MENTAL FATIGUE AND PHYSICAL ACTIVITY DECISION-MAKING

MENTAL FATIGUE, MOTIVATION, AND PHYSICAL ACTIVITY DECISION-MAKING

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LAY ABSTRACT

Mental fatigue has been shown to impair subsequent physical performance, however, the effect of mental fatigue on the decision to engage or not engage in physical activity has received limited attention. This thesis addresses several gaps in the literature by examining potential mediators of the mental fatigue – physical activity decision-making relation, using qualitative methods to understand factors affecting people's choices, and applying methods with strong ecological validity. Findings show perceived effort and benefit vs. cost valuations associated with engaging in physical activity predict the choice to engage in PA. Further, mental fatigue increases perceptions of effort and decreases benefit vs. cost valuations. Collectively, results from this dissertation align with and extend theoretical frameworks of behavioral economics, motivation, and effort-based decision-making.

ABSTRACT

Previous research has demonstrated mental fatigue impairs subsequent physical performance, however, current understanding of the role of mental fatigue on physical activity and exercise decision-making is limited for several reasons. For example, research examining the relation between mental fatigue and physical activity behaviors has relied on experimental methods and physical tasks performed in controlled laboratory settings with limited applicability to everyday experiences. In addition, direct measures of motivation commonly used within the literature are subject to biases, highlighting the importance of alternate methods for assessing motivation using indirect measures. To address these limitations, methods with stronger ecological validity are needed to extend research from controlled, experimental settings to measure mental fatigue in naturalistic settings and provide a diverse range of physical activity and exercise task options. The purpose of this dissertation is to investigate the associations between mental fatigue, motivation, and physical activity behavior to further our understanding of the decision-processes behind choosing to engage or not engage in physical activity.

Study 1 examined the effects of mental fatigue on the decision to engage in an acute bout of moderate-to-vigorous intensity physical activity or a competing sedentary alternative using a mixed-methods study design. Results showed a sequential mediation effect of mental fatigue on choice through subjective perceptions of effort, benefits, and costs. Results of qualitative analyses highlight individual-level consequences of completing cognitively demanding and non-demanding tasks on physical activity decision-making. Findings are consistent with previous research and demonstrate subjective perceptions of engaging in physical activity account for acute choice.

Study 2 investigated the effects of intensity and duration on people's subjective valuations of physical activity tasks using an effort discounting paradigm and the potential moderating effect of mental fatigue on subjective valuations of physical activity. Results showed a reduced willingness to engage in physical activities of higher intensities and longer durations. Further, there was partial evidence suggesting a reduced willingness to engage in vigorous-intensity physical activity with higher levels of mental fatigue. Findings provide novel insight towards factors influencing people's motivation for engaging in physical activity with some evidence that mental fatigue affects people's motivation to exert physical effort.

Study 3 examined the association between mental fatigue, subjective evaluations of perceived benefits and costs, and moderate-to-vigorous intensity physical activity using ecological momentary assessment and accelerometry. Results demonstrate significant associations between all study variables. Although a multilevel mediation model was not significant, evidence supports a partial mediation effect attributable to benefit vs. cost valuation on the relation between mental fatigue and physical activity. Results provide insight into real-time predictors of motivation and physical activity, highlighting the complex relationships between psychological variables and behavior in people's everyday decision making.

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LIST OF ABBREVIATIONS

AIC	Akaike information criterion
ANOVA	analysis of variance
CAD	Canadian dollars
CI	confidence interval
cm	centimetre
CR-10	category ratio-10
d	Cohen's d
DPA	daily physical activity
EBBS	Exercise Benefits/Barriers Scale
EMA	ecological momentary assessment
EDQ	effort discounting questionnaire
EST	Eastern standard time
FITT	frequency, intensity, time, type
h	hour
HCD	high cognitive demand
ICC	intraclass correlation coefficient
IPAQ	International Physical Activity Questionnaire
JITAI	"just-in-time" adaptive intervention
LCD	low cognitive demand
LPA	light-intensity physical activity
M	mean
mm	millimetre
min	minute
MVPA	moderate-to-vigorous intensity physical activity
M-GXT	modified graded exercise test
ηp^2	partial eta squared
PA	physical activity
PACES	Physical Activity Enjoyment Scale
POI	point of indifference
s	seconds
SD	standard deviation
SE	standard error
SPSS	statistical package for the social sciences
TEMPA	theory of effort minimization in physical activity
RPE	rating of perceived exertion
RPE-M	rating of perceived mental exertion
RPM	revolutions per minute
RRV	relative reinforcing value
VAS	visual analogue scale
VO_{2max}	maximum rate of oxygen consumption
W	watts

PREFACE
DECLARATION OF ACADEMIC ACHIEVEMENT

This thesis is prepared in the “sandwich” format as outlined in the School of Graduate Studies’ Guide for the Preparation of Master’s and Doctoral Theses. It includes a general introduction, three independent studies prepared in journal article format, and a general discussion. The candidate is the first author on all of the manuscripts. At the time of the thesis preparation, Chapter 4 was under peer-review.

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Chapter 2 (Study 1)

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S. Harris's role in Study 1:

- Conceived the research question and study design
- Author of ethics application at McMaster University
- Contributed to study design and measure selection
- Lead investigator responsible for data collection, analysis and interpretation
- Primary author of manuscript

Role of co-author in Study 1:

- SB provided feedback about the study design and obtained funding
- SB assisted SH with obtaining ethics approval at McMaster University
- SB assisted SH with the analysis and interpretation of the data
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CHAPTER 1:

INTRODUCTION

1.1 Physical Activity Guidelines and Benefits for Adults

Current physical activity guidelines recommend Canadian adults engage in at least 150 minutes of moderate-to-vigorous intensity physical activity (MVPA) and two muscle-strengthening activities each week, in addition to several hours of light intensity physical activity including standing (Ross et al., 2020). Engaging in physical activity (PA) regularly is associated with numerous health benefits including reduced risk of chronic diseases such as cardiovascular disease, cancer, depression, diabetes, and reduced all-cause mortality (Elagizi et al., 2020; Haskell et al., 2007; Ramakrishnan et al., 2021; Warburton, et al., 2006; Warburton et al., 2010) as well as improved cognitive functioning (Gregory et al., 2012; Kashihara et al., 2009; Sanders et al., 2019).

Despite evidence demonstrating people are generally knowledgeable of the benefits of engaging in regular PA (Fredriksson et al., 2018; Lovell, et al., 2010) and consider physical inactivity to be an important health risk factor (Martin et al., 2000), estimates suggest only 44.8% of Canadian adults are achieving the recommended amounts of PA (Clarke et al., 2019). In addition, Clarke et al. (2019) found that 3% of adults accumulated no MVPA at all. With a recognition that benefits and risks associated with PA are well-established in the scientific literature and among the lay public, and that population PA remains a major public health concern, recent efforts have aimed to identify more effective strategies for the dissemination and implementation of current movement guidelines (Tomasone et al., 2020a) and develop better knowledge translation guidelines for practitioners (Tomasone et al., 2020b) with the goal of increasing uptake of these guidelines in adults. Thus, there is an ongoing need to identify and understand factors contributing to people's decision-making regarding whether or not they will engage in behaviors consistent with current movement guidelines.

1.2. How Do We Make Decisions?

1.2.1 The Law of Least Work

The Law of Least Work can help facilitate understanding how organisms make decisions between tasks requiring different amounts of effort or energy. According to the Law of Least Work, "*If two or more behavioral sequences, each involving a different amount of energy consumption or work, have been equally well reinforced an equal number of times, the organism will gradually learn to choose the less laborious behavior sequence leading to the attainment of the reinforcing state of affairs.*" (Hull, 1943, pp. 294). In other words, when people are faced with a choice between two or more options which differ in effort or energy requirements, over time, they will learn to choose the easier or less effortful option as long as both options are equally reinforced.

While the Law of Least Work provides insight to help explain human decision-making, the law only applies to scenarios when all options are associated with reinforcement or rewards of equivalent values. However, in many decision-making scenarios, choosing to exert more effort is associated with a greater reward than a less effortful option. For example, an employee who invests more effort at their job is more likely to be rewarded by earning a promotion than if they invest less effort. Similarly, a student who spends more effort studying for a test is more likely to earn a higher grade than peers who invest less effort towards their academics. In the context of PA, the decision to expend physical effort on a regular basis is associated with shorter-term benefits such as improved mood (Chan et al., 2019) and sleep (Kline et al., 2021) as well as longer-term or delayed reinforcements such as improved health benefits and reduced health risks. In comparison, the choice to engage in non-physically effortful activities does not come with the same health-protective effects.

In an illustrative study examining physically effortful decision-making, Iodice and colleagues (2017a) placed mice in a T-maze and trained them to make choices between a lower effort-lower reward arm where mice could receive a small reward without climbing over a barrier and a higher effort-higher reward arm requiring the mice to climb over a 10 cm barrier to obtain double the reward of the lower effort-lower reward arm. In the control condition of the experiment, the mice had a greater preference for the higher effort-higher reward arm. However, in the fatigue condition, after the mice were physically fatigued by running on a treadmill at 80% of their peak velocity, the preference of the mice shifted in favour of the lower effort-lower reward option. These findings document how effort-based decision-making depends not only on effort requirements of a task, but on the associated reward for each option. Furthermore, situational experiences, in this case physical fatigue, can modify learned or established preferences for physically-effortful decision-making.

