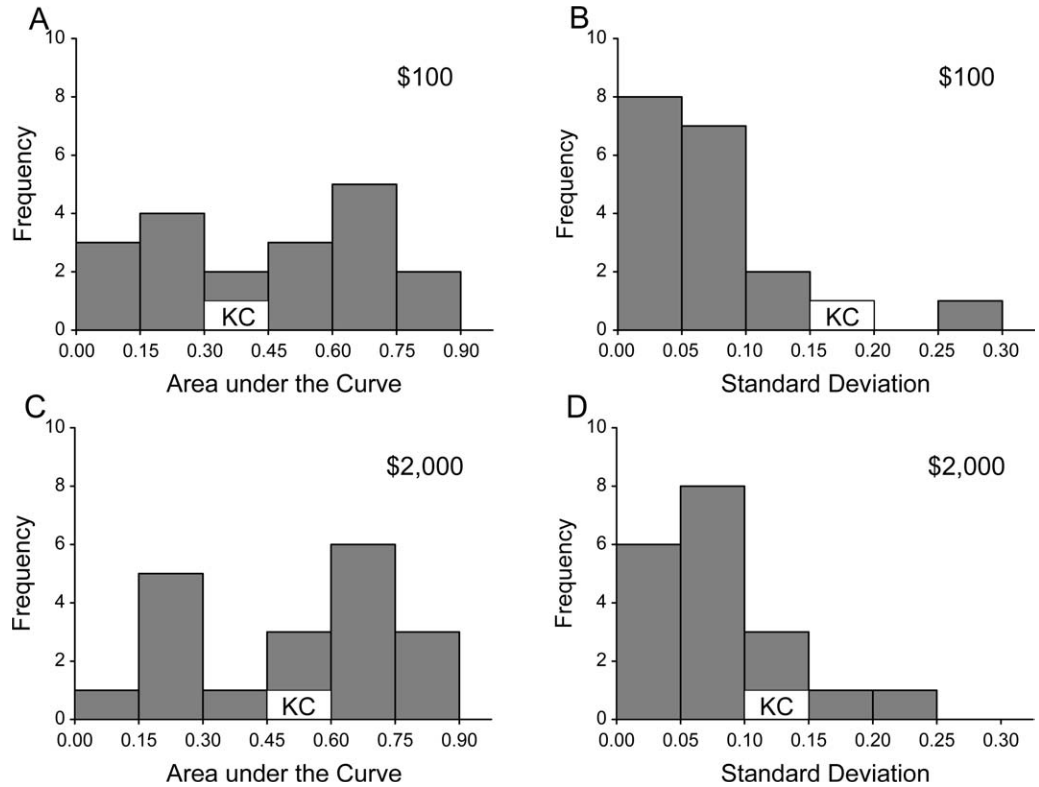

FIGURE 2. Frequency histograms of the mean AuCs and their within-subject standard deviations (SDs) for the $100 and $2,000 delayed rewards. (A) Frequencies of AuCs for the $100 reward. (B) Frequencies of within-subject SDs for the $100 reward. (C) Frequencies of AuCs for the $2,000 reward. (D) Frequencies of SDs for the $2,000 reward. AuCs and SDs for K.C. are indicated.

processes when valuing future rewards. Although animal and human discounting appear similar in certain regards, animals differ from humans in ways that may affect discounting behavior: Animals, unlike K.C. and other humans, do not show a magnitude effect (Green et al., 2004; Freeman et al., 2009), and it is has been argued that, like K.C., animals are incapable of mental time travel (Tulving, 2002, but see Clayton et al., 2003).

An interview with K.C. after he performed the discounting task provided further evidence for a dissociation between the ability to value future rewards and the ability to imagine experiencing future rewards. K.C. reported a "blank" state of mind when asked to construct ways in which he might use future rewards that he had chosen over immediate rewards. When asked about his overall strategy, he reported relying on a gut feeling to choose "the best deal," whereas controls reported relying on both episodic (e.g., "I thought about how I might spend the money in my retirement") and non-episodic (e.g., "I estimated accumulated interest") future-oriented constructions.

In contrast to K.C.'s strategy, which may rely on his relatively intact semantic memory (i.e., knowledge about the world and one's self) (Rosenbaum et al., 2005), the decision-making strategies of healthy individuals, like those of the controls in this study, often involve future-oriented imagery (Suddendorf and Corballis, 2007; Liberman and Trope, 2008; Luhmann et al., 2008; Buckner, 2010). Peters and Büchel (2010) recently reported that individualized episodic cues reduced the rate at which participants discounted future rewards, and this effect was predicted by the degree of self-reported imagery during decision making. Importantly, the effects of episodic cues were also predicted by the degree of coupling between activity in the hippocampus/amygdala and anterior cingulate cortex. Thus, the role of the hippocampus in the relation between episodic thinking and the valuation of future rewards is a rich area for further research, even though this study shows that the valuation of future rewards can occur independently of intact hippocampal function. Interestingly, recent patient research points to a critical role for the medial orbitofrontal cortex (Sellitto et al., 2010), though the role of this region in mental time travel is uncertain.

These results suggest that in the absence of episodic memory, decision-making about future events can be based on semantic memory. These findings support the distinction between imagining and knowing about the future. Continued research with K.C. is needed to determine whether other aspects of future-oriented behavior can also proceed in the absence of mental time travel, or whether discounting is a unique exception. What is clear is that an amnesic person with hippocampal damage who shows a clear distinction between episodic and semantic memory can provide a unique resource for investigating the mechanisms underlying future-oriented decision-making.

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