Faculty of Humanities and Social Sciences

Exercising rationality: Exercise induced elevated glycemic response and cognitively effortful decision making

2015 | Sara Saeedi

B.A. Applied Psychology (Honours) Thesis

DOUGLAS COLLEGE

EXERCISING RATIONALITY:

EXERCISE INDUCED ELEVATED GLYCEMIC RESPONSE AND COGNITIVELY EFFORTFUL DECISION MAKING

by

SARA SAEEDI

B.A. (Honours), Douglas College, 2016

A THESIS PRESENTED TO THE DEPARTMENT OF PSYCHOLOGY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE BACHELOR OF ARTS (HONOURS) DEGREE IN APPLIED PSYCHOLOGY

Faculty and Thesis Supervisor
Nicole Vittoz (PhD), Department of Psychology, Douglas College

B.A. Honours Thesis

April, 2015
Douglas College
New Westminster, British Columbia, Canada

DOUGLASCOLLEGE

Acknowledgements

The author would like to thank Stephanie Dacre for her incredible hard work and dedication as a research assistant and Dr. Nicole Vittoz for her role as thesis supervisor. Thanks also to Dr. Laura Dane for her help as program coordinator and to Dr. David Prime for his feedback on the thesis. The Office of Research and Scholarly Activity at Douglas College supported this project with an award from the RSAPF.

Exercising Rationality:

Exercise Induced Elevated Glycemic Response and Cognitively Effortful Decision Making

Sara Saeedi

Douglas College

Abstract

This study observed Systems 1 (heuristic) and Systems 2 (cognitively effortful) decision making styles in individuals undergoing high and low intensity exercise versus a no exercise control group. The attraction effect and delay discounting were measured to test the hypothesis that post exercise hyperglycaemia can reduce heuristic-based decision making and increase cognitively effortful decisions. Individual differences in decision making traits were also assessed using the General Decision Making Styles questionnaire. Results showed that high-intensity exercise can induce elevation in blood glucose; however this effect was observed only in half the sample. Participants in the high intensity exercise condition were significantly more likely than those in the low intensity exercise condition to elicit post exercise hyperglycaemia. Additionally, results from this study show that higher blood glucose is associated with a greater probability of choosing the non-heuristic option in the apartment task; thus signifying less reliance on heuristic based System 1 decision making. Furthermore, in the delay discounting task, exploratory analyses suggest that high-intensity exercise-induced hyperglycaemia may rescue optimal decision-making for individuals who tend to make more intuitive decisions (i.e., are more reliant on System 1). Further studies with larger sample sizes are needed to further elucidate the effects of exercise on decision making, taking into account blood glucose changes and individual difference profiles.

Key words: Decision Making, Attraction Effect, Delay Discounting, Exercise, Blood Glucose, Cognitive Resources

Exercising Rationality:

Exercise Induced Elevated Glycemic Response and Cognitively Effortful Decision Making

According to prominent theories, human beings make decisions through a dual-process procedure (e.g., Kahneman, 2003). These two processes include a speedy, heuristic-based, intuitive method referred to as System 1 and a slower, more logical, rule-based method referred to as System 2 (Kahneman, 2003). Previous research has proposed that System 2 decision making is an effortful process that is cognitively depleting and requires significant amounts of physiological resources, namely glucose (Masicampo & Baumeister, 2008). These researchers manipulated participants' blood glucose levels through the ingestion of sugar-sweetened lemonade, and found that drinking sugar-sweetened beverages increased System 2 reasoning while decreasing reliance on System 1 heuristics. Other tests of rational decision making and its reliance on blood glucose supply used delay or future discounting -- a paradigm in which greater future rewards are discounted (presumably by System 1) in favour of an immediate but lesser reward (Wang & Dvorak, 2010). Due to the elusive nature of the future, the idea of obtaining a reward at a future time requires more physiological resources than thinking about an immediate gain, thus low blood glucose levels result in greater reliance on System 1 and thus delay discounting (Wang & Dvorak, 2010). These results were complementary to other studies that depicted blood glucose as a metabolic fuel that is one factor that increases brain function thus allowing for more cognitively effortful System 2 processing (Masicampo & Baumeister, 2008; Pocheptsova, Amir, Dhar, & Baumeister, 2007).

Although previous studies have characterized the role of blood glucose on cognitively effortful and rational decision making, they have largely relied on directly increasing blood glucose through the ingestion of sugar (typically a sweetened beverage). To our knowledge, little research has examined more indirect methods of raising blood sugar (e.g. physical exercise) and its effect on decision making processes. Many studies have explored exercise effects on cognition in young and elderly populations (Colcombe & Kramer, 2003; Bielak, Cherbuin, Bunce, & Anstey, 2014; however few have addressed the impact of exercise on decision making in young adults). Glucose is one of the main fuels used by the body – primarily the brain and the muscles. During exercise two key factors involved in glucose regulation allow for enough fuel to reach the muscles that are mobilized: glucose production and glucose utilization (Marliss & Vranic, 2002). In intense exercise, glucose production rises to a much greater extent than glucose utilization (7-8 fold: 3-4 fold). Additionally, at exhaustion glucose utilization decreases at a much faster rate than production, generating a post-exercise hyperglycaemic state (Marliss & Vranic, 2002). In fact, previous research has reported this hyperglycaemic state in healthy lean subjects after a short period of intense exercise (> 80% VO2max) to be 20% above baseline glucose measures (Mitchell, Abraham, Schiffrin, Leiter, & Marliss, 1988). Short duration (15 minutes) intense exercise (> 80% VO2max) raised blood glucose during and immediately after exercise with the greatest blood glucose levels immediately after exercise cessation and sharp decline to reach baseline at 40 minutes into recovery period (Mitchell et al., 1988).

