

Research Article

Toward a Physiology of Dual-Process Reasoning and Judgment

Lemonade, Willpower, and Expensive Rule-Based Analysis

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ABSTRACT—*This experiment used the attraction effect to test the hypothesis that ingestion of sugar can reduce reliance on intuitive, heuristic-based decision making. In the attraction effect, a difficult choice between two options is swayed by the presence of a seemingly irrelevant “decoy” option. We replicated this effect and the finding that the effect increases when people have depleted their mental resources performing a previous self-control task. Our hypothesis was based on the assumption that effortful processes require and consume relatively large amounts of glucose (brain fuel), and that this use of glucose is why people use heuristic strategies after exerting self-control. Before performing any tasks, some participants drank lemonade sweetened with sugar, which restores blood glucose, whereas others drank lemonade containing a sugar substitute. Only lemonade with sugar reduced the attraction effect. These results show one way in which the body (blood glucose) interacts with the mind (self-control and reliance on heuristics).*

The capacity for rational choice based on intelligent analysis and reasoning is one of the most remarkable and distinctive attributes of the human mind. But human decision making does not always adopt such high levels of analysis. Many of the choices people make are quick and effortless, and people's decisions are often based on previously established heuristics, rather than a thorough application of the strict rules of logic. This inconsistency in human reasoning has been explained

through dual-process accounts of decision making. According to these accounts, one reasoning process makes quick and automatic judgments based on associative and intuitive feedback, and the other process is more effortful and relies on the application of normative rules of reasoning. That judgment outcomes vary across contexts is said to be, in part, a reflection of these complementary systems.

In the present research, we sought to establish psychological and physiological causes for the reliance on one decision-making process over the other. Specifically, we tested the hypothesis that more blood glucose (which serves as fuel for the brain) is needed for the effortful, rule-based process than for the less effortful process, so that the former type of decision making is impaired when glucose has been depleted by prior, even irrelevant, activities. For our test, we used a specific pattern of intuitive, heuristic-based decision making that has been identified in previous work. We sought to show (a) that the influence of this heuristic is increased when cognitive resources, presumably including blood glucose, have been depleted by prior acts of self-control and (b) that effortful processing can be increased (and the reliance on heuristics reduced) by administering a snack that restores blood glucose to its normal levels.

TWO DECISION SYSTEMS

Several accounts have analyzed human reasoning into two complementary processes. Epstein (1994) proposed that information processing is executed by an experiential system that is holistic, affective, and associationistic and by a rational system that is analytical, logical, and reason oriented. Sloman (1996) described two similar systems: an associative system based on automatic intuition and a rule-based system based on deliberation and the manipulation of symbols. More recently, Stanovich

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(1999; and later, Kahneman, 2003) described the two processes as a heuristic- and association-based process, referred to as System 1, and a controlled, rule-based process, referred to as System 2. Common to all these models of reasoning is the idea that one of these systems (System 2) is more effortful and rule based, whereas the other (System 1) is relatively effortless and relies on quick associations and heuristics.

Theories of reasoning differ in their descriptions of the relative adaptiveness of the two systems. For example, early work charting the limitations of human rationality described the heuristic-based System 1 process as both biased and prone to systematic error (Kahneman, Slovic, & Tversky, 1982). Furthermore, Kahneman (2003) proposed that one major purpose of the rule-based System 2 process is to monitor System 1 decisions and to correct them when they are in error. Alternative accounts have characterized System 1 processes as providing a fast and frugal substitute for expensive System 2 thinking (Gigerenzer & Goldstein, 1996), and, indeed, some evidence suggests that the role of intuitive, heuristic strategies is to usurp effortful, analytical processes over time, so that comparable benefits can be achieved with much less effort (Reyna & Ellis, 1994).

The aim of the current study was not to compare the adaptive value of the two reasoning systems, but to examine a potential asymmetry in the demands that they exert. We proposed that the effortful System 2 process requires access to limited psychological and physiological resources, and we anticipated that when we manipulated the availability of these resources in a decision-making context, we would observe concordant changes in System 1 versus System 2 processing.

