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Declarative memory is critical for sustained advantageous complex decision-making

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ABSTRACT

Previous studies have reported conflicting evidence concerning the contribution of declarative memory to advantageous decision-making on the Iowa Gambling Task (IGT). One study, in which the measurement of psychophysiology during the task necessitated a 10-s delay between card selections, found that six participants with amnesia due to hippocampal damage failed to develop a preference for advantageous decks over disadvantageous decks [Gutbrod, K., Krouzel, C., Hofer, H., Muri, R., Perrig, W., & Ptak, R. (2006). Decision-making in amnesia: Do advantageous decisions require conscious knowledge of previous behavioural choices? *Neuropsychologia*, *44*(8), 1315–1324]. However, a single-case study (where psychophysiology was not measured and no delay between card selections occurred) showed that an amnesic patient developed normal preference for advantageous decks [Turnbull, O. H., & Evans, C. E. (2006). Preserved complex emotion-based learning in amnesia. *Neuropsychologia*, *44*(2), 300–306]. We sought to resolve these discrepant findings by examining IGT performances in five patients with profound amnesia (WMS-III General Memory Index $M = 63$) and bilateral hippocampal damage caused by anoxia ($n = 4$) or herpes simplex encephalitis ($n = 1$). In one administration of the IGT, psychophysiology measurements were utilized and a 6-s delay was interposed between card selections. In a second administration, no delay between card selections was interposed. While age-, sex-, and education-matched healthy comparison participants showed significant learning with a gradual preference for advantageous decks in both conditions, amnesic patients, irrespective of IGT administration condition and extent of medial temporal lobe damage, failed to develop this preference. These findings strongly discount the possibility that the delay between card selections explains why amnesic participants fail to learn in the IGT, and suggest instead a significant role for medial temporal lobe declarative memory systems in the type of complex decision-making tapped by the IGT.

1. Introduction

The ability to make advantageous decisions relies on rational processes for weighing outcomes, but it is also highly influenced by emotions. This influence can operate in both positive and negative directions: emotions can cloud our judgment, but they can also play an important role in creating a bias (even at non-conscious level) for a certain course of action that is in our best long-range interests. Evidence for the importance of emotional processes in decision-making comes from patients with ventromedial prefrontal cortex (vmPFC) or amygdala damage, who have impaired emotion processing and defective real-world decision-making (Anderson, Barrash, Bechara, & Tranel, 2006; Eslinger & Damasio, 1985; Stuss & Levine, 2002; Tranel & Bechara, in press; Tranel & Hyman, 1990). Decision-making impairments can be seen even after damage to brain areas primarily involved in basic emotion processing, suggesting that decision-making relies on a complex network of neural structures, many of which are involved in a variety of complex emotional and cognitive processes.

A laboratory task sensitive to the decision-making impairments seen in vmPFC and amygdala patients is the Iowa Gambling Task (IGT) (Bechara, Damasio, & Damasio, 2003; Bechara, Damasio, Damasio, & Anderson, 1994; Bechara, Damasio, Damasio, & Lee, 1999; Fellows & Farah, 2005). In this task, participants select from four decks of cards, which are associated with differing amounts of reward and punishment. In order to succeed on the task, participants must learn that certain decks can be rewarding overall as they are associated with small rewards but also have small punishments. By contrast, other decks are disadvantageous overall because despite having larger immediate rewards, they also have larger long-term punishments. While healthy comparison

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subjects show a gradual preference for advantageous decks over trials, participants with vmPFC or amygdala damage show a preference for disadvantageous decks throughout trials (Bechara et al., 2003, 1999; Fellows & Farah, 2005). These findings have been cited in support of the "somatic marker hypothesis," which suggests that areas involved in emotion processing (such as the vmPFC and amygdala) are important for the development and integration of emotion-based cues which can bias decision-making (Bechara, Damasio, & Damasio, 2000; Bechara et al., 1994; Damasio, 1994).

Given the complexity of the IGT, where participants must maintain and update a representation of the contingencies associated with multiple decks of cards over time in order to make advantageous decisions, it seems intuitive that memory systems would play a critical role in successful performance of the IGT (e.g., Maia & McClelland, 2004). Studies have implicated memory, especially working memory, as being important for successful performance on the IGT (Bechara, Tranel, & Damasio, 2000; Fellows & Farah, 2005). However, the necessity of other memory systems besides working memory in complex decision-making has not been clarified. Since advantageous decision-making may often require intact emotion processing, researchers have suggested that emotional memory systems might also be utilized for decision-making (Turnbull & Evans, 2006). Previous research has shown that certain types of simple learning and decision-making can be performed using emotion-based systems rather than the declarative memory system. For example, the severely amnesic patient Boswell was able to learn associations between individuals and affective valences based on previous interactions despite having no declarative memory for these interactions (Tranel & Damasio, 1993). However, this was a rather simple interaction where strong and consistent valences and rewards were associated with each of the people. It is likely that more complex forms of learning require the involvement of multiple memory systems. For example, in the IGT, not only are emotional representations formed (helping to bias behavior towards good outcomes), but choice-outcome associations must be continually formed and updated. A deck that was associated with high rewards may suddenly yield a severe punishment. The IGT in fact models many real-world situations in this regard: we are often confronted with decision-making challenges where the contingencies and magnitudes of reward and punishment are not completely reliable, and may change substantially over time. Also, research on emotional memory has shown that while the amygdala can work independently of hippocampus as in classical fear conditioning, the amygdala can also work in concert with the hippocampus serving to enhance the emotional content of declarative memory (Cahill, Babinsky, Markowitsch, & McGaugh, 1995; Eichenbaum & Cohen, 2001; Richardson, Strange, & Dolan, 2004). Moreover, the amygdala is important for remembering the gist of complex emotional events, while the hippocampus is required for memory for details (Adolphs, Tranel, & Buchanan, 2005). Therefore, both systems play an important role in creating a cohesive representation of a complex situation.