Based on these previous findings, we predicted that participants in the high-intensity exercise condition would exhibit higher levels of blood glucose than the participants who completed low intensity exercise. Our main hypothesis was that this increase in blood glucose would decrease both delay discounting rates and the prevalence of the attraction effect heuristic in high-intensity exercise participants. In addition, the decision-making traits of participants were measured to explore the possibility that individual differences in propensity to rely on System 1 processes would mediate the impact of exercise on both decision tasks.

Method

Participants

Sixty-three students from a western Canadian college between the ages of 18-30 (one 43 year old), took part in the experiment. Participants enrolled in applicable psychology courses received course credit in exchange for their participation, and all participants received a $2 café gift card.

Procedure

Participants were instructed to arrive at the experiment fasted (no food or drink except water) for thirty minutes prior. After giving informed consent and completing the PAR-Q questionnaire on exercise readiness, participants completed a short demographic questionnaire with questions regarding their sex and age, physical activity levels, sports team membership and attitude toward exercise (whether they consider it a treat or a chore).

Participants completed a short General Decision Making Styles questionnaire. The General Decision Making Style questionnaire (GDMS) consists of a series of questions designed by Scott and Bruce (1995) to determine how people make decisions based on the following five factors: rationality, intuitiveness, dependence, avoidance, and spontaneity. The questionnaire consists of 25 questions asking the participant to determine whether they agree or disagree with statements such as, “when making decisions, I rely upon my instincts,” on a scale from 1 (strongly disagree) to 5 (strongly agree).

Participants were randomly assigned to either low (60% VO2 max) or high (95% VO2 max) intensity exercise groups. A no exercise control group was added at the end of the study, so all later participants were assigned to this control group. Pre-exercise blood glucose levels were measured by a blood glucose monitor (FreeStyle Lite, Abbott 70417, Alameda, CA, USA).

Maximal heart rate (HRMax calculated as 220-age) was used to determine what intensity of exercise was appropriate for each participant to reach desired VO2 max for their assigned group (Swain, Abernathy, Smith, Lee, & Bunn, 1994). Then participants were given wrist heart rate monitors (Timex T5K470L3, Middlebury CT, USA) to wear throughout the exercise and initial heart rates were recorded.

Participants were then told to warm up for two minutes on a cycle ergo-meter at a comfortable pace. At the two minute mark, participants were told to cycle at the intensity previously calculated for them by monitoring their heart rates. They were told not to allow their heart rates to drop below the desired values and not to exceed desired values by 10 points. After 12 minutes cycling, participants stopped cycling and their post-exercise blood glucose levels were recorded. The procedure utilized to induce post exercise hyperglycaemia was modeled after a similar method by Mitchell et al. (1988). They were given water and allowed to rest for 5 minutes.

After 5 minutes, participants completed the Kirby Monetary Choice Questionnaire (Kirby, Petry, & Bickel, 1999). The Kirby Monetary-Choice Questionnaire consists of a series of 27 questions in which participants choose between a small, immediate monetary reward and a large delayed, monetary reward. This test includes questions such as “Would you prefer $54 today, or $55 in 117 days”. This questionnaire is used as a measure of delay discounting of rewards and can also indicate a participant’s impulsivity. In addition to the monetary questions, participants answered three exercise questions based on the same principle, such as “would you rather jog one km today or 5 km on the weekend.” The interpretation of the exercise choices was based on their response to the question on the demographic questionnaire regarding attitude toward exercise.

After the delay discounting task, participants in each exercise group were further divided into two groups and each group received an altered version of a consumer decision task designed to measure the attraction effect (Pocheptsova et al. 2007). Participants were told that they were to choose an apartment for the coming school term and were given three options based on apartment size and distance from campus. All participants saw two main options and one of two decoys (dependant on which version of the task they received). The decoy resembled one of the two main options but was an inferior choice based on both size and distance from campus. The theory behind this task was that cognitively depleted participants would be more likely to be swayed by the “decoy” and tend to pick the main option that it most closely resembled (i.e., the heuristic choice). The attraction effect was measured as a group-wise difference in propensity to choose the option closest to the decoy.

After both these tasks were completed, participants were debriefed regarding the rationale for the study and were thanked for their time. All measures and procedures received approval by the Douglas College Research Ethics Board.

Results

Blood Glucose Analysis

The experiment had two experimental conditions: low intensity exercise and high intensity exercise. The change in blood glucose between the two experimental groups, did not show a significantly different change in blood glucose in high intensity exercise conditions (HIGH M = -0.018, SEM = 0.31) compared to those in low intensity exercise conditions (LOW M = -0.415, SEM = 0.10; t (25) = 1.24, P = 0.23). However, a chi-square test of independence revealed that participants in the high intensity condition were significantly more likely than those in the low intensity condition to show an increase in blood glucose (11 of 22 vs. 3 of 20; $\chi^2(1) = 5.306$, P = 0.021). Half of the participants in the high exercise condition (11 of 22) exhibited post exercise hyperglycaemia. Furthermore, for those participants who exhibited an increase in blood glucose, there was a difference in the average size of the increase for the two exercise conditions, though with only three such participants in the low-exercise sample the mean difference was not significant according to a t-test (HIGH M = 1.000, LOW M = 0.167; t (12) = 1.658, P = 0.12).

Apartment Task

The experiment had a 3 (no exercise control vs. low intensity exercise vs. high intensity exercise) X 2 option sets between-subjects design. Table 1 summarizes the features of each apartment option and the choice frequency of each option. Even though three apartment choices were given in each set, it was correctly assumed that no participant would choose the decoy option (A_{Decoy} or B_{Decoy}), therefore leaving a binary choice between options A and B. The attraction effect was observed if the choice frequency of option A was greater in the set with A_{Decoy} or if the choice frequency of option B was greater in the set with B_{Decoy}. Table 1 summarizes the findings and shows an attraction effect in all conditions.