THE ATTRACTION EFFECT

Huber, Payne, and Puto (1982; also Simonson, 1989) identified a useful procedure for studying the different reasoning processes. In their study, some participants faced a difficult decision between two options that traded off on important, relevant dimensions. Other participants faced a choice between those same two options plus a third, “decoy” option. The decoy option resembled one of the others but was inferior to it in every respect. Logically, participants should have ruled out the decoy, which would have left them facing the same two options as in the basic, two-option version of the dilemma. Thus, their choices should have exactly paralleled those of the participants who had only those two options to begin with. The researchers found, however, that even though no one chose the decoy, participants came to favor whichever of the original options was similar to the decoy. In other words, the decoy exerted an irrational bias (attraction) on the two prime options. This phenomenon is called the attraction effect or the asymmetric dominance effect.

Because the attraction effect exerts a seemingly irrational influence on the decision process, its impact on choice can be

seen as working through the intuitive System 1 process rather than the rule-based System 2 process. Indeed, Dhar and Simonson (2003) concluded that the attraction effect operates primarily through intuitive and perceptual System 1 processes, and recent findings have suggested that when cognitive (System 2) resources are low, the attraction effect tends to be increased (Pocheptsova, Amir, Dhar, & Baumeister, 2007). Furthermore, work by Simonson (1989) suggests that the attraction effect serves as a likely tiebreaker when thorough, effortful analysis fails to produce a clear preference. Thus, the attraction effect is greatest when analytical System 2 processes fail and the decision-making process defers to System 1.

DEPLETED RESOURCES AND BLOOD GLUCOSE

Research on self-regulation and the self's executive function has established that they rely on a limited resource. Early studies found that after people engaged in one act of self-control, their performance on subsequent and seemingly irrelevant self-control tasks was impaired (Baumeister, Bratslavsky, Muraven, & Tice, 1998; Muraven, Tice, & Baumeister, 1998). These findings suggested that some resource needed for optimal control on the second task had been depleted during the first task.

The limited resource used for self-control is also used for effortful decision making. Vohs et al. (2007) showed that making multiple or difficult decisions led to subsequent decrements in self-control, as if the same vital resource was needed for both kinds of tasks. In an unpublished study, Pocheptsova et al. (2007) reversed this procedure to assess the effects of acts of self-control on subsequent decision making. They found that heuristic-based decision-making processes, including those that drive the attraction effect, were significantly stronger among depleted participants than among those who were not depleted. These findings support the argument that System 1 processes gain increased influence when scarce cognitive resources do not allow for optimal System 2 reasoning.

What is the nature of the resource that is depleted? The lay term *willpower* has a long history, but has not generally been accorded much respect in psychological theorizing. Gailliot and Baumeister (2007) proposed that willpower is more than a metaphor and that blood glucose may be an important physiological basis for it. Glucose is fuel that is consumed to provide energy for all brain activities, but some brain processes consume much more energy than others. A series of studies by Gailliot et al. (2007) showed that blood glucose levels dropped when people performed laboratory tasks that required self-control (but not neutral tasks) and that these low levels of blood glucose were significantly correlated with poor performance on subsequent behavioral measures of self-control. These studies also showed that replenishing blood glucose with a drink containing sugar counteracted the depletion and restored self-control performance to a good level, whereas sugar-free diet drinks had no such effect.

THE PRESENT RESEARCH

In the present experiment, we sought to provide evidence for a causal relation between blood glucose and effortful (System 2) decision processes. To do this, we applied the resource-depletion and glucose-snack manipulations to participants who then confronted the attraction problem. We sought, first, to replicate the attraction effect (Huber et al., 1982), in which the presence of a decoy option (that hardly anyone would actually choose) sways preferences between the other two options. In addition, we sought to replicate the finding that ego depletion, caused by prior exertion of self-control on a seemingly irrelevant task, intensifies the attraction effect (cf. Pocheptsova et al., 2007). To manipulate depletion, we adapted a procedure originally developed by Gilbert, Krull, and Pelham (1988). In this procedure, participants watch a silent video depicting a woman talking while a series of words flashes on the screen. In one condition, participants are instructed to avoid looking at the words, and if they do find themselves looking at the words, they are to bring their attention immediately back to focus on the woman. This task requires the deliberate control of attention and therefore should deplete the limited resources (i.e., willpower and glucose) needed for self-control and other System 2 activities. Other participants watch the same video without any special instructions.

The prime goal of this work was to test our novel hypothesis that blood glucose reduces the attraction effect and restores effortful decision making. To do this, we adapted the glucose manipulation used by Gailliot et al. (2007). All participants drank a glass of lemonade, which by random assignment had been sweetened with either sugar or Splenda. The latter is a sugar substitute that tastes like real sugar (especially in lemonade). For present purposes, the key is that Splenda does not contribute anything to blood glucose. To the extent that effortful choice requires blood glucose, Splenda should not restore the necessary resources for effortful thought as effectively as sugar does.

