

RESEARCH ARTICLE

Perceived food palatability, blood glucose level and future discounting: Lack of evidence for blood glucose level's impact on reward discounting

Rafał Muda^{1*}, Przemysław Sawicki², Michał Ginszt³

1 Faculty of Economics, Maria Curie-Skłodowska University, Lublin, Poland, **2** Centre for Economic Psychology and Decision Sciences, Kozminski University, Warsaw, Poland, **3** Department of Rehabilitation and Physiotherapy, Medical University of Lublin, Lublin, Poland

* muda.research@gmail.com

Abstract

Some previous studies have shown that an increase in blood glucose level makes people more future oriented, however, results are inconsistent, other studies failing to replicate this effect. Here, we tested whether psychological factors (in this instance, perception of food pleasantness after consumption of more palatable or less palatable meal) can play a moderating role. We hypothesized that consuming more palatable food (perceived as rewarding) should cause blood glucose levels to affect future discounting, but that this should not occur for the consumption of less palatable food. A high-powered, independent groups experiment ($N = 149$, power $\beta = .90$) showed that, subsequent to performing an initial discounting task, the two groups consuming a meal (a control group consumed no meal) displayed a significant increase in blood glucose levels 10 minutes after meal consumption and just before repeating the discounting task. However, the increased blood glucose levels did not cause changes in delay discounting in either experimental group.

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Introduction

Both media coverage and scientific studies have highlighted the fact that blood glucose plays a substantial role in fueling the human brain. Blood glucose has been connected with a wide range of behaviors and aspects of cognitive performance, e.g., memory [1], visuospatial task performance [2], and delay discounting [3, 4]. In the latter case, previous work shows that an increase in blood glucose level shifts people's preferences toward being more future oriented [4, 5]. Simply put, a high level of blood glucose prompts greater patience, people preferring to wait for later larger rewards instead of taking sooner and smaller rewards [3–5]. However, recent literature on blood glucose levels and delay discounting has shown some inconsistency, papers appearing which show no effect [6, 7]. One recent paper [8] has proposed that blood glucose level's effect on decision-making processes might be moderated by self-motivation factors, it being suggested that the pleasantness of a consumed meal is a rewarding experience which shifts people's preferences [9]. The current work aimed to test this suggested mechanism. Support for

this notion would open up the possibility of developing effective intervention methods to help people overcome impulsive behaviors resulting from a lack of patience.

People characterized by steeper discounting are at greater risk of substance abuse and obesity, and are more likely to engage in risky behaviors such as over-borrowing and risky sexual activity—for a review, see [10]. Steep delay discounting means that an individual would prefer to receive a sooner smaller reward instead of waiting for a larger later reward [11]. Because such maladaptive behaviors lead to both significant societal and economic costs [12, 13], researchers have attempted to find methods of reducing the steepness of delay discounting in people, and methods which have been found to be effective include: engaging in episodic future thinking [14, 15], spending time out of doors or generally cueing thoughts of nature settings (i.e., presenting nature photos prior to making delay discounting decisions) [16, 17], and, as previously mentioned, increasing people's blood glucose levels [3–5].

A close look at studies of the effect of blood glucose on delay discounting reveals three strands of findings: (1) a first strand showing that increasing blood glucose levels via caloric intake serves as a metabolic cue providing an organism with information that it can afford to be more patient in waiting for subsequent rewards [3]; (2) a second strand showing that simply registering a sweet flavor in the mouth (without any caloric intake) can serve as a psychological factor that produces the same effect as increasing blood glucose level via food intake [18, 19]—this happens because sensing carbohydrates activates regions of the brain engaged in reward processing [20, 21]; (3) a third strand consisting of studies that have failed to replicate the finding that blood glucose levels have an effect on delay discounting [6–8].