A "heuristic choice" was observed if option A was chosen when A_{Decoy} was present or option B was chosen when B_{Decoy} was present. A "non-heuristic" choice was observed if option B was chosen when A_{Decoy} was present or option A was chosen when B_{Decoy} was present. Figures1.1 and 1.2 illustrate the proportion of participants in each condition (no exercise, low intensity exercise, and high intensity exercise) who made heuristic or non heuristic choices respectively. A chi square test determined that the three exercise conditions did not significantly differ in the probability of selecting the non-heuristic apartment choice ($\chi^2(2) = 4.814$, P = 0.09).

However, when final blood glucose readings were included in a logistic regression analysis of apartment choice, a significant prediction model resulted ($\chi^2(5) = 12.412$, $P = 0.03$). Higher final blood glucose readings were associated with a greater probability of choosing the non-heuristic choice, though this tendency is much more pronounced in the high-exercise group than the other two conditions (see Figure 2).

Delay Discounting

Discounting curves for each participant were calculated using an Excel spreadsheet available for the 27 item Kirby Monetary Choice Questionnaire at the KU ScholarWorks website (Kaplan, 2014). Participants' delay discounting rates were calculated as "k", the point of indifference between small, immediate rewards and large, delayed rewards. The typical k values for delay discounting tasks are between 0.0 and 0.5 with higher values signifying strong delay discounting: preference for immediate rewards even when they are smaller. Kirby "k" scores were transformed using natural log (ln) prior to inclusion in analyses as a dependent variable. This improved the normality of the k distributions and is a commonly used tactic in the analysis of the k measure of delay indifference (e.g. Duckworth, Tsukayama, & Geier, 2010). Transformed k scores will be referred to as "delay discounting scores" from this point onwards.

When analyzed independent of blood glucose changes or individual differences, a one-way ANOVA revealed no significant effect of exercise condition on delay discounting as operationalized by the Kirby measure ($F(2,59) = 1.128$, $P = 0.331$; see Figure 3). In fact, participants who completed the questionnaire without exercising beforehand appeared to be slightly more resistant to delay discounting as compared to those in both exercise conditions.

However, blood glucose increases only occurred in half of the high-intensity exercise participants, suggesting that this variable should be included in analysis. To aid interpretability, blood glucose increase was coded as a binary variable: blood glucose increase vs. no blood glucose increase. For this analysis only low- and high-intensity exercise groups were included (as no-exercise groups only had one blood glucose measurement). A 2x2 two-way ANOVA (factors: exercise condition, blood glucose increase) also revealed no significant effects of exercise ($F(3,37) = 1.17$, $P = 0.286$) or blood glucose ($F(3,37) = 2.378$, $P = 0.132$, see Figure 4). The condition x blood glucose interaction was also not significant ($F(3,37) = 2.44$, $P = 0.127$).

Although there were no significant groupwise differences in delay discounting scores, we explored the possibility that individual differences in decision making style might introduce variability that could be extracted in a regression model. To account for individual differences in decision making, scores on each profile (rational, irrational, intuitive, dependent, and avoidant) from the General Decision Making Styles Questionnaire (GDMS) were calculated for each participant. The only GDMS profile to be significantly correlated to delay discounting was intuitive decision making ($r = 0.38$, $P = 0.03$). Rational, spontaneous and avoidant decision making profiles had no predictive power for delay discounting in this model. To account for the possibility that all three factors may contribute in a synergistic way to explaining delay discounting, a best fit regression model was built based on maximizing R^2 and allowing up to 4 variables, including GDMS intuitive scores as a covariate and exercise condition and blood glucose increase as factors. This generated a regression model that accounted for a substantial and statistically significant proportion of variance in delay discounting (Adjusted $R^2 = 0.364$; $F(7,33) = 4.269$, $P = 0.002$). In this model, the significant predictors for delay discounting were the 2-way interactions between GDMS intuitive scores x low-intensity exercise condition ($\beta = 6.007$, $P = 0.005$) and GDMS intuitive scores x no blood glucose increase ($\beta = -4.655$, $P = 0.03$). These predictors are qualified by a 3-way interaction among GDMS intuitive scores, blood glucose increase, and exercise condition (no blood glucose increase with high intensity exercise, $\beta = 7.022$, $P = 0.003$; blood glucose increase with high intensity exercise, $\beta = 2.387$, $P = 0.022$, see Figure 5).

Discussion

With this experiment, we set out to manipulate blood glucose levels of participants through exercise and to observe the impacts of this hyperglycaemia on cognitively effortful System 2 reasoning. Results from the experiment moderately supported the hypothesis that participants in the high-intensity exercise condition would exhibit higher levels of blood glucose than the participants who were in the low intensity exercise group and that this would support greater engagement in System 2-based decision making.

The current study set out to observe the impact of exercise on decision making through the lens of Kahneman and Tversky's dual processing model. This model assumes that decisions are made either based on heuristics (System 1) or logic (System 2), based on the availability of resources available for optimal cognitive functioning (Kahneman, 2003; Masicampo & Baumeister, 2008). According to the dual system model of thought processing, System 2 continuously monitors the heuristic judgments made by System 1. Errors of intuitive judgment occur when there is a suboptimal heuristic bias in System 1 that System 2 fails to correct (Kahneman, 2003). Numerous factors influence whether System 2 becomes engaged when people make a decision; one of those factors is glucose availability in the bloodstream (Kahneman, 2003; Masicampo & Baumeister, 2008). This study was based on the hypothesis that high intensity exercise could elicit a hyperglycaemic response in participants. This hyperglycaemia would mean that more glucose would be available in the blood stream as metabolic fuel that could possibly aid the intense brain function required to activate effortful System 2 processing. For this reason, glucose is thought of as one substance that helps enhance cognitive function (Gold, 1995). Due to its role in enhancing cognition, previous research has referred to glucose as one factor which allows for more cognitive resources to be available for System 2 or logic-based decision making (Masicampo & Baumeister, 2008; Wang and Dvorak, 2010).