Our main prediction was therefore that the attraction effect would be stronger among depleted participants (i.e., those who had performed a previous task requiring self-control) who drank lemonade made with Splenda. We reasoned that their blood glucose levels would have been reduced by the prior act of self-control, and that lemonade made with Splenda would be useless for raising those levels back to normal. In contrast, we predicted that participants who were depleted but then consumed sugar would be restored to a normal level of blood glucose and therefore would be less prone to rely on the heuristic, low-effort decision-making style.

We also included conditions in which nondepleted participants drank either kind of lemonade. Our prediction was that when blood glucose was already at a normal level, there would be no benefit to be gained from consuming additional sugar, and so the type of lemonade would make no difference. These participants would show at best a weak attraction effect. But if the type of lemonade had some effect on decision making other than by counteracting depletion, we would be able to find that

effect by examining the choices made by these nondepleted participants.

Method

Participants

One hundred twenty-one participants took part in the experiment in exchange for partial credit in their psychology course. Data from 1 participant were lost because of computer problems.

Procedure

Participants had been told that the study dealt with two separate issues, namely, food preferences and impression formation. They were told they would first drink and rate a beverage and then form an impression of someone by watching a video.

After giving informed consent, participants were randomly assigned to receive a lemonade beverage that had been sweetened with either sugar (glucose condition) or Splenda (placebo condition). The lemonade was administered first because it takes time (10–12 min) for glucose to be absorbed into the bloodstream. Neither the experimenter nor the participant was aware of which sweetener had been used. The experimenter then left the room while participants rated the drink for quality of taste, pleasantness, and how difficult it was to drink. A 4-min period was allocated for these ratings (partly to allow time for the glucose to be metabolized). Participants were instructed to sit quietly after completing the ratings and to await the experimenter's return.

After 4 min, the experimenter returned and gave participants instructions for the impression-formation task. Participants were told that they would watch a 6-min video (without sound) of a woman being interviewed by an off-camera interviewer. The experimenter said that the research was aimed at elucidating how people interpret nonverbal behaviors. As the woman was interviewed, the video displayed a series of common words (e.g., *shoe*) for 10 s each. These words appeared in black text in a white box in the lower portion of the screen. By random assignment, half the participants were instructed not to read or look at any of the words (depletion condition). If they caught themselves looking at the words, they were supposed to redirect their gaze immediately to the woman. The other half of the participants were given no such instructions (no-depletion condition).

After participants watched the video, they completed the Brief Mood Introspection Scale (BMIS; Mayer & Gaschke, 1988). The combination of the 4-min lemonade manipulation, the 6-min video, and the BMIS ensured that more than 10 min had elapsed since participants drank the lemonade, so we assumed that by the time they completed the BMIS, the sugar was metabolized and was therefore becoming available as glucose in the bloodstream. Hence, at this point, we administered the primary dependent measure.

Participants were told that the procedure required some time to pass before they rated their impression of the woman in the video. In the meantime, they were asked to pretest a consumer decision task for another study. This task was taken from research by Pocheptsova et al. (2007). Instructions printed on a sheet of paper told participants to imagine that they were searching for a new apartment for the coming school year. They were to choose among three options. All participants saw the main options B and C, plus one of two decoys, A or D. Table 1 shows all four options. Decoy A resembles B but is inferior to it on both dimensions, whereas decoy D resembles C and is inferior on both dimensions.

After the decision task, the experimenter explained that the participants would not be rating their impressions of the woman in the video. Instead, participants were debriefed regarding the true nature of the study. They were thanked for their participation, awarded partial course credit, and dismissed from the lab.

Results

Apartment Choice

The experiment had a 2 (glucose vs. placebo) $\times$ 2 (depletion vs. no depletion) $\times$ 2 (ABC vs. BCD array of options) between-subjects design. The attributes for each apartment option, the choice frequency for each cell, and the magnitudes of the attraction effect are summarized in Table 1. It was assumed (correctly) that no one would select either decoy, so the dependent measure in the following analyses was the binary choice between B and C. The attraction effect is seen in the difference in preferences for B versus C as a function of which decoy (A or D) is present. A one-way analysis of variance (ANOVA) indicated significant variation among conditions, $F(7, 112) = 3.67$, $p_{\text{rep}} = .99$, $\eta_p^2 = .187$. Our main prediction was that the attraction effect would be larger among depleted participants who received the placebo than among participants in the other three groups (depletion plus sugar, no depletion plus sugar, no depletion plus placebo). We tested this prediction using a focused interaction contrast pitting the depletion-plus-placebo condition against the combination of the other three conditions. This

interaction was significant, $F(1, 111) = 5.311$, $p_{\text{rep}} = .92$, $\eta_p^2 = .045$.