Drawing from the findings of Iodice et al. (2017a), we can infer that when people (or mice) are faced with decisions between a higher-effort option of expending more energy such as engaging in a PA task versus a lower-effort option such as engaging in a sedentary task, it is important to recognize that the behavioral options may be reinforced differently. For example, engaging in PA is associated with physical, psychological, and health benefits (Gregory, et al., 2012; Ramakrishnan et al., 2021; Warburton et al., 2010) verses sedentary activities which are not associated with the same health benefits. Therefore, additional considerations are needed to understand people's subjective perceptions of effort and reinforcement, as well as the decision-making process between choice alternatives that are not equally-well reinforced.

1.2.2 Traditional and Behavioral Economics

One perspective that has been applied extensively to understanding decision-making is economics, which is defined as "*the science which studies human behavior as a relationship between ends and scarce means which have alternative uses*" (Robbins, 1945, pp. 16). According to this definition, economics describes the processes involved with deciding how we allocate limited resources which have other potential uses. For example, after a long day of school or work, people will have to choose how to allocate the limited resource of time between spending time with family/friends, cooking or preparing a meal, engaging in household chores, or engaging in a bout of PA.

According to traditional economic theory, there are three core traits of human behavior: unbounded rationality, unbounded willpower, and unbounded selfishness (Mullainathan & Thaler, 2001) suggesting that humans are infinitely rational and unemotional decision-makers who can always make decisions in ways that are consistent with their long-term well-being and self-interest. However, the notion that humans are infinitely rational has received criticism (Simon, 1955), leading to revisions to these assumptions of traditional economics to better account for human behavior, rather than how humans should behave in an optimal setting.

Behavioral economics has emerged from traditional economics in combination with psychology as a theoretical framework recognizing the limitations and complications associated with human computational power, willpower and self-interest. Instead of relying on the traits central to traditional economics, behavioral economics is based on assumptions of *bounded* rationality, *bounded* willpower, and *bounded* selfishness to define more realistic expectations of human decision-making capabilities in people's everyday lived experiences (Mullainathan & Thaler, 2001). Bounded rationality recognizes that humans are limited by factors such as cognitive abilities and time restraints that restrict our ability to successfully process information and make the most informed decisions. Bounded willpower acknowledges that people's ability to make decisions consistent with their long-term self-interest is sometimes limited; such as people spending a lot of money on a luxury purchase rather than adding money to a savings account. Bounded selfishness recognizes that although humans will prioritize their own self-interest, in many scenarios, there is a genuine care or concern for the well-being of others; such as when people are willing to help out a stranger or donate to charity. Collectively, these assumptions provide insight to human decision-making and the departures that are made from "rational" decision-making as predicted by traditional economics.

1.2.3 Behavioral Economics and Physical Activity

Behavioral economics provides a novel perspective to understand how people make decisions between engaging or not engaging in PA. Epstein (1998) offers four principles rooted in behavioral economics that specifically apply to decision-making between engaging in physical activity or competing sedentary alternatives. According to the first principle, choice depends on the behavioral cost such that people will be less likely to engage in behaviors with greater costs. PA decision-making is particularly responsive to cost insofar as the energetic costs associated with engaging in PA compared to sedentary or leisure alternatives is typically much greater. Second, choices regarding PA are dependent on the other choice options that are available, and choice can be shifted to a different behavior based on the other behavioral options. For example, when faced with the choice between going on a walk versus watching new episodes of one's favourite program on TV, a person may consistently choose to watch TV. However, if the choice is between a less reinforcing option such watching re-runs of old programs and going on a walk, the same person may choose to go on a walk in the second choice scenario. Third, some element of choice is necessary to motivate people such that people need to have the autonomy to engage in behaviors regardless of the reinforcing value of the behavior (cf. Ryan & Deci, 2006). Finally, choice is dependent on the delay between choosing a behavior and receiving the expected outcomes of the behavior. Notably, many of the recognized benefits accrued from engaging in PA are typically experienced months or years in the future compared to the more immediate benefits associated with engaging in sedentary activities.

Building from these principles, researchers in the field of physical activity and exercise have developed methods to measure the reinforcing value of engaging in PA and sedentary behaviors. The reinforcing value of a given behavior is determined by the amount of work an individual is willing to complete to gain access to a behavior, and people will be more willing to work to gain access to behaviors that are highly reinforcing. The reinforcing value of a behavior is measured alongside a competing alternative with similar work requirements needed to gain access to each behavior, as a method to determine the relative reinforcing value (RRV) of a behavior, as a measure of reinforcement in contrast with other available alternatives.

One method for measuring the RRV of PA and sedentary behaviors involves using an operant button pressing task which resembles a slot machine, where participants earn points towards their preferred PA or sedentary task by clicking a computer mouse until three matching symbols of identical shapes and colors appear on a computer screen (Barkley et al., 2009; Epstein et al., 1999; Flack et al., 2017a). Points are accumulated to receive access to time towards engaging in either the preferred PA or sedentary task and participants continue to earn points to account for a specified amount of activity time between both tasks or until the participant no longer wishes to work for access to either task. RRV is measured using different schedules of reinforcement such that points are delivered after fewer presses initially and the number of button presses needed to earn a point increases as more points are earned, representing more work being needed.

In addition, the RRV of PA tasks has been investigated using a questionnaire where participants respond to a series of binary choices corresponding with choices from the operant button pressing task. In this questionnaire, participants are asked the number of times they are willing to press a button to gain access to their most preferred PA task or their most preferred sedentary task. The number of button presses required is initially the same for both the exercise and sedentary activities (e.g., 20 presses) and the number of button presses required for the sedentary activity increases with each subsequent question (Epstein et al., 2004; Roemmich et al., 2008).

Studies examining the RRV of exercise compared to sedentary alternatives has shown adults who were meeting current PA recommendations for vigorous-intensity aerobic PA had significantly greater RRV of aerobic training and a lower RRV of sedentary activities than those who were not meeting current recommendations (Flack et al., 2017a). Similarly, participants meeting recommendations for muscle strengthening exercises had significantly greater RRV of resistance training and significantly lower RRV of sedentary activities than those not meeting muscle strengthening guidelines (Flack, et al., 2017a). Interestingly, Flack and colleagues (2017b) found the RRV of aerobic and resistance exercises predicted how much time people would engage in each mode of exercise, independent of how much the mode of activity was liked. Collectively, findings provide evidence supporting the importance of reinforcing value on choice by demonstrating strong associations between the RRV of different modes of PA and the actual PA behaviors people choose to engage in.

Consistent with past work demonstrating the relation between reinforcement value and PA, financial incentives have been used within the field of PA and exercise as one strategy to increase the perceived value associated with engaging in PA. Provision of a financial incentive contingent on successfully engaging in PA behavior increases the immediate benefits associated with the task. Further, use of financial incentives leverages the behavioral economic principle referred to as '*present-biased preferences*' referring to the stronger relative weight people assign to immediate rather than future evaluations of the same reward (O'Donoghue & Rabin, 1999). To date, two systematic reviews have examined the effects of incentives on PA in adults. Results shows incentives increased exercise session attendance by 11.55% (95% CI = 5.61% to 17.50%) (Mitchell et al., 2013) and increased mean daily step counts during incentive interventions (pooled mean difference = 607.1, 95% CI = 422.1 to 792.1). Interestingly, the median incentive size observed by Mitchell and colleagues (2020) was $1.40 US/day showing even modest incentives are associated with increased PA behaviors.

Existing research applying behavioral economic insights to understand PA behaviors has focused primarily on the immediate and short-term rewards and value of outcomes (i.e., reinforcement) of engaging in PA using methodologies such as the RRV and the effects of benefits, represented by financial incentives, on behavioral outcomes. However, less research has examined the costs or barriers that factor into PA decision-making.

1.2.4 Cost-Benefit Analyses

Recent conceptualizations of motivation have argued that key factors influencing decision-making about behavioral engagement include the contrast or trade-off between the perceived costs and benefits of the behavior(s) in question (Chong, et al, 2016; Pessiglione, et al, 2018). Benefits can include the value of the behavior or any expected or potential rewards, while costs may refer to the time or effort demands associated with the task in addition to any other factors which may dissuade someone from engaging in the behavior. For example, exerting effort is known to be aversive (Inzlicht, et al, 2018; Kurzban, 2016) and behaviors requiring more effort will be perceived as more costly if evaluated in terms of effort alone. In addition, opportunity costs are another form of cost representing the foregone benefits associated with the non-selected choice alternative (Kurzban et al., 2013) and may also factor into a person's decisional balances.

Consistent with the theorizing presented above, Pessiglione and colleagues (2018) propose that the subjective value of producing effort can be calculated by subtracting the cost of producing effort from the reward associated with effort. Using this computational framework, people are predicted to engage in behaviors when the perceived benefits are greater than the perceived costs of the behavior. In this way, measuring the perceived costs and benefits associated with a particular behavior provides insight into people's motivation for engaging in effortful tasks as well as the influence of barriers that may bias people away from engaging in effortful behaviors such as PA.

According to a framework proposed by Müller and Apps (2019), fatigue is a barrier influencing people's motivation for engaging in effortful behaviors by increasing subjective perceptions of effort. The increased effort perceptions caused by fatigue, in turn result in amplified cost valuations relative to benefits and decreased motivation to engage in effortful behaviors. Furthermore, lower motivation for exerting effort on subsequent tasks results in decreased task performance.