Results from the current study showed that high-intensity exercise can induce elevation in blood glucose; however we found this effect only happened in half the sample. Consistent with our original hypothesis, participants in the high intensity exercise condition were significantly more likely than those in the low intensity exercise condition to experience post exercise hyperglycaemia. Additionally, results from this study show that higher blood glucose is associated with a greater probability of choosing the non-heuristic option in the apartment task; thus signifying less reliance on heuristic-based System 1 decision making. Furthermore, exploratory analyses examining patterns of individual variability in the delay discounting task indicate preliminary evidence that high-intensity exercise-induced hyperglycemia could potentially rescue System-2 based decision-making for individuals who generally tend to make more intuitive decisions.

Attraction Effect

The apartment choice task was used in this experiment to observe the effects of increased blood glucose on decision making. The apartment choice task was developed previously based upon the attraction effect theory, in which a binary decision between two equally appealing apartment choices was swayed by a third unappealing “decoy” option (Masicampo & Baumeister, 2008; Pocheptsova et al., 2009). The theory states that the person who was swayed by the decoy was likely falling prey to the heuristic option and thus utilizing System 1 heuristic-based decision making rather than System 2 logic-based reasoning (Pocheptsova et al., 2009). The results from this study showed that there was no significant difference between the three different exercise conditions (low intensity, high intensity, and no exercise) in the probability of choosing the non-heuristic apartment option. More interestingly however, when final blood glucose readings were taken into account, the probability of choosing the non-heuristic option increased with increase in blood glucose. This tendency was consistent with our hypothesis that increase in blood glucose would decrease the prevalence of the heuristic choice (see Figure 2). These results comprise moderate evidence that high-intensity exercise-induced hyperglycaemia increases System 2 engagement in a decision-making task.

Delay Discounting

Previous research has shown that the future is an abstract idea that requires more cognitive effort and thus requires System 2 reasoning when it comes to decisions related to the future (e.g. Kirby & Maraković, 1996). The current study was modeled after Wang and Dvorak’s (2010) experiment which examined the effects of blood glucose on a component of System 1 (heuristic-based) decision making known as delay discounting. Delay discounting refers to ignoring bigger future gains when faced with immediate but smaller gains; choosing smaller immediate rewards is a more heuristic-based process that does not require a lot of cognitive effort (Wang & Dvorak, 2010). Therefore our other main hypothesis was that due to the availability of more glucose to aid in optimal System 2 cognitive functioning, delay discounting scores would be lowest amongst participants in the high intensity exercise group. When independently analysing delay discounting scores between the different conditions, exercise condition did not have a significant effect on delay discount rates (see Figure 3). In fact, participants in the no exercise condition appeared to be slightly more resistant to delay discounting.

Decision Making Styles

It seems likely that interpersonal variability in decision making styles may greatly influence the ability of experimental manipulations to affect performance on decision making tasks. To test for interpersonal variability, the General Decision Making Style Questionnaire (GDMS) has often been administered to participants in decision making research (Scott & Bruce, 1995). The GDMS consists of a series of questions designed by Scott and Bruce (1995) to determine how people make decisions based on five factors: rationality, intuitiveness, dependence, avoidance, and spontaneity. Interestingly, rational, avoidant and spontaneous decision making styles were not correlated to delay discounting rates in this study. Intuitiveness was the only decision making style to be significantly correlated to delay discounting scores. This signifies that intuitive people particularly fall prey to delay discounting, theoretically because of their tendency to rely more on System 1 heuristic-based decision making. As mentioned earlier, exercise group and blood glucose increase taken alone did not explain significant variability in delayed discounting scores. However, exploratory analyses revealed an interesting possibility when individual differences in decision making styles were also taken into consideration. Typically delay discounting scores increased with higher GDMS intuitive scores, indicating greater System 1 reliance. However, in those individuals who experienced a blood glucose increase as a result of intense exercise, a reverse trend was observed (see Figure 4). Though our limited sample size and lack of uniformity in exercise-induced hyperglycaemia did not allow for rigorous statistical testing of this hypothesis, this exploratory analysis may indicate that exercise-induced hyperglycaemia can rescue optimal System 2 decision making for those individuals who tend to rely more on heuristic-based System 1 processing. It is possible that a larger high-intensity exercise sample with more uniform blood glucose response might reveal a distinctly lower rate of delay discounting. Overall the present data hint at the possibility that exercise-induced hyperglycaemia can rescue optimal decision-making, particularly for those individuals who tend to make decisions using their emotions or intuitions (see Figure 5). The current findings indicate that there may be benefit to awareness of individual decision making styles. In particular, future experimental decision making research should take into account participants' existing propensity to use intuition.

Exercise and Cognition

Even though no previous research (to our knowledge) has attempted to observe the effects of exercise on the relative reliance on System 1 and System 2 processes in decision making , the role of exercise on other aspects of cognitive function has been studied and results have been controversial. The maintenance of physical and cognitive health has often been attributed to leading a physically active lifestyle; however, the exact mechanism by which exercise improves cognitive function has been disputed amongst scientists (Erikson, 2013). Previous research, conducted mostly on elder populations, has linked physical activity with improvements in executive functioning associated with planning, scheduling, inhibition and working memory (Kramer et al., 1999). Neuroimaging studies have confirmed the relationship between physical activity and improved brain function by showing higher cerebral blood flow and greater grey matter in brains of highly fit individuals (Erikson et al., 2013). Executive control processes are an important function of the prefrontal cortex, which allows for the updating and shifting of information as well as inhibition control (Del Missier, Mäntylä, & Bruine de Bruin, 2010). The prefrontal cortex plays a vital role in completing the cognitively demanding tasks of decision-making and focusing attention on important cues and inhibiting irrelevant environmental stimuli is required for optimal decision-making (Del Missier et al., 2010).