ANOVA also revealed a main effect of which apartment set participants saw, $F(1, 119) = 15.13$, $p_{\text{rep}} > .99$, $\eta_p^2 = .119$. Participants who saw the ABC array were more likely to choose B than those who saw the BCD array. Thus, the basic attraction effect was replicated across all conditions, although the interaction qualified it. The experiment also replicated the finding (Pocheptsova et al., 2007) that ego depletion increases the effect. That is, a planned complex comparison (excluding the depletion-plus-glucose group) indicated a significant interaction between depletion and apartment set, $F(1, 112) = 3.83$, $p_{\text{rep}} = .87$, $\eta_p^2 = .033$. A pair-wise comparison between the depletion-plus-placebo group and the no-depletion-plus-placebo groups did not reach significance, $F(1, 112) = 2.66$, $p_{\text{rep}} = .81$, $\eta_p^2 = .023$.

Furthermore, within the depletion condition, the interaction between beverage and apartment set was significant, $F(1, 112) = 5.07$, $p_{\text{rep}} = .92$, $\eta_p^2 = .043$, such that the glucose group exhibited a smaller attraction effect than the placebo group. The interaction contrast comparing the magnitude of the attraction effect for the depletion-plus-glucose group and the no-depletion-plus-glucose group was not significant, $F(1, 112) = 0.294$, $p_{\text{rep}} = .44$, $\eta_p^2 = .003$; this finding supports the hypothesis that glucose intake eliminates the effect of ego depletion on decision making and restores effortful choice.

Beverage Ratings

We created a liking index by summing each participant's ratings of the quality of the taste of the beverage, the pleasantness of the beverage, and how difficult it was to drink (reverse-scored). A one-way ANOVA yielded a marginally significant effect of beverage type on liking, $F(1, 119) = 3.47$, $p_{\text{rep}} = .86$, $\eta_p^2 = .029$, indicating a trend toward liking the lemonade with sugar ($M = 14.92$, $SD = 3.74$) more than the Splenda version ($M = 13.61$, $SD = 3.94$). Liking for the beverage did not correlate significantly with apartment choice, $r = .138$, $p_{\text{rep}} = .78$, nor did it interact with the depletion manipulation to predict apartment choice, $F < 1$, n.s.

TABLE 1
Choice Frequencies in Each Condition

Apartment	No-depletion condition				Depletion condition			
	Glucose		Splenda		Glucose		Splenda	
	ABC set	BCD set	ABC set	BCD set	ABC set	BCD set	ABC set	BCD set
A: 350 sq ft, 10 miles	0	—	0	—	0	—	0	—
B: 450 sq ft, 7 miles	9	7	12	8	9	10	19	4
C: 800 sq ft, 15 miles	4	7	1	5	5	10	1	9
D: 700 sq ft, 18 miles	—	0	—	0	—	0	—	0
Percentage choice of B: $[B/(B + C)]$	69.2	50.0	92.3	61.5	64.3	50.0	95.0	30.8
Magnitude of attraction effect: %B – %C	19.2		30.8		14.3		64.2	

Note. Each participant chose from among three options—B and C plus either A or D. The apartments varied in both size and distance from the school.

Furthermore, none of the hypothesized effects were eliminated when we controlled for the liking index—in fact, they grew stronger. The one-way analysis of covariance (ANCOVA) on apartment choice, with beverage liking as a covariate, indicated significant variation among conditions, $F(8, 111) = 4.025$, $p_{\text{rep}} > .99$, $\eta_p^2 = .225$, and the factorial ANCOVA replicated the attraction effect, yielding a main effect for apartment set on apartment choice, $F(1, 119) = 17.02$, $p_{\text{rep}} > .99$, $\eta_p^2 = .133$. The focused interaction contrast pitting the depletion-plus-placebo condition against the other three conditions remained significant, $F(1, 111) = 5.57$, $p_{\text{rep}} = .93$, $\eta_p^2 = .048$, which suggests that the attraction effect was strongest among depleted participants who received the placebo beverage. Complex comparisons demonstrated that participants in the depletion-plus-placebo condition exhibited a significantly larger attraction effect than participants in the no-depletion conditions, $F(1, 111) = 4.24$, $p_{\text{rep}} = .89$, $\eta_p^2 = .037$; this finding supports the idea that ego depletion increases reliance on heuristic processing. Furthermore, within the depletion condition, the interaction between beverage and apartment set remained significant, $F(1, 112) = 4.85$, $p_{\text{rep}} = .91$, $\eta_p^2 = .042$; administration of a glucose beverage significantly decreased the attraction effect for participants who were required to control their attention.