Consistent with these theoretical frameworks, previous experimental research has shown a decreased preference for engaging in higher-effort tasks when people are experiencing greater physical fatigue, suggesting fatigue may increase cost perceptions of engaging in higher-effort tasks and bias subsequent choice in favour of lower-effort behaviors (Iodice et al., 2017b). However, given current rates of inactivity in the adult population (Clarke et al., 2019), it is not likely that fatigue caused by prior physical exertion is responsible for these motivational shifts. Thus, there is a need to further investigate the effects of other sources of fatigue which may negatively impact motivation and effort-based decision-making.

1.3 What is Mental Fatigue?

Fatigue has been defined as "*a symptom in which physical and cognitive function is limited by interactions between performance fatigability and perceived fatigability*" (Enoka & Duchateau, 2016, pp. 2236) and has been cited as a barrier to engaging in physical activity (Farah et al., 2021; Salmon, et al 2003). While this definition suggests the presence of both physical and psychological components of fatigue, physically or mentally effortful tasks cause phenomenologically similar feelings of fatigue and lead to similar decreases in people's motivation or willingness to exert effort (Müller & Apps, 2019). *Mental fatigue* refers to a psychobiological state experienced during or following prolonged and challenging cognitive activity (Boksem & Tops, 2008). Hockey (2013) argued that fatigue has an adaptive function by helping manage a person's motivation and redirect behavior towards tasks with greater perceived benefits than costs. According to this view, under conditions of fatigue people are more likely to engage in behaviors perceived to be more rewarding and less costly.

1.3.1 Mental Fatigue and Physical Performance

The negative effects of mental fatigue on subsequent physical performance have been well documented in studies examining isometric, endurance, and anaerobic exercise tasks (Brown et al., 2020; McMorris, et al, 2018; Van Cutsem et al., 2017). In a recent meta-analysis on the effects of prior cognitive exertion on physical performance, a significant small-to-medium sized negative effects was found (Brown et al., 2020) suggesting engaging in physical tasks under conditions of mental fatigue caused by prior cognitive exertion results in performance decrements. While this provides valuable insight on the role of mental fatigue on task performance, it is important to note that in all studies included in these reviews, participants were expected to perform physically demanding tasks assigned by the researchers under manipulated conditions of higher or lower mental fatigue. Although applicable to many scenarios characteristic of different sport or exercise tasks, in many choice scenarios, people can choose whether or not to engage in a task. However, in these studies, since participants did not have the option to withdraw from or defer performing the physical task before engaging in it, the effects of mental fatigue on decisions to engage in PA or not remain largely unexplored from the existing field of study.

1.3.2 Fatigue and Physical Activity Decision-Making

Literature examining the effects of fatigue on decisions to engage in exercise tasks has thus far relied on experimental methods to manipulate feelings of fatigue in controlled settings before providing participants options of engaging in physically effortful and non-effortful tasks. Specifically, participants are exposed to different experimental tasks requiring higher and/or lower physical or cognitive demands before indicating their preference for engaging in exercise or non-exercise tasks. Thus far, findings have been mixed with some studies showing a greater preference for non-exercise tasks with greater mental fatigue and other studies showing no effect of fatigue on physically-effortful decision-making.

In a study by Iodice et al. (2017b), participants made a series of choices between engaging in stationary cycling at a vigorous-intensity or resting comfortably for durations ranging from 10 to 40 minutes. Participants made the same series of choices under two conditions: once after 40 minutes of rest and once after having engaged in 40 minutes of vigorous-intensity cycling. Results showed under conditions of fatigue (i.e., after cycling for 40 minutes), participants had a greater preference for the non-exercise option compared to exercising. These findings were interpreted as a demonstration that physical fatigue biases decision-making towards less effortful behavioral tasks.

Van As et al. (2021) examined the role of physical and mental exertion on effort-based decision-making where participants made a series of choices between engaging in a hand-grip exercise task of varying levels of rewards and physical effort or rejecting the offer and exerting no effort for no reward. Results showed people's willingness to choose the effortful task declined as more effort was required to obtain the reward. Interestingly, there was a reduced likelihood of accepting physically effortful offers following prior physical exertion compared to a control condition. However, prior cognitive exertion did not affect the likelihood of choosing to engage in the physically effortful task or not. A similar study by van As et al. (2022) found participants were more likely to choose to engage in physical over non-physical tasks following a cognitively demanding task in contrast to study hypotheses. However, it is noteworthy that the cognitive manipulation used in experimental condition was unsuccessful at increasing levels of fatigue compared to the control condition, limiting study findings.

An important limitation of the aforementioned studies is that the physically effortful options provided to participants in these studies may not reflect tasks people would choose to engage in consistent with current PA guidelines. For example, while a hand-grip exercise task (van As et al., 2021) and other tasks including weightlifting, juggling, and push ups (van As et al., 2022) require varying levels of physical effort, they may not accurately reflect day-to-day decision-making for more structured types of PA people may choose to engage in during their leisure time.

In a study conducted by Abdel et al. (2021), participants were instructed to ride on a cycle ergometer for as long as they wanted after completing a workplace simulation task requiring either higher demands or lower demands. Following the higher-demand manipulation, participants reported higher perceived emotional and cognitive demands and spent less time cycling compared to the lower-demand simulation.

Harris and Bray (2019) had participants make a choice between engaging in a 22-minute cycling task or a 22-minute sedentary task after completing a mentally fatiguing or non-fatiguing cognitive task. Results showed a significant indirect effect of the cognitive task on choice such that the mentally fatiguing task led to increased mental fatigue, which in turn led to reduced motivation as measured in a cost-benefit analysis and decreased the likelihood of choosing the exercise task. While study findings suggest mental fatigue increases people's preference for engaging in sedentary tasks, specific costs which may be amplified with mental fatigue and influence subsequent decision-making were not explored in this study.

Collectively, findings provide evidence suggesting a reduced likelihood of choosing to engage in exercise tasks when experiencing higher mental fatigue. Importantly, there is notable variety in the experimental methods used across studies including the tasks used to manipulate feelings of fatigue (e.g., stationary cycling, Stroop task) as well as different exercise and non-exercise task options for participants to choose between (e.g., stationary cycling, handgrip exercise task). In addition, studies have relied on simple: manipulation – outcome designs and not examined possible theory-based mechanisms explaining the effects of fatigue on exercise choices.

1.3.3 Mental Fatigue and Perceptions of Effort

One possible mechanism to explain the role of mental fatigue on effort-based decision-making may be increases in perceptions of effort. Effort has been defined as the "*subjective intensification of either mental and/or physical activity in the service of meeting some goal*" (Inzlicht et al., 2018, p. 338) and suggested to act as a mediator between how well people are capable of performing on a task and their actual task performance (Shenhav et al., 2017). In light of theorizing that fatigue leads to stronger effort-avoidance (Massar et al., 2018) and evidence showing greater mental fatigue decreases the likelihood of choosing to engage in MVPA (Harris & Bray, 2019), it is possible that amplified effort perceptions may act as an additional mediator in the sequential pathway consisting of mental fatigue and physically effortful decision-making such that greater mental fatigue leads to increased perceptions of effort and subsequent decisions to engage in a less effortful task.

The psychobiological model of endurance performance is an effort-based decision-making model proposed to describe how people self-regulate submaximal exercise behaviors (Marcora, 2010; Pageaux, 2014). According to this model, perceptions of effort (i.e., the sensation of how challenging or strenuous a physical task is) and potential motivation (i.e., how much effort someone is willing to exert) are important factors which influence the conscious regulation of pace and predict endurance exercise performance. The model suggests increased perceived effort will cause a person to consciously down-regulate their pace leading to performance decrements which helps explain how psychological factors including mental fatigue may lead to subsequent impairments to endurance performance. Consistent with evidence that mental fatigue leads to increased perceptions of effort while performing submaximal endurance exercises (Harris & Bray, 2019; Marcora, et al, 2009; Pageaux, et al, 2014; Smith et al., 2016), it is reasonable to infer that increased mental fatigue may amplify perceived effort requirements of subsequent physical tasks which in turn will decrease motivation and reduce the likelihood someone will choose to engage in an exercise task when given the choice. However, this hypothesis has not been examined using a decision-making paradigm.

1.4. Gaps and Limitations of Research on Mental Fatigue and Physical Activity

1.4.1 Effects of Mental Fatigue on Physical Activity Decision-Making

To date, research examining the relationship between mental fatigue and physical activity and exercise behaviors have focused primarily on performance by way of various task outcomes including isometric and whole-body aerobic endurance time-to-failure, time trial performance, dynamic resistance, motor, and accuracy tasks (see: Brown et al., 2020; McMorris et al., 2018; Van Cutsem et al., 2017 for reviews). However, research examining the role of mental fatigue on PA motivation and decision-making is limited.

The application of insights from behavioral economics stands to offer a novel and valuable perspective with potential to further our understanding of the effects of mental fatigue on the decision to engage or not engage in PA tasks. Notably, recent theorizing of effort-based decision-making highlights the utility of integrating insights and theories from the field of effort-based decision-making (e.g., Chong et al., 2016) with fatigue research (Massar et al., 2018). For example, assessing the perceived costs and benefits of engaging in PA as an indirect measure of motivation may be more advantageous than asking participants to report their current motivation which may be more subject to social desirability response biases where participants respond consciously or non-consciously in the way they believe the researcher wants them to (van de Mortel, 2008).