Non-declarative memory systems have been implicated in certain aspects of complex learning as well (Knowlton, Mangels, & Squire, 1996). Amnesic participants with hippocampal damage and declarative memory impairments have been shown to have intact performance on complex tasks such as the Weather Prediction Task and the Wisconsin Card Sorting Task (Janowsky, Shimamura, Kritchevsky, & Squire, 1989; Knowlton, Squire, & Gluck, 1994; Leng & Parkin, 1988; Shoqeirat, Mayes, MacDonald, Meudell, & Pickering, 1990). Just as with the IGT, successful performance on these tasks requires learning and integration of task contingencies across time. However, the extent to which decision-making on the IGT requires declarative memory systems mediated by the hippocampus, and/or hippocampal-independent memory systems, has not been well defined. Off the face of it, due to the arbitrary associations that must be created of multiple experiences between individual decks and punishment schedules over time, it would seem likely that the IGT would require declarative memory. The declarative memory system is critical for relational memory and supports relational representations of successive events and the information about the arbitrary or accidental co-occurrences of people, places, and things along with the spatial, temporal and interactional relations among them (Cohen & Banich, 2003; Cohen & Eichenbaum, 1993; Eichenbaum & Cohen, 2001). However, previous research using the IGT has provided conflicting evidence for the role of declarative memory in complex decision-making.

Turnbull and Evans (2006) reported a case study of an 85-year-old man with amnesia due to a left posterior cerebral artery stroke who performed the Iowa Gambling Task and showed the normal gradual preference for advantageous decks over time. In fact, the amnesic participant even improved his performance on subsequent administrations of the IGT. However, Gutbrod et al. (2006) reported a group study, in which 6 participants with amnesia and bilateral hippocampal damage due to anoxia, encephalitis, or stroke, and 6 participants with amnesia and basal forebrain damage due to encephalitis or stroke, did not show the normal preference for advantageous decks. Instead they chose equally from the advantageous and disadvantageous decks and did not gravitate towards the advantageous decks over time. These two studies differed in their presentation of the IGT: the second study measured psychophysiology during the task which interposed a 10-s delay between card selections while the first study did not interpose a delay between card selections. Gutbrod et al. (2006) suggest that this difference may be critical as previous studies have found that even short delays (e.g., 1000 ms) can affect amnesics' performance on tasks such as classical conditioning (e.g., Clark & Squire, 1998).

In an effort to resolve these discrepant findings, the current study was designed to determine whether the delay between card selections contributes to amnesic participants' performance on the IGT, and in a broader sense, to further understand the role of the hippocampus and medial temporal lobe in complex decision-making. In order to do so we evaluated the performance of five amnesic subjects with bilateral hippocampal damage on the Iowa Gambling Task, both with and without a delay interposed between card selections.

2. Methods

2.1. Participants and procedures

Participants were five individuals (1 woman) with amnesia and 10 healthy comparison participants (2 women) drawn from the Patient Registry of the Division of Behavioral Neurology and Cognitive Neuroscience at the University of Iowa and the Iowa City community. All participants gave informed written consent approved by the Institutional Review Board of the University of Iowa.

Of the five participants with amnesia, four sustained bilateral hippocampal damage, with no apparent damage elsewhere, from an anoxic/hypoxic event (e.g., cardiac arrest, one-time seizure event (non-epileptic)) and one sustained more extensive bilateral damage (including to amygdala) from herpes simplex encephalitis. Structural magnetic resonance imaging (MRI) examinations were completed on four of the five patients confirming bilateral hippocampal damage. For participant 2563 (who wears a pacemaker and was unable to undergo the MRI examination) anatomical analysis was based on computerized tomography, and only damage in the hippocampal region was visible. For three patients, high-resolution volumetric MRI analyses were conducted revealing significantly reduced hippocampal volumes (studentized residual differences in hippocampal volume relative to a matched comparison group were decreased by 2–4 z-scores) (Allen, Tranel, Bruss, & Damasio, 2006). For participant 2308, who sustained more extensive damage (and for whom high-resolution volumetric MRI analyses are not available), a coronal section from an MRI is shown in Fig. 1. This participant has bilateral damage to hippocampus, amygdala, and insula with more extensive medial and lateral temporal lobe damage on the left than the right; however, there is no visible damage to the prefrontal cortex.

All patients had memory impairments that were sufficiently severe to interfere with activities of daily living, including preventing them from independent living or employment since the onset of their amnesia. Neuropsychological testing confirmed a selective and severe memory impairment disproportionate to any deficits in