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Deciding Advantageously Before Knowing the Advantageous Strategy
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Deciding advantageously in a complex situation is thought to require overt reasoning on declarative knowledge, namely, on facts pertaining to premises, options for action, and outcomes of actions that embody the pertinent previous experience. An alternative possibility was investigated: that overt reasoning is preceded by a nonconscious biasing step that uses neural systems other than those that support declarative knowledge. Normal participants and patients with prefrontal damage and decision-making defects performed a gambling task in which behavioral, psychophysiological, and self-account measures were obtained in parallel. Normals began to choose advantageously before they realized which strategy worked best, whereas prefrontal patients continued to choose disadvantageously even after they knew the correct strategy. Moreover, normals began to generate anticipatory skin conductance responses (SCRs) whenever they pondered a choice that turned out to be risky, before they knew explicitly that it was a risky choice, whereas patients never developed anticipatory SCRs, although some eventually realized which choices were risky. The results suggest that, in normal individuals, nonconscious biases guide behavior before conscious knowledge does. Without the help of such biases, overt knowledge may be insufficient to ensure advantageous behavior.

In a gambling task that simulates real-life decision-making in the way it factors uncertainty, rewards, and penalties, the players are given four decks of cards, a loan of $2000 facsimile U.S. bills, and asked to play so that they can lose the least amount of money and win the most (1). Turning each card carries an immediate reward ($100 in decks A and B and $50 in decks C and D). Unpredictably, however, the turning of some cards also carries a penalty (which is large in decks A and B and small in decks C and D). Playing mostly from the disadvantageous decks (A and B) leads to an overall loss. Playing from the advantageous decks (C and D) leads to an overall gain. The players have no way of predicting when a penalty will arise in a given deck, no way to calculate with precision the net gain or loss from each deck, and no knowledge of how many cards they must turn to end the game (the game is stopped after 100 card selections). After encountering a few losses, normal participants begin to generate SCRs before selecting a card from the bad decks (2) and also begin to avoid the decks with large losses (1). Patients with bilateral damage to the ventromedial prefrontal cortices do neither (1, 2).

To investigate whether subjects choose correctly only after or before conceptualizing the nature of the game and reasoning over the pertinent knowledge, we continuously assessed, during their performance of the task, three lines of processing in 10 normal participants and in 6 patients (3) with bilateral damage to the ventromedial sector of the prefrontal cortex and decision-making defects. These included (i) behavioral performance, that is, the number of cards selected from the good decks versus the bad decks; (ii) SCRs generated before the selection of each card (2); and (iii) the subject’s account of how they conceptualized the game and of the strategy they were using. The latter was assessed by interrupting the game briefly after each subject had made 20 card turns and had already encountered penalties, and asking the subject two questions: (i) “Tell me all you know about what is going on in this game.” (ii) “Tell me how you feel about this game.” The questions were repeated at 10-card intervals and the responses audiotaped.

After sampling all four decks, and before encountering any losses, subjects preferred decks A and B and did not generate significant anticipatory SCRs. We called this period pre-punishment. After encountering a few losses in decks A or B (usually by card 10), normal participants began to generate anticipatory SCRs to decks A and B. Yet by card 20, all indicated that they did not have a clue about what was going on. We called this period pre-hunch (Fig. 1). By about card 50, all normal participants began to express a “hunch” that decks A and B were riskier and all generated anticipatory SCRs whenever they pondered a choice from deck A or B. We called this period hunch. None of the patients generated anticipatory SCRs or expressed a “hunch” (Fig. 1). By card 80, many normal participants expressed knowledge about why, in the long run, decks A and B were bad and decks C and D were good. We called this period conceptual. Seven of the 10 normal participants reached the conceptual period, during which they continued to avoid the bad decks, and continued to generate SCRs whenever they considered sampling again from the bad decks. Remarkably, the three normal participants who did not reach the conceptual period still made advantageous choices (4). Just as remarkably, the three patients with prefrontal damage who reached the conceptual period and correctly described which were the bad and good decks chose disadvantageously. None of the patients generated anticipatory SCRs (Fig. 1). Thus, despite an accurate account of the task and of the correct strategy, these patients failed to generate au-
period. However, there was a significant increase in the magnitude of these SCRs during the pre-hunch period, but only for normal controls. During the next two periods, SCR activity in normal subjects was sustained in the case of the bad decks, but it began to subside in the case of the good decks (8). (Bottom panels) Bars in the “Behavioral responses” plots represent means (±SEM) of the mean number of cards selected from the bad decks versus those selected from the good decks. Normal controls selected more cards from the good decks during the pre-hunch, hunch, and conceptual periods. In contrast, prefrontal patients selected more cards from the bad decks during these periods (9).

Fig. 2. Diagram of the proposed steps involved in decision-making.

REFERENCES AND NOTES

3. The patients who participated in the experiment were drawn from the Division of Cognitive Neuroscience’s Patient Registry and have been described previously (1, 2). Three are female (ages 53, 63, and 64), and three are male (ages 51, 52, and 63). All have stable focal lesions. Years of education: 13 ± 2 (mean ± SEM); verbal IQ: 111 ± 8 (mean ± SEM); performance IQ: 102 ± 8 (mean ± SEM).
4. The results in this group of normal participants are similar to the results described previously in other normal participants (2).
6. We envision these biases to act as markers or qualifiers in the manner suggested by A. Damasio (in chapter 8) and by A. R. Damasio, D. Tranel, and H. Damasio (in...
Single Molecule Force Spectroscopy on Polysaccharides by Atomic Force Microscopy

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Recent developments in piconewton instrumentation allow the manipulation of single molecules and measurements of intramolecular as well as intermolecular forces. Dextran filaments linked to a gold surface were probed with the atomic force microscope tip by vertical stretching. At low forces the deformation of dextran was found to be dominated by entropic forces and can be described by the Langevin function with a 6 angstrom Kuhn length. At elevated forces the strand elongation was governed by a twist of bond angles. At higher forces the dextran filaments underwent a distinct conformational change. The polymer stiffened and the segment elasticity was bound by the bending angles. The conformational change was found to be reversible and was corroborated by molecular dynamics calculations.

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