Previous work has found no differences following mentally fatiguing and control tasks on subsequent intrinsic motivation (Marcora et al., 2009; Smith et al., 2015) or task motivation (Brown & Bray, 2019) which may be due to participants' beliefs that researchers expect high self-reported motivation on these direct, transparent measures. In contrast to these methods, asking participants to report the perceived costs and benefits of engaging in MVPA may lessen the demand characteristics associated with the term "motivations" and provide insight towards how motivation and decision-making differ based on subjective perceptions of mental fatigue.

1.4.2 Ecological Validity of the Mental Fatigue – Physical Activity Literature

An additional gap within the mental fatigue – physical activity literature is the limited ecological validity of the physically effortful tasks that are used. For example, existing research is limited to studies conducted in controlled, laboratory-based settings which use tasks such as the incongruent Stroop (1935) color word task (Graham et al., 2017; Harris & Bray, 2019), AX-Continuous Performance Task (Brown & Bray, 2019; Marcora et al., 2009), and N-Back task (van As et al., 2021) to experimentally induce feelings of mental fatigue. While these methods are feasible and practical for administering in controlled laboratory settings, studies are limited as the effects observed when mental fatigue is artificially contrived may not translate to mental fatigue developed and experienced in people's authentic, lived experiences. In addition, group-based analyses are commonly used to assess the effects of mental fatigue following exposure to cognitive tasks with different cognitive demands. These cognitive tasks create an artificial dichotomy and group-based analyses examine overall group effects and differences between groups rather than effects due to individual levels of mental fatigue. To advance this body of literature, future research should measure mental fatigue in naturally-occurring settings and use analysis strategies that investigate individual-level feelings of mental fatigue.

Similarly, the physical activity and exercise task options provided in the fatigue/decision-making literature are limited to those that can be conveniently administered and measured in laboratory settings. For example, stationary cycling (Abdel et al., 2021; Harris & Bray, 2019; Iodice et al., 2017b), isometric hand-grip exercise (van As et al., 2021) and other tasks including weightlifting, juggling, and push ups (van As et al., 2022) have been used which may not be consistent with PA tasks people will choose to engage in during their leisure time. Further, existing studies do not account for other contexts where people may choose to engage in physical activity such as with friends or groups, organized sports, or in fitness facilities. Thus, methods with improved ecological validity are needed with greater applicability to real-world PA decision-making.

1.5 Objectives and Hypotheses

1.5.1 General Purpose of Dissertation

The overarching objective of this dissertation was to investigate the associations between mental fatigue, motivation, and physical activity decision-making.

1.5.2 Specific Objectives and Hypotheses

The specific objectives and hypotheses of the studies in this dissertation are as follows:

Study 1) Examine the effects of mental fatigue on decisions to engage in an acute bout of MVPA and whether this relationship is mediated by anticipated effort and benefit vs. cost valuations using a mixed-methods study design. It was predicted that higher levels of mental fatigue would decrease the likelihood that participants would choose to engage in an exercise task through a sequentially mediated pathway consisting of increased perceptions of anticipated effort of the exercise task and decreased benefit vs. cost valuations.

Study 2) Investigate the effects of intensity and duration on motivation to engage in physical activity and examine the effect of mental fatigue on motivation using an effort discounting paradigm. It was hypothesized that people would be less motivated to engage in physical activities of higher intensities and longer durations and higher levels of mental fatigue would result in lower motivation for engaging in physical activities.

Study 3) Examine the associations and sequential relationships between real-time mental fatigue, benefit vs. cost valuations and MVPA using ecological momentary assessment and accelerometry methodologies. Higher levels of mental fatigue were expected to be associated with engaging in fewer minutes of MVPA and lower benefit vs. cost valuations, higher benefit vs. cost valuations would be associated with engaging in more MVPA, and benefit vs. cost valuations would mediate the relation between mental fatigue and MVPA.

1.6 Summary

Three studies were conducted to test the associations between mental fatigue and physical activity decision-making by examining the potential mediating effects of anticipated effort (Study 1) and benefit vs. cost valuations (Studies 1, 3), and the influence of parameters including intensity, duration, and their interaction with mental fatigue (Study 2). Novel methodologies to improve ecological validity including accelerometry and ecological momentary assessments were used (Study 3). Each of these three studies is presented in detail in the following three chapters followed by a general discussion summarizing key findings and how this work extends our knowledge of

mental fatigue – physical activity decision-making relation. Theoretical and practical implications are discussed.

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CHAPTER 2

Mental fatigue, anticipated effort, and subjective valuations of exercising predict choice to exercise or not: A mixed-methods study

Preamble

Mental fatigue, anticipated effort, and subjective valuations of exercising predict choice to exercise or not: A mixed-methods study is the first study in the dissertation series. The study examined the effect of mental fatigue on the decision to engage or not engage in an acute bout of MVPA in a sample of insufficiently active participants using a mixed-methods study design. Using a sequential mediation model, we examined whether perceived effort and benefit vs. cost valuations mediated the relation between mental fatigue and choice. Exit interviews were conducted with each participant to further probe the reasoning behind their choice.

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Contribution of Study 1 to overall dissertation

Study 1 demonstrates mental fatigue alters physical activity decision-making through a sequentially mediated process including subjective perceptions of anticipated effort and benefit vs. cost valuations. Findings from Study 1 also highlight various consequences of engaging in cognitively demanding tasks on exercise decision-making. Study 1 contributes to the overall dissertation by providing evidence of the sequential pathways in which feelings of mental fatigue influence effort-based decision-making related to physical activity behaviors using an experimental and qualitative research methods.

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Mental fatigue, anticipated effort, and subjective valuations of exercising predict choice to exercise or not: A mixed-methods study

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ABSTRACT

Objectives: This study examined the effects of mental fatigue on people's decisions to engage in an acute bout of exercise quantitatively, through a sequentially mediated pathway consisting of perceived effort and benefit vs. cost valuations and qualitatively, using exit interviews to survey the conscious reasoning behind participants' choices.

Design: Mixed methods, randomized, experimenter blind to group.

Method: Participants ($N = 84$, $M_{age} = 19.07 \pm 1.86$ years) completed either a high cognitive demand (incongruent Stroop) task or low cognitive demand (documentary viewing) task for 12 min. Before and after the cognitive task, participants rated their anticipated effort and subjective evaluations (benefits and costs) of engaging in a 20-min moderate-to-vigorous intensity exercise task. After completing the latter ratings, participants chose between the exercise task or a non-exercise task (seated "free time" and use of smartphone or computer). Participants were led to believe they would actually engage in the task; however, once their choice was made, they were not required to complete the task but were invited to complete a semi-structured interview to probe the reasoning behind their choice.

Results: Serial mediation analyses revealed a significant indirect effect from mental fatigue to choice through perceived effort and benefit vs. cost valuations (95% C.I. = −0.01 to −0.0004). Qualitative data, organized by categories based on group/choice pairings, yielded twelve unique codes explaining how the cognitive tasks affected choice.

Conclusions: Results demonstrate mental fatigue alters decision-making through a sequentially mediated process including subjective perceptions of effort, benefits, and costs. Interview responses also highlight the individual-level consequences of completing cognitively demanding and non-demanding tasks on effort-based decision-making. Future research should explore additional feeling states as they relate to people's choices to engage in exercise or sedentary behaviors.

Physical activity (PA) is associated with many important health benefits (Warburton & Bredin, 2017) and in order to accrue such benefits, adults should engage in at least 150 min of moderate-to-vigorous intensity PA (MVPA) each week (Haskell et al., 2007; Tremblay et al., 2011). Yet, despite the fact that most adults consider physical inactivity to be an important health risk factor (Martin, Morrow, Jackson, & Dunn, 2000), most are not active enough to meet public health guidelines (Norris, Clarke, & Schiller, 2018), which highlights the importance of understanding what motivates people's choices to engage in exercise or not.

Chong, Bonnelle, and Husain (2016) define motivation as a "*process which facilitates overcoming the cost of an effortful action to achieve the desired outcome*" (p. 72). Chong et al. further describe motivation as a trade-off between the perceived costs and perceived benefits of a particular action where people seek to maximize benefits and minimize costs. Conceptualizing motivation as a subjectively-evaluative cost-benefit trade-off may be important for understanding PA decision-making. In light of evidence suggesting universal agreement among people about the benefits of exercise regardless of whether they are active or not (Lovell, El Ansari, & Parker, 2010), perceived costs may have a stronger influence on one's decision-making about exercising than perceived benefits. Accordingly, it is important to assess perceived costs and consider how different cognitive/feeling states may bias a person's perceived costs of exercising, even when opportunities to be active are

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The effects of cognitively-demanding tasks on exercise performance has been a topic of interest in the exercise science literature for several years. One perspective suggests performing cognitively challenging tasks causes mental fatigue, which in turn, impairs physical performance (Van Cutsem et al., 2017). Another perspective proposes cognitive tasks, particularly those involving response inhibition, consume self-control resources leading to a state of ego-depletion, which impairs motor performance (Englert, 2016).

Regardless of the conceptual framework underpinning the research, meta-analysis shows consistent evidence that engaging in cognitively challenging tasks prior to exercising results in performance decrements (Brown et al., 2020). Importantly, these effects are seen regardless of the duration of the cognitive task performed with larger effects observed for self-paced aerobic exercises (e.g., Brown & Bray, 2019; Brownsberger, Edwards, Crowther, & Cottrell, 2013), resistance exercises (e.g., Graham, Martin Ginis, & Bray, 2017), and isometric endurance exercises (e.g., Boat & Taylor, 2017; Graham & Bray, 2015).

