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Sweet Future: Fluctuating Blood Glucose Levels Affect Future Discounting

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Abstract

This study explored metabolic mechanisms of future (delay) discounting, a choice phenomenon where people value present goods over future goods. Using fluctuating blood glucose as an index of body energy budget, optimal discounting should regulate choice among rewards as a function of temporal caloric requirement. We identified this novel link between blood glucose levels measured in lab and future discounting rate of the participants who made choices between a smaller-sooner reward and a larger-later option, with possible actual monetary consequences. The sugar-drink group showed a reduced future discount rate after the drink, when controlling for sex, age, body mass index, and the taste rating of the drink. In contrast, zero-sugar drink increased the rate of future discounting. The blood glucose levels not only varied as a result of caloric intake but also regulated the rate of future discounting according to dynamic body energy budget.

“These high wild hills and rough uneven ways,
Draw out our miles and make them wearisome;
But yet your fair discourse hath been as sugar,
Making the hard way sweet and delectable.”

William Shakespeare

Would a grain of sugar itself, instead of a Shakespearean metaphor, make our expected future sweeter? Would the mind read fluctuating blood glucose levels? Would daily body energy budget affect the evaluation of future rewards?

Surprisingly little is known about how fluctuating blood glucose levels affect cognitive functions. From a perspective of body energy regulation, we examined how the daily fluctuation of blood glucose levels regulates evaluation and choice of present versus future rewards, as measured by future or delay discount rate. People ‘discount the future’ when they value present goods over future goods and when they prefer a smaller and sooner (SS) reward to a large and later (LL) reward in making inter-temporal choices (Ainslie, 1975; Frederick, Loewenstein, & O'Donoghue, 2002; Soman et al., 2005).

Our exploration of the interplay between the body (fluctuation of blood glucose levels) and the mind (future discounting) was informed by three theoretical approaches: evolutionary psychology, risk sensitive foraging models, and life-history theory. Evolutionary psychologists argue that selection should favor allocations of effort depending on how quickly expected future utility or fitness declines. Thus, the higher the body energy budget, the more affordable the organism to future-oriented actions.

Life-history theory assumes that individuals make specific tradeoffs at different times in life (Kaplan, Gangestad, & Buss, 2005; Wang, Kruger, & Wilke, 2009). Future discounting thus should be adjusted to both actual life expectancy of a population and individual subjective life-expectancy (e.g., Read & Read, 2001; Wang et al., 2009). Similarly, at a physiological level, daily changes in energy consumption and expenditure, as indicated by blood glucose levels, should also provide a dynamic weighting scale for evaluating immediate versus future returns.

According to risk sensitive foraging theory (Stephens & John, 1986), organisms regulate their degree of risk taking according to their dynamic body energy condition to maximize the chance of reaching daily energy requirements and at the same time minimize the probability of an energy-shortfall. Based on an energy budget rule (Kacelnik & Bateson, 1997; Real, 1991; Wang, 2002), we hypothesize that when the status quo (i.e., body energy budget) is positive or increasing, organisms should be, on average, more future oriented to increase the chance of reproductive success. However, when the status quo is negative or decreasing, organisms should value present resources more than future resources to avoid survival threatening consequences. In general, optimal future discounting should regulate choice among rewards as a function of temporal caloric requirement.

In contrast to the above energy budget regulation hypothesis, an equally plausible alternative is a model in which cognitive resources are based on self-regulatory strength (Dvorak & Simons, 2009; Gailliot et al., 2007). Baumeister and colleagues (1998) have proposed that impulsive action may be a result of depleted self-regulatory abilities. As such, the choice of a small reward now over a larger reward in the future may be due to depleted resources. In fact, research has shown that making difficult choices depletes effortful resources (Vohs et al., 2008) and these resources can be restored by increasing blood glucose (Gailliot et al., 2007). This suggests that this resource may really on energy consumed during processing.

Accordingly, future is more abstract than present, and thus may require more energy to process. Blood glucose as brain fuel would strengthen effortful cognitive processing for future events. However, when glucose levels are low, people would be less able to process the questions so that present rewards may have seemed worth more than the future rewards due to cognitive errors. This alternative hypothesis is in line with recent work by Masicampo and Baumeister (2008) showing that decision biases can be induced by depleting cognitive resources.