In the current work, we attempted to combine findings from the above mentioned strands of research: we sought to test whether the effect of blood glucose on delay discounting is moderated by psychological factors. We hypothesized that food consumption (and in turn an increase in blood glucose level) would impact delay discounting when more palatable food—perceived as rewarding—was consumed (we operationalized this as a psychological factor), but that there would be no effect when less palatable food was consumed. This hypothesis was based on findings showing that food and monetary rewards are processed similarly in the brain [22], and that reward magnitude influences how our brains process the receipt of rewards [23]. We reasoned that the more palatable food should produce a signal strong enough to activate the reward system, and thus shift people's preferences toward larger and later rewards, whereas the less palatable food should be less likely to be rewarding enough to have such an impact.

It should be noted that either soft drinks or glucose have been used to increase blood glucose levels in almost all previous studies. All of these are sweet and should also activate the motivational mechanisms potentially underlying the effect under examination, and in a study using the same procedure as previous studies, but in which a more complex meal was used (i.e., solid food with complex nutritional values), the effect of blood glucose on delay discounting was non-significant [8]. Thus, we believe that the proposed mechanism whereby psychological perceptions of food moderate the effect of blood glucose level on delay discounting has not been adequately tested previously.

Materials and methods

Participants

We recruited 155 participants through an external research company. The sample size was determined using sensitivity analysis, with $N = 153$ providing $\beta = .90$ power to detect an effect as small as $f = 0.08$ ($d = 0.16$), assuming a correlation among repeated measures of $r = 0.85$, three groups, and two measurements [24]. All participants were informed that the study was

investigating the association between blood glucose levels and financial decision making, with real-life payoffs being conditional on their choices. All the participants were healthy individuals in the age range 18 to 35 years who were not on a diet excluding their consumption of the ingredients of the meals provided (e.g., they were not vegetarians or vegans). Seven participants were excluded before our main analysis because they did not meet the inclusion criteria relating to discounting task consistency, and it was therefore impossible to compute their discount parameters (see the delay discounting task section for more details). Thus, we analyzed data for 149 participants ($M_{\text{age}} = 23.4$ years, $SD_{\text{age}} = 3.70$ years; 67.8% females). Participants had an average weight of 66.9 kg ($SD = 13.00$), an average height of 171 cm ($SD = 8.28$), and an average BMI of 23.00 kg/m² ($SD = 3.39$).

Procedure

The study was carried out according to the Helsinki Declaration's recommendations and with the consent of the Ethics Committee of the Kozminski University. During an online recruitment procedure (service done by Flow Research Center, Poland) participants were informed about the study's objectives and asked to visit our laboratory on an empty stomach at least 6 hours after their last meal. We also instructed them not to eat or drink sweet beverages or alcohol the evening day before they participated in the experiment. The experiment commenced between 8 a.m. and 10 a.m. The whole procedure was run during one session. Participants began by providing written consent for their participation, and then anthropometric measures (height and weight) were taken. Next, the first measurement of blood glucose level was taken by a trained paramedic. A blood sample was taken from the middle, ring, or small finger of participants' non-dominant hands using an Optium Xido blood glucose monitor (manufactured by Abbott Diabetes Care Inc., Alameda, CA, USA), in accordance with World Health Organization guidelines [25]. We collected capillary blood samples rather than venous blood since the former is more sensitive to glycaemic responses and displays lower between-subjects variation [26].

After their blood glucose level was measured, participants completed the discounting task for the first time. To increase their engagement, we informed them that they would have the opportunity to win a prize, which would be dependent on a choice they made: one randomly selected choice from both measurements would be realized in line with the characteristics of the alternative they chose. For example, if they opted for a larger later reward such as 200 PLN (about USD 50) in two weeks on the choice selected for payment, they received a 200 PLN payment two weeks after the experimental session. The payment was delivered to participants by a research assistant.