In addition to studies examining the effects of self-control exertion or mental fatigue on physical task performance, two studies have investigated the aftereffects of performing challenging cognitive tasks on intended exercise intensity. Martin Ginis and Bray (2010) had participants report the amount of physical exertion they planned to invest in a 30-min circuit-based exercise session after performing either a mentally fatiguing task or a non-fatiguing task. Results indicated a decrease in planned exercise intensity for participants who completed the mentally fatiguing task. Similarly, Brown and Bray (2019) reported participants' intended exercise intensity for a 30-min self-paced cycling task decreased significantly after performing a mentally-fatiguing task. Together, these studies suggest that people plan to invest less effort in exercise tasks when they feel mentally-fatigued. However, participants in those studies were not given an opportunity to opt out of exercising which raises questions as to whether mental fatigue might cause people to avoid exercising altogether if given a choice.

To address this question, Harris and Bray (2019) examined whether mental fatigue affected people's choices when given opportunities to engage in either an exercise or a non-exercise task. In that study, recreationally-active participants completed either a mentally fatiguing or non-mentally fatiguing task and then reported their subjective mental fatigue, perceived benefits, and perceived costs related to a 20-min bout of self-paced exercise before choosing between an exercise or a non-exercise task. Results showed greater mental fatigue was associated with increased perceived cost valuations of exercise, which in turn, predicted a reduced likelihood of choosing to exercise. Although Harris and Bray's (2019) study provides preliminary evidence that mental fatigue may bias subjective valuations of exercise, since perceived benefits and costs of exercise were not measured prior to the experimental manipulation, it is unclear whether baseline differences existed between groups. Additionally, what people rated as the increased "costs" of exercise that appeared to be amplified with mental fatigue could not be determined from their data.

Exerting effort is aversive (Kurzban, 2016) and it has been well established that organisms choose less effortful behaviors when afforded equally-reinforced options (Hull, 1943; Kool, McGuire, Rosen, & Botvinick, 2010). Emerging theoretical models of effort-based decision-making suggest perceptions of effort may be a potential cost that is amplified following a mentally fatiguing task. For example, Kool and Botvinick (2014) propose a labor/leisure trade-off model, in which people are motivated to achieve a balance between labor (e.g., exerting effort) and leisure (e.g., relaxing). This motivation for balance manifests itself in one's decision-making and may explain why people perform poorer on physically-demanding tasks (Brown et al., 2020) and are more likely to opt for a leisure activity rather than exercise after exerting themselves mentally (Harris & Bray, 2019). Similarly, the psychobiological model of endurance performance proposes mental fatigue intensifies perceptions of effort, which causes conscious decisions to slow down one's pace and ultimately leads to performance decrements in self-paced endurance exercise (Pageaux, 2014). Other conceptualizations of the effort-motivation relation propose that allocating effort towards a task carries opportunity-costs representing the foregone benefit of other available alternatives (Kurzban, Duckworth, Kable, & Myers, 2013). Thus, the opportunity costs associated with engaging in physical activity may be inflated by mental fatigue and bias choice in favour of more rewarding or less effortful alternatives that one does not wish to miss out on. In summary, each of these models suggest that when people are mentally fatigued and have a choice about what to do or not to do, a conscious and deliberate shift in decision-making in favour of a less effortful option may occur.

Together, the aforementioned models support a prediction that people should prefer less effortful activities following cognitive exertion, in part, due to changes in the anticipated effort perceptions for the tasks they forecast themselves engaging in. Thus, the anticipated effort requirements of an exercise task may be one such "cost" that factors more strongly into exercise decision-making when people are feeling mentally fatigued compared to when they are not.

To this point, studies examining the effects of mental fatigue on physical task performance and decision-making have relied on quantitative research methods. Although quantitative approaches provide valuable insights through the direct measurement of specific constructs and allow examination of the strength of association between variables of interest (Castro, Kellison, Boyd, & Kopak, 2010), they fail to capture important contextual information and exclude participants' accounts of the meaning and purpose of their own behavior (Guba & Lincoln, 1994). In contrast, mixed-methods designs use qualitative data to help inform the interpretation of quantitative data (Pluye & Hong, 2014), resulting in a more holistic understanding of human behavior. However, to the best of our knowledge a qualitative approach has not yet been used to investigate the effects of mental fatigue on exercise-related cognitions.

The purpose of the present study was to investigate the effect of mental fatigue on people's exercise decision making using a mixed-methods approach. Specifically, we examined whether levels of self-reported mental fatigue would predict the anticipated effort associated with a 20-min session of MVPA, benefit vs. cost valuations of exercise, and whether people would choose to engage in a 20-min session of MVPA or opt for engaging in 20 min of a non-exercise behavior instead. We also conducted post-decision interviews with participants to explore the feelings and reasoning behind their choice to exercise or not. Drawing from the labor/leisure trade-off model (Kool & Botvinick, 2014), it was hypothesized that greater mental fatigue would lead to increased ratings of anticipated effort associated with the exercise task, a biasing of benefit vs. cost evaluations of exercising towards greater costs (Harris & Bray, 2019), and a greater likelihood of choosing a non-exercise task rather than exercise. The hypothesis was evaluated using a sequential mediation model (See Fig. 2). From the qualitative perspective, we expected anticipated effort and cost-benefit valuations to emerge from post-decision interview conversations; but did not hypothesize what reasons participants would give for choosing to exercise or not.

1. Method

1.1. Participants and design

Participants were 84 (n = 55 women) university students (M_{age} = 19.07 ± 1.86 years) who self-reported engaging in <150 min of MVPA/week (M = 89.06 ± 42.39 min). Sample size was determined based on results from Iodice et al. (2017) that demonstrated a medium-large effect size (η_{P2} = 0.30) of fatigue on exercise decision-making. According to G*Power (Faul, Erdfeller, Lang & Buchner, 2007) a sequential mediation analysis with three independent variables, a sample size estimate based on a η_{P2} of 0.30, α = 0.05 and β = 0.80, indicated a sample of 31 was sufficient for serial mediation analyses. Since the sample

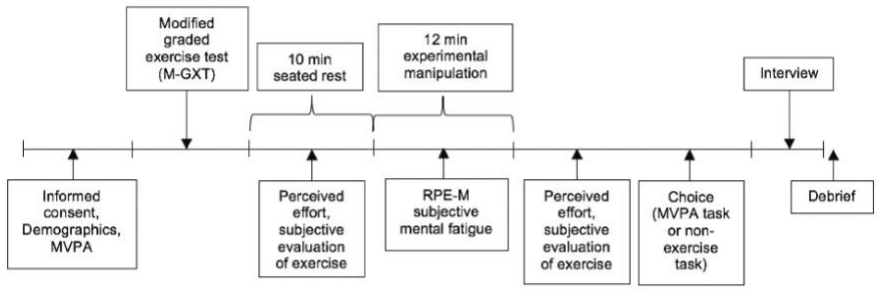

Fig. 1. Timeline of study procedures.

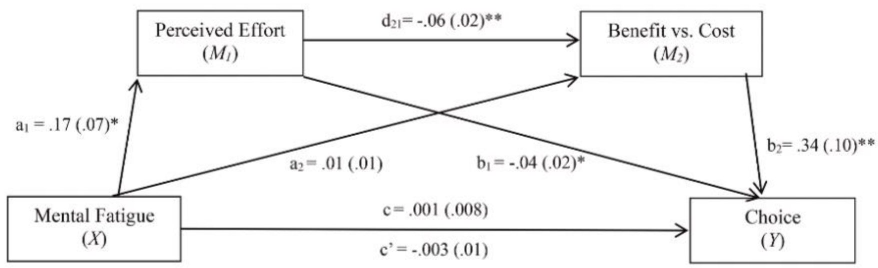

Fig. 2. Mental fatigue – choice serial mediation model with perceived effort and benefit vs. cost score. c = the direct effect of X on Y. c′ = the direct effect of X on Y when controlling for M_1 and M_2. Coefficients are presented in unstandardized form with SE in parentheses. $*p < .05$, $**p < .01$.

size-estimate was considerably smaller than other estimates for regression analyses, the sample size was increased to 74 participants according to Green's (1991) recommendations of an N of $50 + 8(x)$, when x = the number of predictor variables. Participants were screened for non-normal vision (color-blindness) using self-report, health-related contra-indicators of performing MVPA (Thomas, Reading, & Shephard, 1992), and provided informed consent. The study was reviewed and approved by an institutional research ethics board prior to recruitment and data collection. Participants received partial course credit for their contributions to the study.

The study employed a participant-blind/researcher blind to treatment (experimental group) allocation, between-groups study design. The sample was stratified by sex and randomized to either high cognitive demand (HCD) or low cognitive demand (LCD) manipulation groups. The experimental manipulation was completed by a second experimenter while the first experimenter left the room. Since fatigue vulnerability is not uniform across all participants (Van Dongen, Caldwell, & Caldwell, 2011) the cognitive tasks were thus used to create a more diverse range of mental fatigue scores than would occur naturally in the lab environment.

1.2. Procedures

Participants attended one laboratory session (see Fig. 1 for study procedure timeline) and were instructed to not consume caffeine or engage in vigorous physical activity within 6 h of the session. Upon arrival at the laboratory, participants provided informed consent, confirmed adherence to these instructions, and completed demographic and questionnaire measures for descriptive purposes and use as potential covariates (see below). They then completed a modified graded exercise test (M-GXT) protocol on a cycle ergometer (described below). Following the M-GXT protocol, participants engaged in 10 min of seated rest to allow sufficient recovery prior to starting the cognitive task. During the rest period, they were asked to imagine themselves performing a MVPA task and a non-exercise task. The MVPA task was described as cycling on a stationary bike within an RPE range between a three and six (the range they were familiarized with during the M-GXT) for a duration of 20 min. The non-exercise task was described as "free time" in which they could use their smartphone, personal computer, or the laptop computer in the lab for a duration of 20 min. They then completed measures assessing their anticipated effort and subjective evaluations (benefits and costs) of engaging in the MVPA task.