Method

Participants

Participants were 65 undergraduate students who received course credit for participation. There were 32 participants (19 females) in the experimental condition and 33 participants (22 females) in the control condition. Participants age ranged from 19-51 ($M = 23.1$, $SD = 4.5$).

Measures

Future discounting was assessed by 14 choice options. Seven of the choice options were presented prior to the experimental manipulation and 7 after. Participants were presented with two monetary options and shown actual money in two separate piles. Participants were asked questions such as: "Would you prefer \$120 tomorrow or \$450 in 31 days?" To encourage accurate responding participants were told they would roll dice at the conclusion of the study for the opportunity to win one of their actual choices. Their responses were used to compute discounting parameters pre- and post- experimental manipulation as the dependent measure.

Pleasantness of the soft drink used in the experimental manipulation was assessed with an 11-point scale (1 = *very unpleasant* to 11 = *very pleasant*).

Apparatus

Blood glucose was measured using a ReliOn Ultima© blood glucose monitor. Participants were informed of the blood glucose measurement during recruiting and were instructed to not eat prior to the experiment.

Procedure

Participants were randomly assigned to condition prior to arrival at the lab. Upon arrival they completed informed consent and demographic information; their height and weight was then assessed. Next, the first blood glucose check was completed followed by the initial future discounting task. Participants then consumed a caffeine free soda (Sprite© or Sprite Zero©). All participants were blind to the type of soda. Immediately after consumption participants rated the pleasantness of the soda. After a 10 minute break in which each participant answered other questions for a different study (life expectancy, ratings of likelihood of engaging in different risky behaviors, school performance and goals, and risk choice questions), participant's blood glucose was again assessed. They then completed the final future discounting task and were debriefed. After completing all tasks, participants rolled two standard dice, and anyone who threw double ones or sixes received his/her choice on one randomly drawn pair, in the form of a check, post-dated to the appropriate delay.

Height and weight were assessed to compute body mass index (BMI) using the formula: $(\text{Weight in pounds} \times 703) \div \text{Height}^2$ (in inches).

Measuring Individual Discount Parameters

In a modification of the method of Wilson & Daly (2004), instead of using successive screens, real money was used to provide participants with choices between two monetary options: a specified sum 'tomorrow' or a larger sum (range over the 14 choices of \$90 to \$570) after a specified delay (range of 4 to 939 days). Seven pairs were given before and seven pairs were given after the experimental manipulation (a sugar drink or a sweet non-caloric drink).

Although classic research on delay discounting in economics and finance assumes an exponential function, people and other animals typically behave as though they discount near futures at higher rates than more distant futures, such that experimentally assessed discount rates approximate a hyperbolic, rather than exponential, function of delay (e.g., Frederick et al. 2002; Green, & Myerson, 2004; Laibson, 1997, 2001; Loewenstein & Prelec, 1992). Thus, in our measure of future discounting, indifference between a smaller, earlier reward (tomorrow) and a larger, later reward (future) indicates the following hyperbolic discount parameter k (Kirby & Marakovic, 1996; Wilson & Daly, 1997, 2004): $k = (\text{future\$} - \text{tomorrow\$}) / ((\text{delay [in days]} \times \text{tomorrow\$}) - (\text{future\$}))$.

More detailed Method and Results sections are provided in online supplementary material.