Limitations

Since previous research (Mitchell et al., 1988) has demonstrated a hyperglycaemic response in all subjects after intense exercise in healthy lean subjects, one can assume that this study's inability to replicate this response in all participants in the high exercise condition to be due to the limitations of the experiment and the sample. Firstly, a very limited number of studies have actually recorded the hyperglycaemic response to exercise, and they have done so in a very specific sample of participants. The participants in the Mitchell et al. (1988) experiment were all healthy, lean males; whereas the Douglas College sample from which participants for the current study were drawn had more diverse fitness levels and included both males and females (with a female majority). In fact, the literature shows that there is a difference in fitness levels, namely maximal oxygen consumption (VO_2 Max) between males and females; with an average VO_2 max of 50mL/(kg.min) for males and an average VO_2 max of 40mL/(kg.min) for females (McArdle et al., 2010). The formula 220-age that was used to predict 80% VO_2 max for the high-intensity exercise could have been too general to successfully allow participants in the study to exercise at an intensity that corresponded with their actual 80% VO_2 max. It is possible that participants who did not exhibit a hyperglycaemic response to high-intensity exercise could have not yet reached their 80% threshold. Furthermore, the participants who showed a hyperglycaemic response in the lower-intensity exercise group could have been simply less fit and far exceeded the 60% VO_2 intensity level. We should also acknowledge that a slight delay (generally less than 1 minute) was imposed between the end of exercise and the second blood glucose measurement due to the necessity of moving participants to another room for blood testing. Given that the hyperglycaemia effect rapidly diminishes, our assessment of blood glucose change may have been blunted.

Additionally, different intensities and different modes of exercise can cause different effects on decision making processes. At very high intensities of exercise, physical fatigue can hinder performance on cognitively demanding tasks. In our study a trend was observed that showed higher overall delay discounting in the high-intensity exercise condition compared to the no exercise condition (see Figure 3). However, this finding was not statistically significant and held only for those who did not increase their blood glucose levels. The role of fatigue on cognitive function was studies by Isaacs and Pohlman (1991) who conducted tasks to test cognitive performance of adult cyclers at progressively increasing VO_2 Max intensities. Their results showed cognitive function to be marginally inhibited by a fatigue state elicited at near maximal VO_2 Max exertion (Isaacs & Pohlman, 1991). Additionally in a review which looked at 5 studies conducted between 1971 and 1995, cognitive performance increased linearly with exercise intensity output (on a treadmill or cycle ergo-meter) which corresponded to 25%-75% VO_2 max conditions; however it decreased at workloads of 85% VO_2 Max and above (Tomporowski, 2003). Nevertheless, the cognitive functions (e.g., speed of response) measured in these studies were not necessarily related to the constructs of interest here: the capacity to engage more effortful System 2 processes in the context of decision making.

According to Kahneman (2003), some factors that could hinder System 2 engagement include time pressure and simultaneous involvement in cognitively demanding tasks. Perhaps participants in the high and low intensity exercise conditions felt the effects of time constraint, as only an hour block was set aside to complete the experiment. Furthermore, the impact of self-regulation and the expenditure of finite resources of executive control on decision making should be acknowledged (Pocheptsova et al., 2009). One could argue that participants in either exercise condition, but particularly in the high-intensity group, depleted some of their cognitive resources while completing the task of cycling to reach a specific VO_2 max and then maintaining it, as this required them to monitor their heart rate and exert self-control to adjust their cycling intensity accordingly. Most participants in the high-intensity group found it very challenging to keep their cycling intensity at the required level. Thus, at least some of the high-intensity exercise participants were likely experiencing depletion of cognitive resources, particularly if they simultaneously experienced a blood glucose decrease. In our particular sample, it seems clear that exercise was not universally beneficial for promoting System 2 engagement.

Future Directions

Contrary to what one may assume, being in a good mood could hinder System 2 processes in the context of decision making (Kahneman, 2003). In fact exercise is often associated with a euphoric ‘feel-good’ state of being (i.e., the “runner’s high; Boecker et al., 2008). Thus if participants were in a good mood after the intense exercise session, they might have been more prone to generally making poorer decisions due to reliance on System 1. Future research on exercise and cognition can factor in the influence of mood on decision making.

The current study found that a manipulation intended to increase blood glucose levels in fact only succeeded in half the participants. Previous studies examining in the impact of glucose on decision making did not conduct a manipulation check to confirm that blood glucose actually did increase (Masicampo & Baumeister, 2008; Wang & Dvorak, 2010). Given the variability in our results, we propose that in future studies it is important to directly test blood glucose changes in participants.

Moreover, due to the unanticipated variability in blood glucose response in this study, some interesting trends were difficult to test with adequate statistical power. It would be interesting for further studies to examine the effect of exercise and blood glucose changes on decision making using larger samples.

Conclusion

This study sought to elicit a hyperglycaemic state in participants as a response to high-intensity exercise. Findings from the experiment moderately supported the hypothesis that System 2 decision making would improve as a result of increased availability of glucose in participants in the high-intensity exercise condition. Results showed that higher blood glucose was associated with greater probability of choosing non-heuristic options in the apartment task. Additionally, it was found that individual tendencies in decision making style (as determined by the GDMS) represented a predictive factor in delay discounting scores. Finally, we found preliminary evidence that exercise-induced hyperglycaemia may help engage System 2 reasoning on delay-discounting tasks in otherwise intuitive individuals.

References

Bielak, A. A., Cherbuin, N., Bunce, D., & Anstey, K. J. (2014). Preserved Differentiation Between Physical Activity and Cognitive Performance Across Young, Middle, and Older Adulthood Over 8 Years. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *69*(4), 523-532.

Boecker, H., Sprenger, T., Spilker, M. E., Henriksen, G., Koppenhoefer, M., Wagner, K. J., ... & Tolle, T. R. (2008). The runner's high: opioidergic mechanisms in the human brain. *Cerebral Cortex*, *18*(11), 2523-2531.

Colcombe, S. & Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults a meta-analytic study. *Psychological Science*, *14*(2), 125-130.