Following the 10-min rest period, participants completed their respective experimental manipulation (i.e., HCD or LCD) with perceived mental exertion (RPE-M) and mental fatigue recorded at baseline and at 2-min intervals throughout the task. Following the cognitive task, participants were provided with the same descriptions of the MVPA and non-exercise tasks given previously and asked to choose between the two tasks. They then completed the perceived effort and subjective evaluation measures again before verbally indicating their choice to exercise or not to the experimenter. Participants were then informed they were not required to perform their chosen protocol and then engaged in a brief (~5-min) interview with one of the experimenters. Interviews followed a semi-structured script using open-ended questions (see Appendix in supplemental file). Following the interview, participants were debriefed and thanked for their participation. Given the use of deception, participants were asked to re-consent to study procedures. Participants who had chosen to exercise were encouraged to do so and provided directions to the university fitness facility located in close proximity to the lab. A written script was followed throughout the experiment to minimize experimenter effects and ensure instructions were presented in the same manner to all participants. There was no motivational encouragement provided at any time.

1.3. Tasks and apparatus

Modified graded exercise test (M-GXT). Participants completed a modified graded exercise test (M-GXT) protocol on a cycle ergometer (Lode Corival, Groningen, The Netherlands) to familiarize them with a specific range of intensities (moderate-vigorous) they would need to consider later on in the study. The protocol began with a two-minute warm-up at a fixed resistance of 50 Watts (W) followed by a progressive ramp protocol involving incremental increases of workload of one W every 3 s. Participants were instructed to maintain a cadence between 60 and 100 RPM and to inform the experimenter whenever their RPE increased by one unit on Borg's (1998) CR-10 scale. The target range of interest was between an RPE of three (verbal anchor of *"moderate")* and an RPE of six (between the verbal anchors of *"strong"* and *"very strong"*). Once within the target RPE range, participants were instructed to focus on and familiarize themselves with the sensations they were experiencing while cycling. Once participants rated their RPE = 7, they were informed the intensity they were exercising at was beyond the target range, the M-GXT was terminated, and the experimenter adjusted the workload to 50 W at which participants continued to pedal for 2 min as a cool-down.

1.4. Measures

Ratings of perceived exertion (RPE). Ratings of perceived exertion (RPE) were measured using Borg's (1998) CR-10 scale ranging from 0 (no exertion at all) to 10 (maximal exertion). Participants were educated on providing RPEs using Borg's instructions (Borg, 1998, p. 47) and were provided the opportunity to ask the experimenter any questions for clarification.

Ratings of perceived mental exertion (RPE-M). Participants provided ratings of perceived mental exertion (RPE-M) using Borg's (1998) CR-10 scale ranging from 0 (no exertion at all) to 10 (maximal exertion). This scale has been previously used in studies examining mental exertion during performance of cognitive tasks (e.g., Graham & Bray, 2015).

Subjective mental fatigue. A Visual Analogue Scale (VAS; Wewers & Lowe, 1990) was used to assess mental fatigue. Participants were instructed to: *"Please mark (X) on the line at the point that you feel represents your perception of your current state of mental fatigue"*. The response continuum consisted of a 100-mm line with the anchors ranging from 'none at all' on the left to 'maximal' on the right. Scores were calculated by measuring the distance in millimetres that the 'X' was placed from the left side of the scale.

Perceived effort. A Visual Analogue Scale (VAS; Wewers & Lowe, 1990) was used to assess perceived effort, which was defined as the *"subjective intensification of either mental and/or physical activity in the service of meeting some goal"* (Inzlicht, Shenhav, & Olivola, 2018, p. 338). Participants responded to the statement: *"In thinking about the 20-min exercise task, please mark (X) on the line, how much effort you feel it would take for you to complete the task."* The response continuum consisted of a 100-mm line with the anchors ranging from 'no effort at all' on the left to 'maximal effort' on the right. Scores were calculated by measuring the distance in millimetres the 'X' was placed from the left side of the scale.

Subjective evaluation of exercise. A 2-item measure was used to assess each of the perceived costs and benefits of engaging in the MVPA task. For perceived costs, participants were presented with: "For the exercise option, there are:…" and responded on a 1–10 scale anchored at 1) "no disadvantages" and 10) "many disadvantages". For perceived benefits, participants were presented with: "For the exercise option, there are:…" and responded on a 1–10 scale anchored at 1) "no advantages" and 10) "many advantages". Responses were also converted into a composite measure: "benefits vs. costs", calculated by subtracting the perceived costs value from the perceived benefits value. Greater positive values represent greater benefit - cost valuations and greater negative values represent greater cost - benefit valuations. This measure has been previously used to examine perceived costs and benefits of engaging in a physical task (Harris & Bray, 2019).

1.5. Potential covariates

Since the decision task involved choosing between either a MVPA or a non-exercise activity, we felt it was important to assess and control for any group differences in habitual MVPA and physical activity enjoyment based on the possibility that people engaging in greater amounts of physical activity or those who enjoy physical activity more would be more likely to choose to engage in MVPA regardless of their fatigue state.

MVPA. MVPA was assessed using four items selected from the International Physical Activity Questionnaire (IPAQ; Craig et al., 2003). Participants reported how many days per week and minutes per day they spent engaging in each of moderate and vigorous intensity physical activity during a typical 7-day period in the past three to five months.

Physical activity enjoyment. The Physical Activity Enjoyment Scale (PACES; Kendzierski & DeCarlo, 1991) was used to assess physical activity enjoyment. Consistent with other studies (Williams et al., 2006), the wording of the original scale was altered from "Please rate how you feel *at the moment* about the physical activity you have been doing," to "Please rate how you feel *while* engaging in physical activity," to represent participants' overall enjoyment of PA. Internal consistency was acceptable (Cronbach's $\alpha = 0.90$).

1.6. Experimental manipulations

Although some authors (Van Cutsem et al., 2017) have proposed mental fatigue induction manipulations should be > 30-min duration, these claims lack empirical substantiation. Indeed, recent meta-analytic findings based on over 90 effect sizes show no association between cognitive task manipulation duration and subsequent effects on physical performance (Brown et al., 2020). A 12-min manipulation, that has shown significant and large effects on subjective mental fatigue in previous research (e.g., Harris & Bray, 2019) was used in the current study.

High cognitive demand (HCD) task. Participants in the HCD group performed a computerized version of the incongruent Stroop colour word task (Stroop, 1935) programmed on Presentation™ software. The task consisted of five, 2-min blocks of 135 trials, separated by 30-s breaks during which participants rated mental fatigue and RPE-M, for a total duration of 12 min. The color-word stimuli were presented on a 17″ LCD monitor for 800 milliseconds on a white background in 48-size, Times New Roman font, followed by a 100 millisecond inter-trial interval in which the screen was blank. Participants were instructed to respond as quickly and accurately as possible to each stimulus by saying aloud the color of the font in which the word was printed and ignoring the semantic meaning of the word (e.g., for the word "red" presented in "blue" font, the correct response was to say aloud the word "blue").

Low cognitive demand (LCD) task. Participants in the LCD group watched a segment of a documentary video titled: "Planet Earth: Fresh Water" (Fothergill, Attenborough, & Fenton, 2007), consisting of five, 2-min sequences, separated by 30-s breaks during which participants provided ratings of mental fatigue and RPE-M, for a total duration of 12 min. During the task, participants were instructed to monitor the audio content and record instances in which they heard the word "water".

2. Data analysis

Quantitative data analysis. Descriptive statistics were computed for all study variables. Independent samples *t*-tests were computed for age, MVPA, and physical activity enjoyment as well as post-cognitive task mental fatigue. Separate 2 (group) X 6 (time) mixed ANOVAs were conducted on mental fatigue and RPE-M scores recorded during the experimental manipulations. Greenhouse–Geisser correction was utilized when sphericity was violated. Next, a 2 (group; HCD vs. LCD) X

2 (choice; non-exercise vs. exercise) chi-square analysis was computed to compare frequencies of choice between groups. Separate 2 (group) X 2 (time) mixed ANOVAs were computed on subjective perception scores (i.e., effort, benefits, costs) measured before and after the experimental manipulation.

A serial mediation analysis was conducted to assess the hypothesized sequential relationships between post-cognitive task ratings of mental fatigue and subjective perceptions in the prediction of exercise choice using Model 6 in version 3.3 of the PROCESS software macro (Hayes, 2017). Bootstrap procedures utilizing 10,000 simulations were computed (Hayes & Scharkow, 2013) in IBM SPSS Version 20.0. In these analyses, a 95% confidence interval that does not include zero indicates a significant ($p < .05$) indirect (mediation) effect.