Results

Univariate and bivariate analyses of control variables

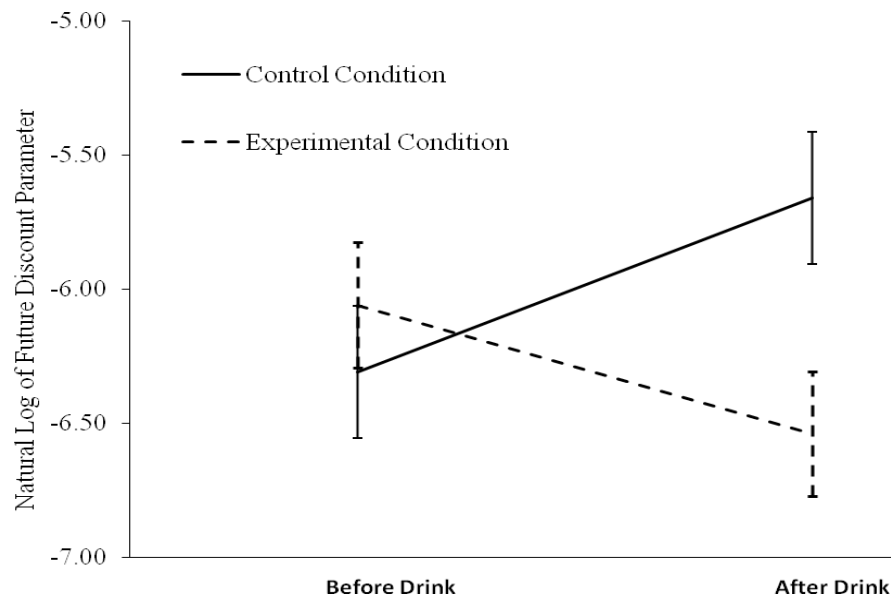
A Levene's test of homogeneity of variance was significant for the Time 2 discounting parameter, thus we performed a natural log transformation on the discounting parameters to normalize the variable distributions. Following the transformation, the Levene's tests for both Time 1 (T1) and Time 2 (T2) discounting parameters were non-significant. There were no

differences in gender distribution across conditions, $\chi^2(1) = 0.37, p_{rep} = .46$. There were no differences between the control and experimental conditions in age (control: $M = 23.61, SD = 5.88$; experimental: $M = 22.56, SD = 2.50$; $t(63) = 0.93, p_{rep} = .74$), body mass index (control: $M = 23.75, SD = 3.92$; experimental: $M = 24.85, SD = 5.17$; $t(63) = 0.97, p_{rep} = .66$), pleasantness ratings of the drink (control: $M = 5.42, SD = 2.02$; experimental: $M = 5.19, SD = 2.29$; $t(63) = 0.44, p_{rep} = .34$), T1 blood glucose levels (control: $M = 98.58, SD = 12.95$; experimental: $M = 94.41, SD = 11.33$; $t(63) = 1.43, p_{rep} = .83$), nor the natural log of T1 future discounting (control: $M = -6.26, SD = 1.61$; experimental: $M = -6.11, SD = 1.32$; $t(63) = 0.43, p_{rep} = .33$). There was a small, but significant decrease from T1 blood glucose ($M = 98.58, SD = 12.95$) to T2 blood glucose ($M = 94.39, SD = 12.18$) in the control condition, $t(32) = 3.32, p_{rep} = .998$, Cohen's $d = 0.58$. In contrast, there was a considerable increase from T1 blood glucose ($M = 94.41, SD = 11.33$) to T2 blood glucose ($M = 125.28, SD = 22.95$) in the experimental condition, $t(31) = 8.40, p_{rep} > .999$, Cohen's $d = 1.49$. As predicted, an ANCOVA controlling for T1 blood glucose showed T2 blood glucose was significantly higher in the experimental, relative to the control, condition, $F(1, 62) = 77.90, p_{rep} > .999, \eta_p^2 = 0.56$.

Primary analyses of effects of blood glucose on future discounting parameter

We tested a mixed within-between ANCOVA, with Condition as the between subjects factor and the natural log of the discounting parameters at Times 1 and 2 as the within subjects factor. Gender, T1 blood glucose, time of day, and pleasantness of the drink were added as covariates in order to rule out possible effects of these factors on future discounting due to sex differences in metabolism, the length of fasting, or mood-dependent choice preference. As predicted, there was a significant interaction between Condition and Time (i.e., T1 future discount to T2 future discount), $F(1, 59) = 15.61, p_{rep} > .999, \eta_p^2 = 0.21$. This was the only significant predictor in the model. As depicted in Figure 1, there was a decrease in future discounting after a sugar drink, $t(31) = 2.55, p_{rep} > .95$, Cohen's $d = 0.45$; but an increase in future discounting after a zero-calorie drink, $t(32) = 3.12, p_{rep} > .99$, Cohen's $d = 0.54$.

