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.

References and Notes
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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 face value 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 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.
Fig. 1. Presentation of the four periods in terms of average numbers of cards selected from the bad decks (A and B) versus the good decks (C and D), and the mean magnitudes of anticipatory SCRs associated with the same cards. The pre-punishment period covered the start of the game when subjects sampled the decks and before they encountered the first loss (that is, up to about the 10th card selection). The pre-hunch period consisted of the next series of cards when subjects continued to choose cards from various decks, but professed no notion of what was happening in the game (on average, between the 10th (range: 7 to 13) and the 50th card (range: 30 to 60) in normals, or between the 9th (3 to 10) and the 80th card (60 to 90) in patients. The hunch period (never reached in patients) corresponded to the period when subjects reported “liking” or “disliking” certain decks, and “guessed” which decks were risky or safe, but were not sure of their answers (on average, between the 50th (30 to 60) and 80th card (60 to 90) in normals). The conceptual period corresponded to the period when subjects were able to articulate accurately the nature of the task and tell for certain which were the good and bad decks, and why they were good or bad (on average, after the 80th card (60 to 90) in both normals and patients). (Top panels) Bars represent means (±SEM) of the mean magnitude of anticipatory SCRs generated before the selection of cards from the bad decks versus the good decks. Anticipatory SCRs are generated in the time window before turning a card from any given deck, that is, during the time the subject ponders from which deck to choose (2). SCRs in association with the good and bad decks from normal controls or patients were not significantly different during the pre-punishment (baseline) 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.

autonomic and neurotransmitter nuclei (such as those that deliver dopamine to selected cortical and subcortical forebrain regions), among other regions. The ensuing nonconscious signals then act as covert biases on the circuits that support processes of cognitive evaluation and reasoning (6). In the other chain of events, the representation of the situation generates (i) the overt recall of pertinent facts, for example, various response options and future outcomes pertaining to a given course of action; and (ii) the application of reasoning strategies to facts and options. Our experiment indicates that in normal participants, the activation of covert biases preceded overt reasoning on the available facts. Subsequently, the covert biases may have assisted the reasoning process in a cooperative manner, that is, biases would not decide per se, but rather facilitate the efficient processing of knowledge and logic necessary for conscious decisions (7). We suspect that the autonomic responses we detected are evidence for a complex process of nonconscious signaling which reflects access to records of previous individual experience—specifically, of records shaped by reward, punishment, and the emotional state that attends them. In this light, damage to ventromedial cortices acts by precluding access to a particular kind of record of previous and related individual experience.

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 (6), chap. 8] and by A. R. Damasio, D. Tranel, and H. Damasio [in

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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 intermolecular as well as intramolecular 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 dominated by the bending of bond angles. The conformational change was found to be reversible and was corroborated by molecular dynamics calculations.

Recently a series of single molecule experiments provided detailed insight into intermolecular and intramolecular forces, providing relevant information on molecular mechanisms (1–4). In previous experiments we and others chemically linked molecular pairs such as biotin and avidin (3, 5), or conjugated DNA strands (6), between the tip of an atomic force microscope (AFM) cantilever and support structures. Molecule-specific bond forces between binding pairs were measured upon separation and compared with known thermodynamic parameters (4). Here we used this approach to probe elastic properties of single polymer strands.

The experimental geometry is depicted in Fig. 1A. Dextrans (average molecular weight 500,000) linked to a gold surface through epoxy-alkanethiols were activated with one carboxymethyl group per glucosyl unit on average (7) and reacted with streptavidin such that several molecules were chemically bound to each dextran filament (Sensor Chip SA5, Pharmacia Biosensor AB, Upsalla, Sweden). The mean distance between the grafting points of two different polymer strands was about 200 Å, and the hydrated "polymer brush" extended 1000 to 2000 Å into the solution (7). Because in physiological buffer dextran behaves like an ideal polymer, the coil overlap is expected to be low. In our experiments streptavidin served as a molecular handle for the manipulation of the polymer to be investigated. An AFM cantilever with biotin bound to the AFM tip, following the protocol given in (3), was used to pull on individual dextran filaments through the biotin-streptavidin bond (8). To minimize the number of multiple bonds, which typically occur when the tip penetrates the polymer brush, we let the tip approach and retract step by step without it indenting into the sample until a binding event was registered. In this "fly fishing mode" the undesirable multiple bonds can be efficiently avoided (9). Alternatively, one can "manually" disentangle an individual filament from the polymer brush by slowly pulling back the tip while monitoring all multiple bonds and tangles rupturing until just one last filament is stretched (see the first trace of Fig. 4, discussed further below). This filament can then be repeatedly manipulated as long as the force is kept below the force limit of the molecular handles.

Several measured elongation curves of dextran strands of various lengths are shown in Fig. 1B (10). At the given extension rate of 0.5 μm/s the biotin-streptavidin bond is known to hold up to a force of 250 ± 25 pN (4). The measured deformation curves were modeled by entropy springs with segment elasticity (11). Although the contour lengths Lcontour of the polymers varied from 0.4 to 1.6 μm, the measured Kuhn length lK = 6 ± 0.5 Å and the segment elasticity ksegment = 670 ± 100 pN/Å showed only marginal variation between the filaments. This result was reproduced for several hundred filaments that were measured with different cantilevers in different experiments (12). The finding that the segment elasticity and Kuhn length are virtually identical for all measured dextran strands confirms that predominantly individual filaments are measured by this method and that the deformation of the couplers is negligible at polysaccharide lengths greater than 2000 Å (13).

An interpretation of the measured segment elasticity is given by molecular dynamics (MD) calculations. These reveal that at low forces the main contribution of the elasticity stems from a twist of the C5-C6 bond.