Qualitative data analysis. Interviews were digitally recorded and transcribed verbatim. Transcribed interviews were read and re-read by the first author to become familiarized with the data. After familiarization with the data, a content analysis of the transcribed interviews was conducted to describe and interpret common ideas. Two researchers (SH and SRB) independently identified meaningful units related to effects of the cognitive task on participant's choice using an inductive approach (Elo & Kyngäs, 2008). Meaning units were then transposed onto individual cards and three researchers (SH and two research assistants) worked independently to generate codes to best fit the data, by working through each of four categories defined by group/choice pairings (e.g., HCD/chose exercise, HCD/chose non-exercise, LCD/chose exercise, and LCD/chose non-exercise). During a consensus meeting, the researchers compared coding schemes, discussed any discrepancies, and agreed upon the final coding schemes. The unit of analysis was counted at the level of each individual occurrence across the entire data set such that one participant could be responsible for multiple phrases or no phrases at all (see Table 2).

3. Results

3.1. Data screening

Data were screened for normality by assessing the absolute values of skewness and kurtosis of the distributions based on conditions proposed by Lei and Lomax (2005). For variables with moderate non-normality, square-root and reflect and square root transformations were used for positively skewed variables (mental fatigue, RPE-M) and the negatively skewed variable (perceived exercise benefits), respectively. Analyses were computed using both transformed and non-transformed data and, in all cases, produced identical results. Results of analyses using the non-transformed values are reported for ease of interpretation. Results are presented as $M \pm SD$.

3.2. Preliminary analyses

Descriptive statistics for measured variables and manipulation effects are presented by group in Table 1. Results of the independent samples *t*-tests revealed no significant between-group differences in MVPA or PA enjoyment ($ps > .16$, $ds < 0.31$).

Mental fatigue and RPE-M scores recorded during the experimental manipulations are presented by group over time (at 2-min intervals) in supplemental material Figures S1 and S2, respectively. As shown in the Figures, the HCD group reported significantly higher RPE-M and mental fatigue ratings throughout the cognitive task compared to the LCD group. For mental fatigue, the main effect for group and the group × time interaction were significant [(F (1, 82) = 40.11, $p < .001$, η_P^2 = 0.33) and (F (2.62, 214.43) = 22.88, $p < .001$, η_P^2 = 0.22), respectively]. Similarly, the main effect for group and the group × time interaction for RPE-M scores were significant [(F (1, 82) = 38.00, $p < .001$, η_P^2 = 0.32) and (F (2.55, 209.08) = 34.24, $p < .001$, η_P^2 = 0.30), respectively].

Table 1

Descriptive statistics for potential covariates, post-task mental fatigue, effort, costs, and benefits by high cognitive demand and low cognitive demand group.

	Low Cognitive Demand n = 42 (27 females)	High Cognitive Demand n = 42 (28 females)			
	$M \pm SD$	$M \pm SD$	t	p	d
Age	19.07 ± 1.40	19.07 ± 2.24	<.001	1.00	.005
MVPA	92.09 ± 37.05	86.02 ± 47.39	.65	.52	.14
PA enjoyment	103.45 ± 16.76	98.24 ± 18.01	1.37	.17	.30
Post-task mental fatigue	24.69 ± 19.19	61.10 ± 25.04	7.48	<.001	1.63
Pre-cognitive task perceived effort	63.62 ± 22.35	60.05 ± 17.23	.82	.42	.18
Pre-cognitive costs	4.00 ± 2.29	3.98 ± 2.18	.05	.96	.009
Pre-cognitive benefits	7.98 ± 1.97	7.40 ± 2.00	1.32	.19	.29
Pre-cognitive benefit vs. cost	3.98 ± 2.72	3.43 ± 3.55	.79	.43	.17
Post-cognitive task perceived effort	68.86 ± 21.00	68.60 ± 18.68	.06	.95	.01
Post-cognitive task costs	4.57 ± 2.24	4.05 ± 2.16	1.09	.28	.24
Post-cognitive task benefits	7.88 ± 1.92	7.48 ± 2.06	.93	.35	.20
Post-cognitive task benefit vs. cost	3.31 ± 3.11	3.43 ± 3.48	.17	.87	.04

Note. M = mean, SD = standard deviation, d = Cohen's d, MVPA = moderate-to-vigorous physical activity. Post-task mental fatigue = mental fatigue rating reported immediately following the cognitive task.

3.3. Group analyses

In the group-based analyses, an equal number of participants in the LCD group selected the non-exercise (n = 21) and exercise options (n = 21). Participants in the HCD group chose the non-exercise task (n = 22) and the exercise task (n = 20) in similar frequencies. These frequencies of task selection were not statistically significant (χ^2 (1) = 0.05, p = .83, d = 0.05).

Results from the 2 (group) X 2 (time) ANOVAs revealed no group effect for perceived effort (F (1,82) = 0.23, p = .64, η_P^2 = 0.003), benefits (F (1, 82) = 1.37, p = .25, η_P^2 = 0.02), costs (F (1, 82) = 0.34, p = .56, η_P^2 = 0.004), and benefit vs. cost scores (F (1,82) = 0.10, p = .76, η_P^2 = 0.001). However, there was a significant main effect of time for perceived effort (F (1, 82) = 17.38, $p < .001$, η_P^2 = 0.18) and perceived costs (F (1, 82) = 6.18, p = .02, η_P^2 = 0.07). Thus, on average participants perceived the MVPA task was going to be more effortful and more costly following the experimental manipulations compared to baseline. There was no effect of time on perceived benefits (F (1, 82) = 0.01, p = .92, η_P^2 < 0.001) or benefit vs. cost scores (F (1,82) = 3.84, p = .05, η_P^2 = 0.05). All interactions were not significant ($p > .05$, $\eta_P^2 < 0.05$).

3.4. Serial mediation analysis

In the serial mediation analysis, choice (non-exercise/MVPA; coded 0,1, respectively) was specified as the dependent variable and post-cognitive task mental fatigue as the independent variable; perceived effort (M_1), and benefit vs. cost scores (M_2) were included as mediators. As hypothesized, results showed a significant overall indirect effect (Effect = −0.004, 95% C.I. = −0.01 to −0.0004, SE = 0.002). The direct effects of all pathways were significant (a_1 95% C.I. = 0.02 to 0.31, SE = 0.07, p = .03, d_{21} 95% C.I. = −0.10 to −0.03, SE = 0.02, p = .0007, b_2

95% C.I. = 0.14 to 0.54, SE = 0.10, $p = .0008$). Direct effect coefficients are shown in Fig. 2.

3.5. Qualitative analysis

Twelve codes were identified from the data relating to the effects of the cognitive task on choice (Table 2). As shown in the table, "Increased feelings of fatigue due to the cognitive task" was most frequently cited (23 times) across the HCD/chose exercise, HCD/chose non-exercise, as well as the LCD/chose exercise categories. "Changes in motivation for the non-exercise task" was mentioned 21 times, most frequently in the HCD/chose non-exercise category, whereas "Changes in motivation for the exercise task" was mentioned 20 times, most frequently by participants in the HCD/chose exercise and LCD/chose exercise categories. There were 19 instances in which participants in the HCD/chose exercise and LCD/chose exercise categories expressed a desire to switch from engaging in a mental/cognitive task to a physical task. Negative or aversive feelings towards the cognitive task and altered perceptions of the effort requirements of the exercise task were noted 10 and five times, respectively, across the HCD/chose non-exercise and LCD/chose exercise categories.

Two codes unique to categories choosing to exercise were identified. "Increased feelings of alertness following the cognitive task" was present only in the HCD/chose exercise category and "cognitive task acting as a break" preparing participants for a bout of exercise was present only in the LCD/chose exercise category. Three codes unique to the LCD/chose non-exercise category were identified: 1) the cognitive task causing a state of low activation, which participants expressed a desire to maintain, 2) the cognitive task prompting evaluations of task difficulty/task demand between the exercise versus non-exercise tasks, and 3) the cognitive task eliciting thoughts related to one's preference for the non-exercise task. There were 27 instances of participants citing no effect of the cognitive task on one's choice, occurring most frequently in the LCD categories.

4. Discussion

In this study we investigated the effect of mental fatigue on people's exercise decision-making using a mixed-methods approach. Specifically, we examined whether levels of self-reported mental fatigue would predict the anticipated effort associated with a 20-min session of MVPA, benefit vs. cost valuations of exercise, and whether people would choose to engage in a 20-min session of MVPA or opt for engaging in 20 min of a non-exercise behavior instead. Results of the serial mediation model supported the hypothesis that mental fatigue is associated with higher levels of anticipated effort for exercising that, in turn affect benefit vs. cost valuations and decisions to exercise or not. A content analysis of participants' feelings and reasoning behind their choice to exercise or not revealed a variety of reasons, highlighting the roles of both the HCD and LCD manipulations affecting choices in both directions.

4.1. Quantitative discussion

Results from the serial mediation analysis support the hypothesis that higher mental fatigue led to greater perceived effort of the MVPA task, which led to reductions in benefit vs. cost valuations, predictive of selecting the non-exercise task. Consistent with Harris and Bray (2019), these findings support an interpretation that engaging in a cognitively-demanding task affects exercise choice through an evaluation of perceived benefits and costs. Findings also extend that work by demonstrating perceptions of anticipated task effort act as an additional mediator in the pathway between mental fatigue and exercise vs. non-exercise choice.

Recent theorizing has defined effort as a process mediating the relation between a person's ability to perform a task and task performance (Shenhav et al., 2017), such that a person who is capable of

Table 2
Reasons for choice between exercise and non-exercise task.