Del Missier, F., Mäntylä, T., & Bruine de Bruin, W. (2010). Executive functions in decision making: An individual differences approach. *Thinking & Reasoning*, *16*(2), 69-97.

Duckworth, A. L., Tsukayama, E., & Geier, A. B. (2010). Self-controlled children stay leaner in the transition to adolescence. *Appetite*, *54*(2), 304-308.

Erickson, K. I. (2013). Therapeutic Effects of Exercise on Cognitive Function. *Journal of the American Geriatrics Society*, *61*(11), 2038-2039.

Gold, P. E. (1995). Role of glucose in regulating the brain and cognition. *The American Journal of Clinical Nutrition*, *61*(4), 987S-995S.

Isaacs, L. D. & Pohlman, E. L. (1991). Effects of exercise intensity on an accompanying timing task. *Journal of Human Movement Studies*, *20*(3), 123–131.

Kahneman, D. (2003). A perspective on judgment and choice: mapping bounded rationality. *American Psychologist*, *58*(9), 697.

Kaplan, Brent A.; Lemley, Shea M.; Reed, Derek D.; Jarmolowicz, David P. (2014). "21- and 27-Item Monetary Choice Questionnaire Automated Scorers" [software]. Center for Applied Neuroeconomics, University of Kansas. Retrieved from http://kuscholarworks.ku.edu/handle/1808/15424

Kirby, K. N. & Maraković, N. N. (1996). Delay-discounting probabilistic rewards: Rates decrease as amounts increase. *Psychonomic Bulletin & Review*, *3*(1), 100-104.

Kirby, K. N., Petry, N. M., & Bickel, W. K. (1999). Heroin addicts have higher discount rates for delayed rewards than non-drug-using controls. *Journal of Experimental Psychology: General*, *128*(1), 78.

Kramer, A. F., Hahn, S., Cohen, N. J., Banich, M. T., McAuley, E., Harrison, C. R., Colcombe, A. (1999). Ageing, fitness and neurocognitive function. *Nature*, *400*(6743), 418-419.

Marliss, E. B. & Vranic, M. (2002). Intense exercise has unique effects on both insulin release and its roles in glucoregulation: implications for diabetes. *Diabetes*, *51*(suppl 1), S271-S283.

McArdle, W. D., Katch, F. I., & Katch, V. L. (2010). *Exercise physiology: Nutrition, energy, and human performance*. Lippincott Williams & Wilkins.

Mitchell, T. H., Abraham, G., Schiffrin, A., Leiter, L. A., & Marliss, E. B. (1988). Hyperglycemia after intense exercise in IDDM subjects during continuous subcutaneous insulin infusion. *Diabetes Care*, *11*(4), 311-317.

Masicampo, E. J. & Baumeister, R. F. (2008). Toward a physiology of dual-process Reasoning and judgment: Lemonade, willpower, and expensive rule-based analysis. *Psychological Science*, *19*(3), 255-260.

Pocheptsova, A., Amir, O., Dhar, R., & Baumeister, R. F. (2009). Deciding without resources:

Resource depletion and choice in context. *Journal of Marketing Research*, *46*(3), 344-355.

Scott, S. G. & Bruce, R. A. (1995). Decision-making style: The development and assessment of a new measure. *Educational and Psychological Measurement*, *55*(5), 818-831.

Swain, D. P., Abernathy, K. S., Smith, C. S., Lee, S. J., & Bunn, S. A. (1994). Target heart rates for the development of cardiorespiratory fitness. *Medicine and Science In Sports and Exercise*, *26*(1), 112-116.

Tomporowski, P. D. (2003). Effects of acute bouts of exercise on cognition. *Acta Psychologica*, *112*(3), 297-324.

Wang, X. T. & Dvorak, R. D. (2010). Sweet Future Fluctuating Blood Glucose Levels Affect Future Discounting. *Psychological Science*, *21*(2), 183-188.

Table 1

Attraction Effect and Choice Frequencies of Options in Each Set

Apartment		No Exercise Control (n=21)		Low Intensity Exercise (n=20)		High Intensity Exercise (n=22)	
		A_{Decoy}	B_{Decoy}	A_{Decoy}	B_{Decoy}	A_{Decoy}	B_{Decoy}
A_{Decoy}	350 sq ft,10 km	0	---	0	---	0	---
A	450 sq ft, 7 km	50%	27%	89%	18%	81%	8%
B	800 sq ft, 15 km	50%	63%	11%	81%	18%	92%
B_{Decoy}	700 sq ft, 18 km	---	0	---	0	---	0

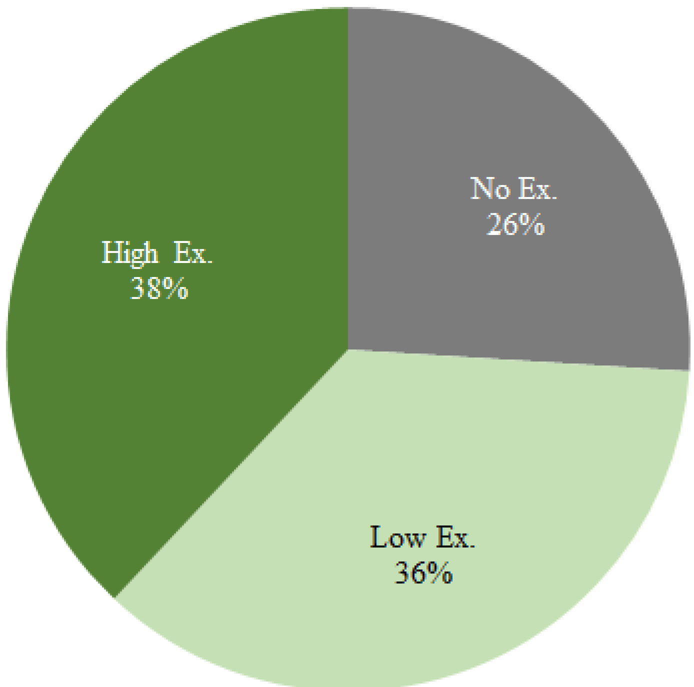

Figure 1.1. Proportion of participants that chose the heuristic choice on the apartment task in each exercise condition.

