

# Component processes underlying choice

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The processes underlying choice were once thought to be straightforward: individuals were conceptualized as rational decision makers who intuitively calculated the expected value of alternatives and selected the option with the highest expected value. As seen through the lens of the behavioral sciences, this characterization of choice processes is simplistic and often misleading. Human decisions are subject to a variety of internal biases and context effects from the availability heuristic and confirmatory bias to groupthink (1–5). Psychological research has demonstrated how alternative choices, previous experiences, associations, culture, and ways of thinking about a situation all affect decisions in ways that are not predicted by simple Bayesian models and rational choices. For instance, mental simulation of alternative outcomes through counterfactual reasoning can dramatically influence our evaluations and decisions, so much so that silver medalists in the Olympic Games are generally less happy with their achievements than are bronze medalists (5).

To examine other deviations from rational choice, in this issue of PNAS Dickhaut *et al.* (6) manipulated the nature of one of two lotteries in a choice task between pairs of lotteries. The expected value of the pair of lotteries varied across trials, but the expected value of each lottery within a pair was equal. Half of the pairs of lotteries represented gains, and half represented losses. Crossed with the gain/loss manipulation, half of the pairs included one risky lottery, and half included a certain lottery (as defined by the variance in possible outcomes). Choice behavior on trials in which the lotteries represented losses indicated no preference for either pair, consistent with expected value theory. Choice behavior on trials in which lotteries represented gains, in contrast, revealed a preference for the lottery in the pair that was the least risky, as predicted by Kahneman and Tversky's prospect theory (7). Choice did not vary as a function of context. These behavioral results are consistent with numerous previously reported findings in this area of research.

Dickhaut *et al.* (6) also collected response time and positron emission tomography (PET) data during the trials. Contrary to the choice data, both response latencies and PET images varied,

although differently, as a function of context. Based on these data, Dickhaut *et al.* (6) suggested: "Thus very different neurophysiologic processes appear to govern similar choice behavior. This study unequivocally indicates that, in humans, choice behavior alone does not reveal completely how choices are made." However, it has been clear for

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some time that the same preference or choice behavior could be the consequence of different processes and underlying mechanisms (8, 9). Moreover, the choice among the same magnitude-value alternatives can be changed just by changing the way the choice is expressed (8, 10).

Analyses of the reaction time data revealed it took longer to make a choice when lotteries: (i) involved losses rather than gains, and (ii) were in a risky context compared with certain context. The former effect is consistent with the choice data, indicating rational choice when the lotteries represent losses and risk aversion when the lotteries represent gains. The latter effect, a significant effect of context, was used as evidence for different choice processes underlying similar choices (6). Inspection of figure 1 in Dickhaut *et al.* (6), however, shows that the outcomes in the certain lottery are identical, whereas the outcomes in the risky lottery do not have this redundancy. Because the pieces of unique information are more numerous in the risky than certain context, it may have taken longer to formulate choices in the risky than certain context even were the choices derived through the same underlying process. The finding that choices took longer in the risky than certain contexts, therefore, does not provide evidence that different choice processes were necessarily involved.

The PET data produced clear differences in the images across conditions, and the images were consistent with the

notion that there were different patterns of brain activity in viewing the gain and loss lotteries in risky and certain contexts. The question of what specific processes were elicited was left unanswered (6). Fortunately, there is an emerging literature in psychology on the processes underlying affect and choice in situations similar to those in Dickhaut *et al.* (6). For instance, winning \$6 when an alternate choice would have yielded \$50 has been termed a "disappointing win," whereas losing \$6 when another outcome in the lottery would have resulted in a loss of \$50 has been termed a "relieving loss" (11). When affective reactions are measured on a bipolar (good-bad, pleasant-unpleasant, preferred-nonpreferred) scale, disappointing wins are indistinguishable from certain wins of a smaller amount and relieving losses are indistinguishable from certain losses of a smaller amount. When positive affect and negative affect are measured separately, disappointing wins and relieving losses are characterized by the coactivation of positive and negative affect, whereas smaller certain wins and losses are characterized by pure positive affect and negative affect, respectively (12, 13). In sum, gambles of the type described by Dickhaut *et al.* (6) as "certain" have been found to activate positive affect in the case of gains and negative affect in the case of losses, whereas gambles of the type described as risky coactivate positive and negative affect (10).