The discounting task was followed by a meal eating phase. Depending on their experimental condition (randomly selected for each participant), participants ate a more palatable meal, a less palatable meal (the taste of these meals was pre-tested, see [S1 Appendix](#) for more details), or did not receive a meal. After eating a meal, participants rated the taste of their meal (in line with the method proposed by Flint et al. [27] and Symmonds et al. [28], see [S1 Appendix](#) for the questionnaire used). Next, participants moved to a resting room for a 10 minute break, and had the opportunity to listen to music on a tablet computer using headphones. Subsequently, a second blood glucose measurement was taken, and participants performed the discounting task again (this was a repetition of the initial discounting task). The timeline of the experiment is presented in [Fig 1](#).

The delay discounting task. To measure future discounting at both time points, participants completed the Monetary Choice Questionnaire (MCQ) [29]. This questionnaire consists of 27 choices between smaller sooner and larger later payoffs in the domain of gains (e.g., \$69 "now" or \$85 in 91 days). For each choice, a discount-rate parameter k can be estimated. The MCQ characterizes respondents using 9 groups of different discount-rate parameters (i.e., for each group, three choices have the same k value but differ in their payoffs and delays, e.g., the

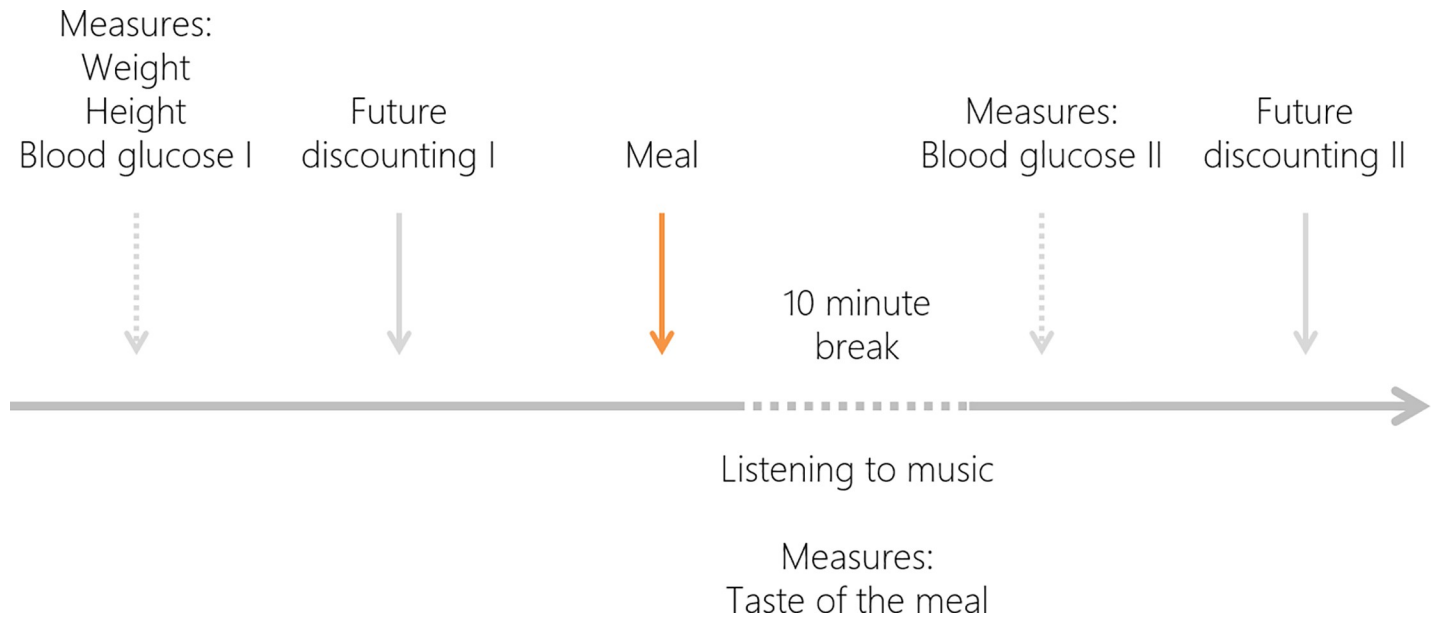


Fig 1. Timeline of the experimental procedure.