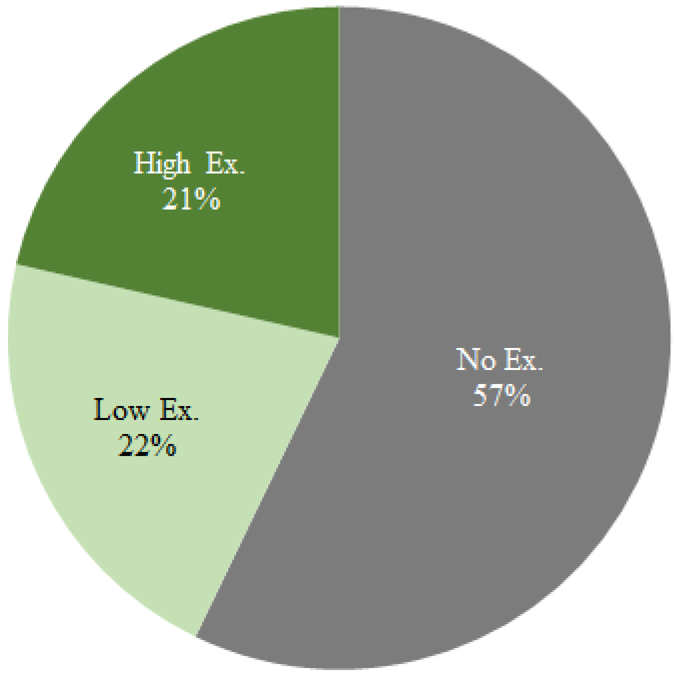

Figure 1.2. Proportion of participants that chose the non-heuristic choice on the apartment task in each exercise condition.

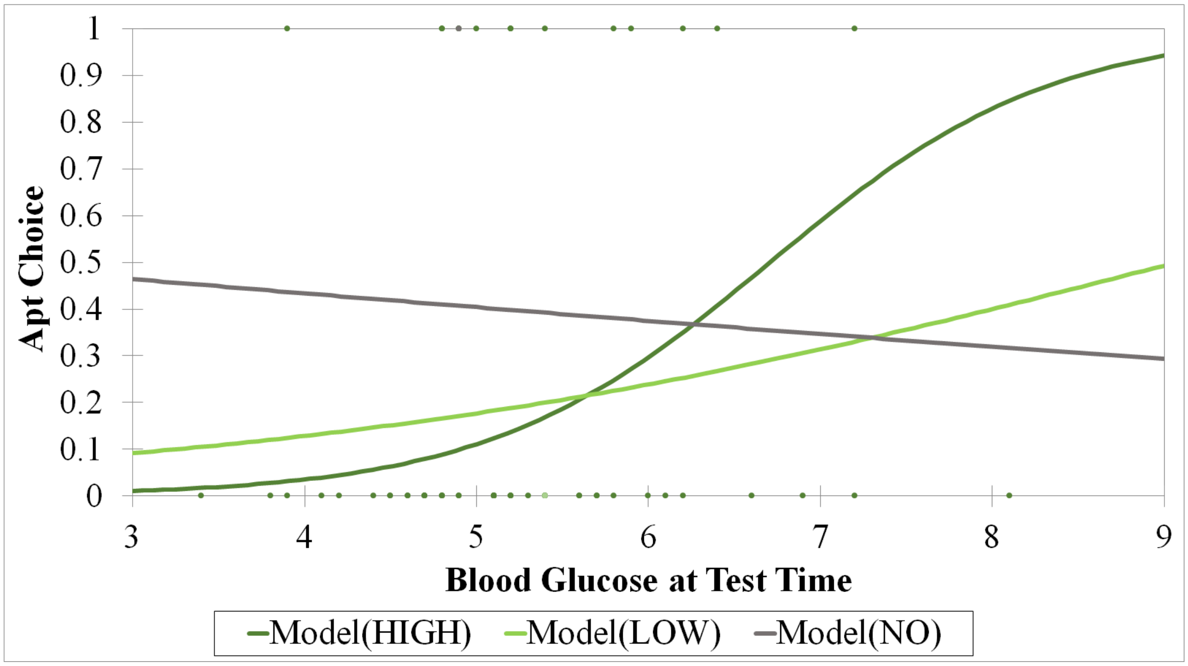

Figure 2. Probability of apartment choice depending on final blood glucose reading for each exercise condition (Apt choice 0=heuristic choice, Apt choice 1=non-heuristic choice; High-intensity exercise condition is shown in dark green, Low-intensity exercise in light green, and no exercise in gray).

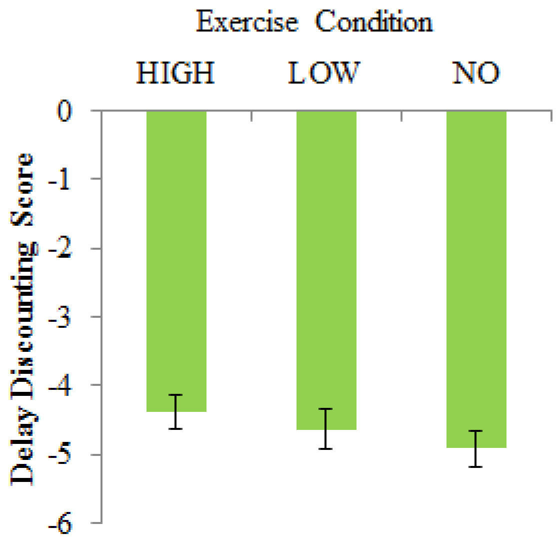

*Figure 3.*Group means of delay discounting scores by exercise group (high intensity exercise, low intensity exercise, and no exercise). Larger (more positive) delay discounting scores correspond to greater tendency to choose immediate rewards even when they are smaller (i.e., greater reliance on System 1-based decision making).