Figure 1. Paired contrast effects of the Condition x Time interaction for the future discounting parameter

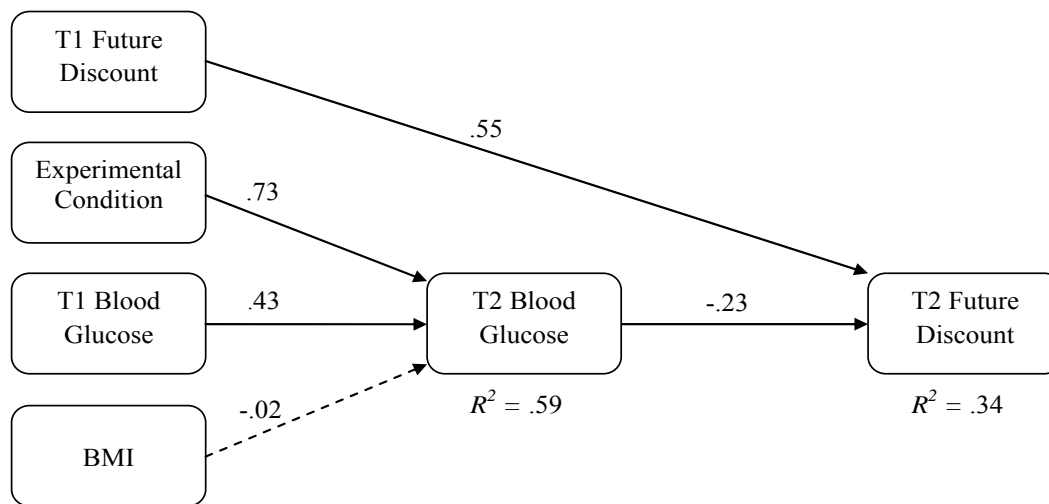


Note. Error bars are based on 95% Confidence Intervals of the mean within each group at the two separate time points.

We also conducted an observed variable path analysis using Mplus 5.1 with maximum likelihood (ML) estimation (see Figure 2). T2 future discounting was specified as the endogenous variable, T2 blood glucose as the mediator variable, and Condition and Body Mass Index were specified as exogenous variables. T1 blood glucose and future discounting were added as exogenous covariates on their respective T2 endogenous criterions. The model showed excellent fit of the data, $\chi^2(4) = 2.77$, $p_{rep} = .40$, CFI = 1.00, RMSEA = .00, SRMR = .035.

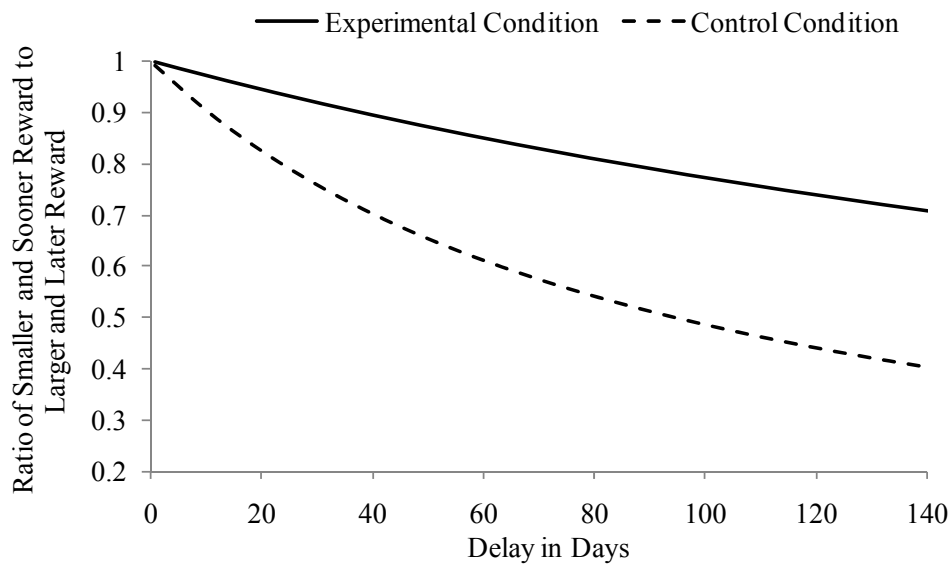
Condition was positively associated with T2 blood glucose. T2 blood glucose was negatively associated with T2 future discounting. The model shows that the effect of Condition on T2 future discounting was fully mediated by change in blood glucose; thus, the observed difference in T2 future discounting between conditions is due solely to the experimental manipulation on blood glucose. As shown in Figure 3, the hyperbolic discounting curves at T2 between the two conditions were markedly different, with the control condition having a steeper discounting rate.