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trials “\$19 now or \$25 in 53 days”, “\$40 now or \$55 in 62 days”, and “\$55 now or \$75 in 61 days”, all have a k value of 0.006). To correctly estimate a discount-rate parameter for a person, a certain amount of consistency among preferences is necessary, i.e., for a specific group of choices a person should consistently select smaller sooner options or consistently select larger later options. If consistency is lower than 80% it is impossible to estimate a person’s discount-rate parameter and it is necessary to exclude their data from analysis [30].

Meals. Two types of meal were prepared so that they had different sensory profiles (a more palatable meal and a less palatable meal). Both meals were identical in appearance (the meal itself, the type of plate, and the cutlery supplied), main food ingredients, total calories (550 kcal), and the percentage of calories contributed by different nutritional contents (carbohydrates 55%, fat 20%, protein 25%). The only difference was in the way the meals were prepared and the condiments that were used: the less palatable meal had almost no salt and pepper added, contained non-juicy dry meat and burnt sun-dried tomatoes (which made the tomatoes taste bitter), and had overcooked potato dumpling. All these features were intended to make the less palatable meal less pleasant. The meals were prepared by the same experienced cook immediately prior to consumption. All participants given a meal received a glass of still water (250 ml) with their meal. A researcher was present during consumption of the meal to ensure compliance with procedural requirements. The entire meal was consumed within a time period of between 5 and 15 minutes.

Statistical analyses

2x3 ANOVA with the first factor referring to time of measurement (pre-manipulation vs. post-manipulation; within-subject) and the second factor referring to consumed meal (more palatable meal vs. less palatable meal vs. no meal; between-subject) was used to assess changes in: (1) blood glucose level, and (2) participants’ discount parameters.

To test whether the experimental manipulation was successful (in terms of experimental group participants’ perceptions of their meal’s pleasantness), we computed a mean value from ratings of smell, taste, aftertaste, and palatability, and compared the resulting values using an

independent samples *t*-test with meal (more palatable meal vs. less palatable meal) as a grouping variable.

All post-hoc tests were Bonferroni corrected.

Data and code are to be found: <https://osf.io/5fnwr/>

Results

The experimental manipulation's effect on perceptions of meals' pleasantness

As predicted, we observed a significant difference in perceptions of the pleasantness of the meals served, $t(101) = 6.55, p < .001, d = 1.30 [0.82, 1.77]$: on a scale from 0 to 10, participants in the more palatable meal condition rated their meal as highly pleasant ($M = 8.09, SD = 1.45$), whereas participants in the less palatable meal condition only rated their meal's pleasantness as moderate ($M = 5.77, SD = 2.00$ –see Fig 2 for more details). Thus, we concluded that our experimental manipulation was highly successful.

Blood glucose levels

The ANOVA for blood glucose levels revealed significant main effects for both time of measurement, $F(1, 145) = 163.1, p < .001, \eta_p^2 = 0.529$, and meal, $F(2, 145) = 18.5, p < .001, \eta_p^2 = 0.203$. There was also a significant time of measurement x meal interaction, $F(2, 145) = 49.8, p < .001, \eta_p^2 = 0.407$. Decomposing the interaction, we observed increases in blood glucose after consuming meals for both the group given the more palatable meal, $t(145) = 8.63, p < .001$, and the group given the less palatable meal, $t(145) = 14.67, p < .001$, but not for the group given no meal, $t(145) = -0.27, p > .999$. These results also suggested that the experimental manipulation was robust. Detailed results are presented in Fig 3.