Mood

A two-way ANOVA indicated that the interaction between the depletion manipulation and the beverage manipulation had no significant effect on the valence, $F < 1$, n.s., or arousal, $F < 1$, n.s., of participants' mood, as measured by the BMIS. In addition, the manipulations did not have main effects on either valence or arousal, all F s < 1 , n.s.

DISCUSSION

We set out to elucidate the interplay of mind and body in decision making. The simple and seemingly unrelated act of drinking a beverage sweetened with sugar restored the capacity for effortful, System 2 reasoning and decreased reliance on heuristic-based System 1 reasoning, thereby decreasing the observed attraction effect.

In recent years, most interest in the mind-body interface has focused on the brain, but the brain depends on the body for its fuel. Specifically, brain processes use energy from glucose in the bloodstream. Although all brain activities require some of that fuel, some activities are much more expensive than others in the sense that they consume a notable amount of the supply and therefore deplete what is left in the blood. Recent work has indicated that self-control is one such expensive process (Gailliot et al., 2007). The present work suggests that effortful decision making is another process that draws heavily on the same resource. Most important, we showed that the outcome of a decision process could be changed by manipulations aimed at increasing or decreasing the available supply of blood glucose.

Many dual-process models of reasoning posit that expensive and effortful choice is a key criterion for distinguishing between modes of decision making (e.g., Gigerenzer & Goldstein, 1996; Kahneman, 2003; Reyna & Ellis, 1994), and the current data are consistent with this view. Previous work on self-control suggests that the feature common to expensive (and hence depleting) cognitive processes is that they require active and effortful guidance by the self, usually to select between many potential thoughts, rules, or behaviors (Baumeister et al., 1998). If System 2 reasoning strategies share a limited resource with self-control, then it is plausible that System 2 decision making may be defined by a similar deliberation by the self. Thus, System 2 decision making may involve analyses that are expensive and effortful, and that enable people to choose between multiple options.

Alternative models of reasoning have characterized System 2 processes primarily as logical (De Neys, 2006; Epstein, 1994) or based on the application of rules (Sloman, 1996). To modify such models, we propose that the difference between rule- or logic-based processes and heuristic-based processes may be meaningful only when the former involve effortful choice. In decision-making contexts in which the conclusions or the means for obtaining them have been previously established (thereby obviating choice), an application of normative rules is more likely to resemble heuristic strategies than the effortful and analytical strategies that rely on blood glucose. For example, long division requires an application of the normative rules of math and logic, but the rules to be applied have been predetermined. Therefore, the methods for long division and similar rule-of-thumb processes are not likely to exert the same demands as effortful forms of rule-based choice. The proper complement to heuristic-based processing may be not rule-based processing per se, but rather the effortful rule-based processing that is required for making novel decisions. It is perhaps only the latter type of decision making that one can expect to be impaired when cognitive resources are scarce or need to be conserved.

Furthermore, the current data may speak to the relationship between the two systems of decision making. We found that heuristic influence was more prevalent when physiological resources were low than when they were at baseline levels. Thus, although some models have described the development of decision making as progress away from expensive analysis and toward more efficient, intuitive strategies (Reyna & Ellis, 1994), heuristics may not usurp System 2 processes completely. The current findings suggest that as heuristics form, they may serve as a default strategy, rather than as a blanket replacement for costly System 2 thinking. This idea is consistent with Kahneman's (2003) view of System 2 as a monitor of System 1 output. Although System 1 decisions are the default, System 2 processes may override System 1 processes when their conclusions are undesirable. According to this view, a lack of System 2 resources should not affect heuristic processing when heuristics produce perfectly sound conclusions, which some models of decision

making suggest they generally do (e.g., Gigerenzer & Goldstein, 1996; Reyna & Ellis, 1994). But when a heuristic can be seen as irrelevant or irrational, as happens in the case of the attraction effect in the current study, its influence will be conditional upon whether cognitive resources are at an adequate level for System 2 processes to override it.

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