Given there are recognizable differences in the lotteries in the risky and certain contexts, the neurophysiological processes elicited when perusing these lotteries and choosing between them must also differ. It does not follow, however, that the areas isolated by using PET exhaustively identify the regions involved in differential choice processes or that all of the areas identified by PET bear on choice processes (14). Moreover, the data presented by Dickhaut *et al.* (6) do not unequivocally support the conclusion that there are differences in the cortical networks underlying choices involving gains and losses in risky and certain contexts. Because the four contrasts reflect different kinds of emphasis in information pro-

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cessing terms, it is possible that the results reported for cortical activity may reflect the greater modulation of activity within the same network or set of networks between conditions.

In light of the extant research in cognitive and social neuroscience, many of the areas that appear different in the contrasts displayed in figure 3 of ref. 6 are closely related and commonly associated. For example, there is activity throughout the motor system in premotor areas, cerebellum, presupplementary motor area, and various frontal and motor regions, areas that would typically be coordinated in planned motor behavior (15). These aspects of the PET data suggest that there is planned motor activity involved when making choices, with choices in certain contexts characterized by simpler motor planning and execution processes than choices in risky contexts.

Second, neural circuits that have been implicated in mental calculation (16) appear to be involved. Specifically, the elevated activity in the precuneus, central sulcus, paracentral sulcus, and parietal cortices in the risky compared with certain context suggests that more mental calculation occurred for choices in risky contexts. As noted above, however, the risky lotteries involve more pieces of distinct information and more variance among choices than the certain lotteries, which could account for differences in mental calculation (and cortical activity) even if choice processes were similar in risky and certain contexts.

Finally, there is evidence of cortical activity in regions associated with abstract rewards and punishments in the form of monetary payoffs or losses (17). In the gain relative to loss contrast in the risky context, there is reliable orbitofrontal activity as well as activity in the left frontal pole. This finding suggests that the participants were evaluating the affective values of the outcomes more so in the risky context and more

so for gains than losses. It is important to note that the PET data are also consistent with evaluative networks being activated in all of the conditions of the study but greater activation in some conditions than others.<sup>†</sup>

In sum, for centuries human nature has been conceived as having two sides: a rational, admirable side and an emotional, darker side. Aristotle, St. Thomas Aquinas, and Freud all espoused such a view. Economics has generally emphasized the former, whereas neuropsychology, psychiatry, and clinical psychology have emphasized the latter. Cognitive and social neuroscience are now providing evidence for a more interactive, unified view. Although it is popular in science to highlight the foibles of cognitive biases in choice behavior, the same irrational processes that at times produce these foibles are also the foundation of some of the finest human qualities. Positive illusions of a spouse produce longer and happier marriages (19). Without a biased weighting of the odds, few would begin a new business, run for public office, or seek to change society for the better. Simply going by statistics alone, it may be irrational for individuals to assume they can paint a masterpiece, make a breakthrough in science, or marry for life. And yet humans are not all so rational that they avoid putting paint to canvas, a lifetime into scientific

inquiry, or a ring on their beloved's finger.

Neuroscience research can constrain and inspire hypotheses about choice processes, foster experimental tests of otherwise indistinguishable theoretical explanations or behavioral outcomes and, in so doing, increase the scope and comprehensiveness of choice theories. These advances require an understand-

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ing of the limitations and advantages of various methods and measures (e.g., PET and more recently, functional magnetic resonance imaging, response time, behavior) so they can be used in a convergent fashion to illuminate mechanisms underlying choice. The differential appearance of some cortical regions in some experimental conditions and not in others is not sufficient itself to demonstrate the operation of different choice processes. The present data from Dickhaut *et al.* (6) suggest that choices emerge from the use of calculation, affective evaluation and motor processes, and apparent differences reflect the emphasis of a task rather than the nature of the mechanism itself. Identifying the specific nature, timing, and integration of the component processes underlying choice; the antecedents and moderators of different choice processes; and the unique consequences of the choices (e.g., prediction of behavior, persistence, resistance to change) resulting from different choice processes (20) remain important scientific challenges.

<sup>†</sup>Relating individual differences in regional brain activity to choice and response time data provide an important additional means of examining the component processes underlying choice (18) that could be applied to data of the sort reported by Dickhaut *et al.* (6). For instance, Dickhaut *et al.*'s operationalization of risky lottery produced a lottery that not only had an equivalent expected value and higher variance compared to the paired lottery but also was a "surer-bet" (the minimum outcome in this lottery was a pay out of four whereas the minimum payout of the alternative was 0; see their figure 1A). It is possible that the individual differences reported by the authors were attributable in part to individual differences in the construal of risk in the alternatives in the risky context. Relating individual differences in the PET data to individual differences in choice and response time provide a means of examining this and related component processes.

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