Individual discount parameters

Regarding this analysis, we extended the classical NHST analysis (based on *p*-values) with Bayesian analysis. Bayesian analysis allow not only to accept the alternative hypothesis but

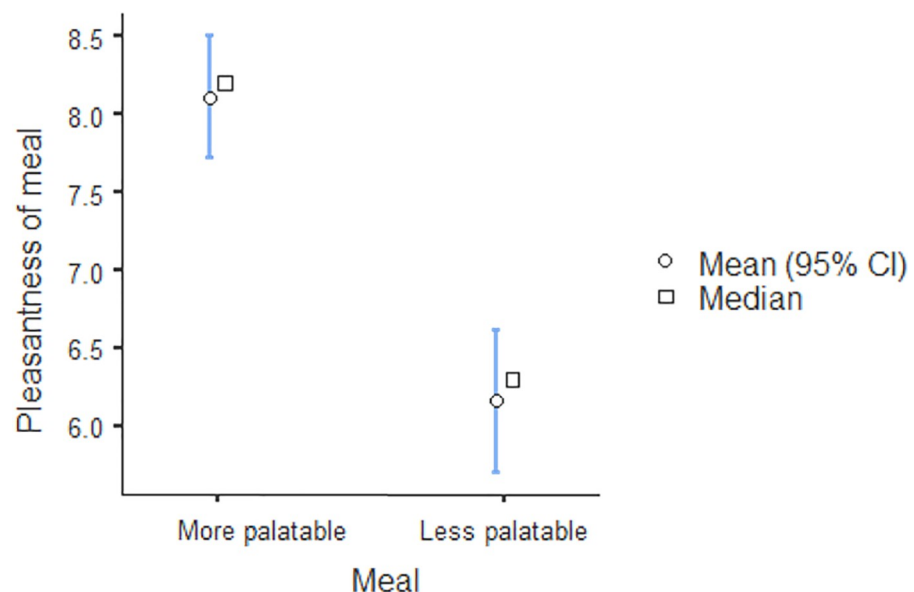


Fig 2. Pleasantness of meals according to experimental condition.

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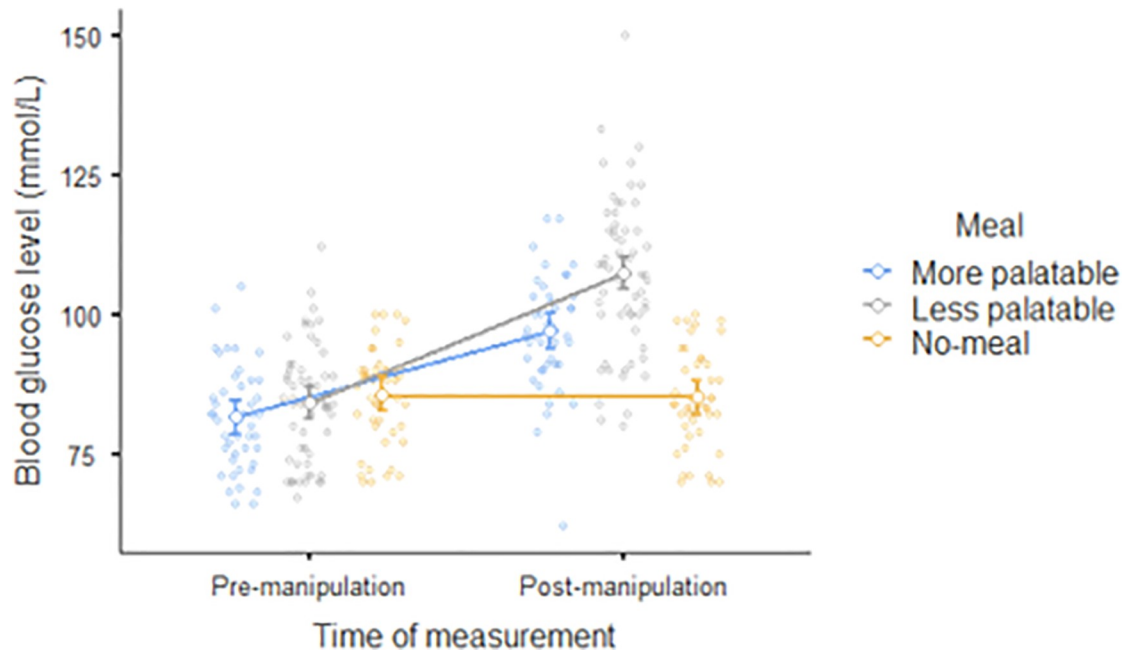


Fig 3. Mean pre-manipulation and post-manipulation levels of blood glucose for three groups varying in meal consumption. Dots indicate observed scores.