Figure 2. Path model depicting hypothesized mediated effect of change in blood glucose on future discounting.



Note. All paths are standardized coefficients. Solid paths are significant ($p_{rep} > .95$); dashed path is non-significant ($p_{rep} < .95$).

Figure 3. Mathematical extrapolation of hyperbolic discounting curves over time based on k values of the glucose-drink group and zero-calorie drink group. The ratio of SS/LL = $1 / (1 + k * \text{delay})$, where k is the delay discounting parameter derived from the choice data.



Discussion

Our results showed that human preferences for future versus current rewards fluctuated from moment to moment based on blood glucose levels. As actually measured in the lab, increasing blood glucose levels via a caloric drink led to an increase in the value placed on future rewards. In contrast, a 'zero-calorie' drink led to an increase in the value placed on current rewards. These findings suggest an adaptive mechanism linking human decision making to metabolic cues indicating environmental scarcity on a micro level. Moreover, artificial sweeteners may alarm the body about caloric crisis, leading to increased body weight and obesity. In fact, (Swithers & Davidson, 2008) in a recent study showed that rats eating sweet non-caloric substances increased food intake and/or reduced energy expenditure. Contrary to the advertised notion that 'sugar-free' products are the key to weight loss, humans who consume artificial sweeteners gain more weight than those who do not (Stellman & Garfinkel, 1986). Similarly, DeCesare and Honey (2009) found that participants exposed to sweetener trials showed a smaller blood glucose response to a sugar drink compared to participants in the control group, suggesting that artificial sweeteners may disrupt body metabolism by altering responses to sweet foods that do contain calories.

Although unpredicted, an energy budget regulation model can account for the observed increase in future discounting rate after non-sugar drink as a response to a detected caloric problem due to the use of artificial sweetener. However, it would be more difficult for a cognitive resource model to account for this finding. Future research should continue to distinguish these two mechanisms in inter-temporal choice.

In a recent paper, Briers, Pandelaere, Dewitte, and Warlop (2006) argue that people's desire for money is a modern derivative of their desire for food. Consistent with this argument, they showed that hungry people were less likely than satiated people to donate to charity. Helping behaviors appear to be regulated in part by glucose levels (see DeWall, Baumeister, Gailliot, & Maner, 2008; Gailliot et al., 2007). People often help in hopes of future reciprocity. Perhaps low blood glucose undermines current helping because future reciprocity is more discounted.

A variety of hints in the literature suggest that there is a multitude of regulation on future discounting and intertemporal choice, ranging from actual life-span of a person (Wilson & Daly, 1997), his/her subjective life expectancy (Hill, Thomson Ross, & Low, 1997), life-history traits (Wang et al., 2009), situational variables (Wilson & Daly, 2004), to physiological factors (Kirby, Petry, & Bickel, 1999; McClure, Laibson, Loewenstein, & Cohen, 2004). Although this study is only an analog experiment and thus generalization must be tempered, it adds to the list a metabolic mechanism of using daily fluctuating blood glucose levels as cues in regulating body energy balance and its behavioral manifestation in future discounting. If regulating blood glucose levels can affect delay (future) discounting, reducing the degree of fluctuation in blood glucose may offer a possible means for the treatment and intervention of some impulsive behaviors as seen in compulsive and impulsive disorders, anorexia, drug addiction, and gambling addiction. Metabolic disorders such as diabetes may also affect delay discounting so that people with diabetes might fail to eat properly and exercise because these tend to benefit the person in the future more than in the present. The findings of the present study fortify the idea that future discounting varies adaptively as a function of multiple levels of life-history and daily adjustments, and suggest that it may be more dynamic than has been assumed.

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