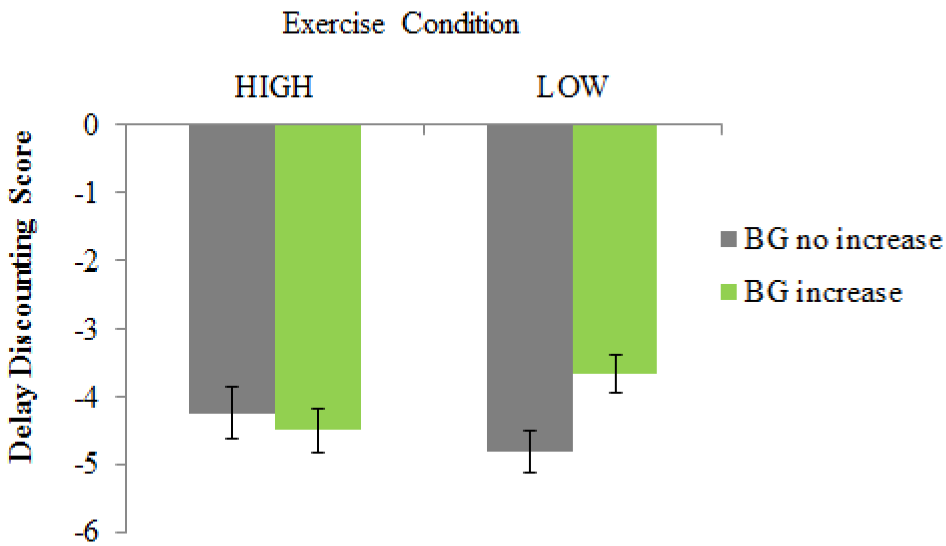

Figure 4. Mean Delay Discounting scores by exercise condition (high and low intensity) depending on whether there was an increase in blood glucose or not.

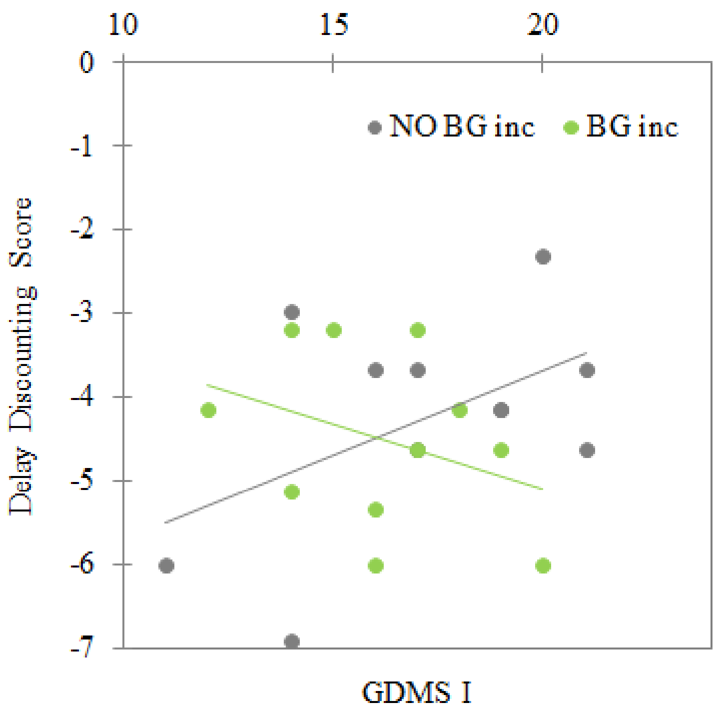

Figure 5.1. Difference in the relationship between delay discounting scores and intuitive decision making scores (GDMS I) of participants in the high-intensity exercise condition, depending on whether or not an increase in blood glucose occurred (participants whose glucose increased are shown in red; those whose glucose did not increase are shown in blue).

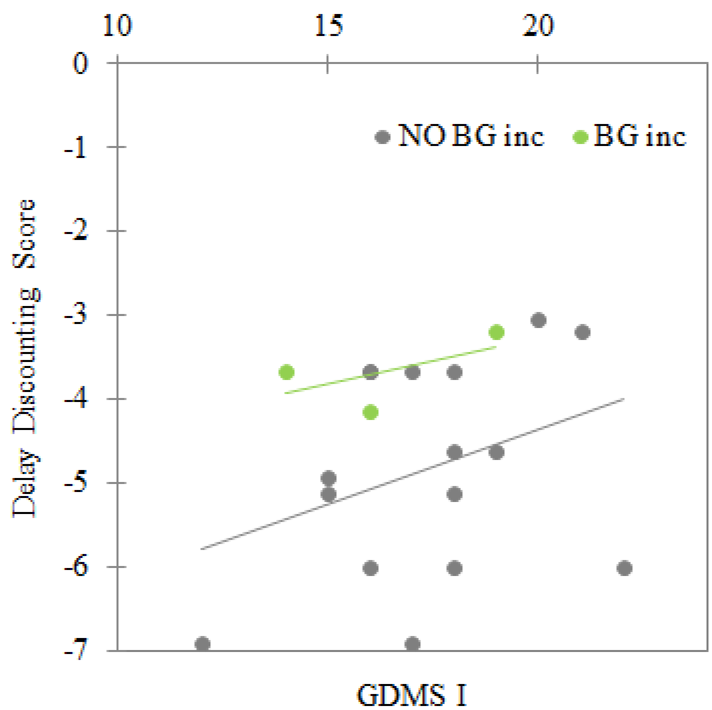

Figure 5.2. Difference in the relationship between delay discounting scores and intuitive decision making scores (GDMS I) of participants in the low-intensity exercise condition, depending on whether or not an increase in blood glucose occurred (participants whose glucose increased are shown in red; those whose glucose did not increase are shown in blue).