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also to support null effects. Specifically, Bayes factor weights evidence supporting null and explicitly stated hypothesis giving the precise ratio of support. For example, $B_{10} = 10$ suggests that alternative hypothesis is 10 times more likely than the null, given the data collected. Or that 10 out of 11 times such results would be obtained given H1 being true. Prior to analysis, we estimated participants' discount parameters with the dedicated auto-scoring provided by Kaplan and colleagues [30], which returns natural log k values fitted to a hyperbolic curve. Lower log k values indicate less-steep discounting of future rewards. ANOVA results revealed only a significant main effect of time of measurement, $F(1, 146) = 5.57, p = .020, \eta_p^2 = 0.037, BF_M = 5.54, BF_{10} = 2.23$. Participants showed steeper discounting of future rewards when performing the discounting task for the second time (see Table 1 for more details). Neither the main effect of meal, $F(2, 146) = 0.36, p = .700, \eta_p^2 = .005, BF_{10} = 0.17, BF_{exclusion} = 7.95$, nor the time of measurement x meal interaction, $F(2, 146) = 0.54, p = .586, \eta_p^2 = 0.007, BF_{10} = 0.40, BF_{exclusion} = 22.27$ was significant. Results of Bayesian analysis (run with default priors) showed that the best model included

Table 1. Mean levels of participants' discount parameters (log k) for pre-manipulation and post-manipulation measurements. Lower values indicate steeper discounting of future rewards.

Meal	Time of measurement	Mean	SE	95% Confidence Interval	
				Lower	Upper
More palatable	Pre-manipulation	-1.96	0.0996	-2.16	-1.77
	Post-manipulation	-2.01	0.0996	-2.20	-1.81
Less palatable	Pre-manipulation	-1.88	0.0943	-2.07	-1.70
	Post-manipulation	-2.04	0.0943	-2.23	-1.86
No-meal	Pre-manipulation	-1.82	0.0991	-2.02	-1.62
	Post-manipulation	-1.94	0.0991	-2.14	-1.75

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only effect of time of measurement. Inclusion of meal effect and meal x time of measurement interaction into the model provided evidence against the idea that increase in blood glucose level nor pleasantness of the meal consumed impacted discount rates. Note that $BF_{\text{exclusion}} = 22.27$ means that our data changed the odds in favor of models that do not include the specific predictor by a factor of 22.

Discussion

We observed no evidence that increases in blood glucose levels lead to changes in future discounting of monetary rewards. This was true both for meals perceived as highly pleasant and for meals perceived as only moderately pleasant. In general, people consuming meals made the same decisions as those not consuming meals, whose blood glucose levels were not changed. We observed a decrease in strength of future discounting among all three groups: participants slightly changed their preferences toward larger later payoffs after 10 minutes waiting time. These results provide evidence that increasing people's blood glucose levels using food with complex nutritional contents (as opposed to sweet beverages) does not influence future discounting levels [8]. In a more general sense, the results also provide additional evidence about the lack of a connection between blood glucose levels and discounting of monetary rewards, and confirm some other previous findings also showing that increases in blood glucose levels do not impact delay discounting [6–8].

Our findings add various insights to the debate as to whether either energy factors are solely responsible for changes in delay discounting (e.g., food ingestion, [5, 31]) or whether motivational aspects also play a part (e.g., as tested in studies where people rinse their mouths with a sugared beverage without swallowing it [18, 19]). In a recent paper [8] in which no changes in delay discounting were observed even in the presence of extremely large increases in blood glucose levels, it was theorized that behavioral responses to increases in levels of blood glucose might be conditional on the type of meal consumed. More specifically, it was suggested that the food consumed needs to be desirable and produce rewarding feelings. Simply put, the food needs to be tasty and perceived as something more pleasant than the usual homemade breakfast. In our experiment, we manipulated the taste of meals very successfully while keeping their caloric and nutritional values at the same level in both the more palatable and less palatable meal groups. If the hypothesis suggesting a mediating role for the pleasantness of a meal is true, people given a tasty meal should be more patient (i.e., prefer larger later rewards), whereas people given a less tasty meal should not change their preferences. But this was not the case. Instead, we observed no difference between the relevant groups. The current results suggest either that the previously proposed mechanism might not play as significant a role as supposed, or that more rewarding food is needed, e.g., a hamburger or pizza. The need for different kind of food might be highly plausible explanation irrespectively of observed differences in perception of pleasantness of consumed meal between meal-groups—the more pleasant meal was rated on more than 8 on a 10 point scale, but this was a dinner-type meal. On a reflective level such a meal might be perceived as highly pleasant. On the deeper level, such a food rather does not produce crave to eat it once again or will not lead to overeating (in contrast to fast foods that might create addiction [32]). As we collected only self-rated measures, we do not have data to confirm above explanation. This would require neuro-imagining study what we perceive as interesting avenue for further research.

Another possible explanation for the present observation is that only sweet beverages cause blood glucose levels to have an effect on delay discounting: solid foods do not produce the same effect. To date, almost all studies have increased blood glucose levels by either using soft drinks with sugar or glucose itself [3, 5–7, 31]. To our best knowledge, only one previous study

has used solid food, and this found no effect of blood glucose levels on delay discounting in the two experiments performed [8]. These differences may be attributable to differences in glucose responses between solid and liquid foods with comparable energy densities [33]. We cannot definitely state whether this is true on the basis of our data, but this possibility is a promising avenue for future research.

It is also possible that blood glucose levels did not influence delay discounting because of the task we used: delay discounting in a non-food domain was considered. As a recent meta-analysis on risk taking and blood glucose levels shows, low levels of blood glucose increase willingness to take risks, but only with respect to food: the effect does not transfer to non-food-related activities such as gambling [34]. This would suggest that low levels of blood glucose (i.e., hunger) should change people's preferences toward smaller sooner food rewards, but that they should not affect preferences in the domain of monetary rewards. Future studies are needed to confirm this reasoning.

Finally, we should stress that we are not claiming that blood glucose does not impact delay discounting. In this paper, we have reported the results of only one experiment, and, although the experiment was highly-powered and adopted virtually the same procedures as those used in previous studies of blood glucose and delay discounting (see e.g., [3]), there are still questions to be answered and potential moderators to be tested (e.g. previously mentioned fast foods).

To summarize, we aimed to test whether food pleasantness moderates the relationship between people's blood glucose levels and delay discounting. We successfully manipulated perceptions of meal pleasantness while controlling for caloric and nutritional values. We also successfully increased the blood glucose levels of two groups of participants consuming meals, but this did not lead to changes in delay discounting levels in either of these groups—there are several possible reasons for this observation which should be considered in future studies.

Supporting information

S1 Appendix. Appendix glucose paper.

(DOCX)

S1 Data.

(RAR)

Author Contributions

Conceptualization: Rafał Muda, Przemysław Sawicki, Michał Ginszt.

Data curation: Rafał Muda.

Formal analysis: Rafał Muda.

Funding acquisition: Przemysław Sawicki.

Investigation: Rafał Muda, Michał Ginszt.

Methodology: Rafał Muda, Przemysław Sawicki, Michał Ginszt.

Project administration: Rafał Muda, Michał Ginszt.

Validation: Rafał Muda.

Visualization: Rafał Muda.

Writing – original draft: Rafał Muda.

Writing – review & editing: Rafał Muda, Przemysław Sawicki, Michał Ginszt.

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