	Frequency	Example quote
HCD/Chose Exercise		
Change in motivation for the exercise task	$N = 7$	"I think that the cognitive task frustrated me a lot and it made me lose motivation to even take on the bike again when I had the alternative to just browse the internet"
Increased feelings of fatigue/ feeling tired	$N = 3$	"It made me more tired, which made me think riding on the bike would make me even more tired"
Desire to switch from mental to physical	$N = 14$	"I just felt like I did not want to do any other mental task anymore. So, I wanted to just get on the bike and not think about things for a while"
Increased alertness resulting from cognitive task	$N = 4$	"The [cognitive] task just woke me up"
HCD/Chose Non-exercise		
Change in motivation for the exercise task	$N = 6$	"The more times that we went through [the cognitive task], it lessened my motivation
Increased feelings of fatigue/ feeling tired	$N = 17$	"At first, I was fine with doing the 20-min biking [be]cause it didn't seem that bad, but then after the [cognitive] task, I was too tired for it."
Change in motivation for the non-exercise task	$N = 15$	"At the end I put it [non-exercise task] as having advantages where the advantages were just that I could relax and not have to do anything"
Aversive feelings towards the cognitive task	$N = 7$	"I did not like that at all"
Changes in effort perceptions of the exercise task	$N = 2$	"I would have to take more to do the exercising task just [be]cause I didn't want to do it and to sit around it would be no effort at all to me"
No effect of cognitive task on choice	$N = 2$	"I think if you asked me beforehand it still would be the same [be]cause I don't want to exercise"
LCD/Chose Exercise		
Change in motivation for the exercise task	$N = 7$	"I was motivated to complete the [cognitive] task here and it made me even more motivated"
Increased feelings of fatigue/ feeling tired	$N = 3$	"Made me more fatigued and not want to do the bike exercise"
Desire to switch from mental to physical	$N = 5$	"It was more of like, you know, you'll feel better after so I did it … I was like I need to wake up again"
Aversive feelings towards the cognitive task	$N = 3$	"It really bummed me out"
Changes in effort perceptions of the exercise task	$N = 3$	"I knew it would be more effort, so it made me not want to put in the effort"
Cognitive task as a break to prepare for exercise	$N = 8$	"It kind of calmed me down a lot and I kind of just had time to rest, so I was like I want to get up and do something."
No effect of cognitive task on choice	$N = 16$	"No matter what it would be better exercising rather than watching something or be on social media"
LCD/Chose Non-exercise		
Change in motivation for the non-exercise task	$N = 6$	"I was less motivated to do something, I just wanted to sit and watch Netflix some more"
Deactivated state following the cognitive task	$N = 8$	"Since I've already kind of mellowed out over here doing this cognitive task, I didn't want to go back to a physical task"
	$N = 7$	"I think because it [cognitive task] was involving the internet it kind of

(continued on next page)

Table 2 (*continued*)

	Frequency	Example quote
Task difficulty/demand requirements of exercise vs. non-exercise task		made me want to do the second task [non-exercise task] more than the first one [exercise task], it uses less energy"
Preference for non-exercise task	$N = 4$	"I was kind of just like oh I would rather do this than exercise"
No effect of cognitive task on choice	$N = 9$	"It didn't change my outcome because I still chose not to do it. But it did give me more time to think about if I should do it"

Note: Multiple responses were possible.

performing a challenging task will need to exert sufficient effort to perform well. Although theorizing from Shenhav et al. (2017) propose that a sufficient amount of effort is required to successfully perform a task, results from this study suggest increases in the perceived effort requirements of a task actually lead to a decreased likelihood that a person will choose to engage in an effortful task in the first place. These findings are consistent with previous research on cognitively effortful decision-making which show cognitive fatigue causes people to avoid cognitively effortful tasks (Kool & Botvinick, 2014; Massar, Csathó, & Van der Linden, 2018). However, to the best of our knowledge, this is the first study to show that cognitive fatigue increases perceived effort in anticipation of performing a physical task, which shifts one's decisional balance in favour of a less effortful task. Additionally, the significant pathway between perceived effort and choice in the serial mediation model (b_1 coefficient = −0.04, 95% C.I. = −0.07 to −0.006, SE = 0.02, $p = .02$) demonstrates perceptions of effort both directly and indirectly (through benefit vs. cost valuations) affect one's choice between engaging in exercise or not. In simpler terms, results show mental fatigue amplifies perceptions of effort, such that the same task is perceived to require more effort to perform and these increased effort perceptions make people less likely to choose exercise when a sedentary alternative is available to them.

These findings are of particular interest in light of recent conceptualizations of self-control as a value-based choice (Berkman, Hutcherson, Livingston, Kahn, & Inzlicht, 2017). Previous decrements in physical performance following highly demanding cognitive tasks have been attributed to reductions in a limited resource (Bray, Martin Ginis, Hicks, & Woodgate, 2008). More recently, the validity of the resource based account of self control has been questioned and criticized (see: Friese, Loschelder, Gieseler, Frankenback, & Inzlicht, 2018; Inzlicht & Marcora, 2016). Results from this study support a conceptualization of self-control as a decision-making process wherein people are less motivated to engage in an effortful task following prior cognitive exertion and can explain observed decrements in performance as people are less willing to engage in effortful tasks.

Given evidence of effort's aversiveness (Hull, 1943; Kurzban, 2016) it is not surprising that higher perceptions of effort were associated with reduced willingness to engage in a physically demanding task. However, it is important to note that effort can also add value and take on rewarding properties (see Inzlicht et al., 2018 for review). For example, through the process of learned industriousness which involves pairing the sensation of effort with a reinforcer, effort may take on secondary rewarding properties (Eisenberger, 1992). Given half of the participants in the HCD group chose to exercise, it is possible that these participants were more "industrious" and therefore selected the more effortful task because they perceived exerting effort to be rewarding. To more holistically understand how effort perceptions affect one's choice to be physically active, future research should assess the relationship between learned industriousness and effort-based decision-making. In addition, industriousness should be investigated as a potential moderator of choice such that people with higher industriousness may be more likely to select a more effortful option despite holding higher effort perceptions.

An interesting finding emerging from the quantitative data was that participants in both groups perceived the MVPA task to be more effortful and costly following the experimental manipulations. These findings may be contextualized within literature comparing the phenomenology and consequences of cognitive effort and boredom. According to Bench and Lench (2013), similar to fatigue, boredom is a feeling state that emerges when one's current situation is no longer stimulating and this feeling motivates them to pursue an alternate goal. Milyavskaya, Inzlicht, Johnson, and Larson (2019) recently observed participants experienced heightened reward sensitivity following a boredom-inducing task, suggesting people experiencing a state of boredom may be more likely to engage in reward-seeking behaviors. In the context of the present study, having participants monitor audio content throughout the LCD task may have induced feelings of boredom, making it more likely for them to choose the task they considered to be more rewarding. In line with evidence that the experience of fatigue and boredom are phenomenologically similar (Milyavskaya et al., 2019), future research should examine whether fatigue, boredom, and other qualitatively distinguishable feeling states uniquely predict benefit vs. cost valuations and exercise choices or whether induction of similarly low-activation feeling states results in generalized demotivation to exercise.

4.2. *Qualitative discussion*

Results from quantitative analysis are interesting to interpret in light of the qualitative findings. In particular, content from the *HCD/chose non-exercise* category maps, conceptually, onto the sequential mediation results by demonstrating that "increased feelings of fatigue resulting from the cognitive task" and "effects of the cognitive task on motivation" (i.e., benefits and cost) were the most frequently expressed reasons for choosing the non-exercise option. For example, one participant stated "At the end I put it [non-exercise task] as having advantages where the advantages were just that I could relax and not have to do anything". Also consistent with the mediation analysis, there were two instances in which participants referred to effort perceptions affecting their choice. For example, one participant stated that it would "take more effort to do the exercising task" following the HCD task compared to the non-exercise option which they indicated "would be no effort at all".

Based on predictions from the labor/leisure model, it appears contradictory that following cognitive exertion participants would seek out opportunities for physical exertion when a non-demanding option is available. However, qualitative insights from participants in the *HCD/chose exercise* category demonstrated a predominant code reflecting a desire to switch from a mental task to a physical task. Thus, although the non-exercise task was explained as "free time" in the lab, data from the interviews suggest that some participants were motivated to exercise in order to avoid perceived cognitive demands associated with the non-exercise task.

Interestingly, two common codes, which emerged in both the *HCD/chose exercise* and *LCD/chose exercise* categories ("Change in motivation for the exercise task" and "Increased feelings of fatigue/feeling tired") suggest altered perceptions that might favor choosing the non-exercise task, yet, participants in these categories still chose to exercise. This evidence supports the idea that motivation exists on a spectrum and that shifts in motivation do not necessarily translate into shifts in behavior, particularly when only two behavioral options are available. Future research should investigate whether there is a discernible motivation threshold or tipping point that predicts when people will choose to exercise or not and whether there are certain traits or habits that may make people more willing to engage in exercise behaviors despite experiencing lower levels of motivation to do so.

4.3. Practical implications

Findings from this study hold practical importance for contexts involving physically effortful decision-making such as sport and exercise. Given people's reduced willingness to engage in physically-effortful tasks when reporting higher levels of mental fatigue, interventions known to mitigate the effects of mental fatigue on physical task performance may also be effective strategies encouraging decisions to engage in physically effortful tasks when mentally fatigued. For example, evidence shows financial incentives increase levels of PA in adults (Mitchell et al., 2020) and attenuate effects of mental fatigue on physical performance (Brown & Bray, 2017). Findings from the present study also suggest interventions aimed to reduce anticipated effort of physical tasks (e.g., cognitive restructuring) could be effective strategies to encourage volitional engagement in physical activity. In addition, qualitative data highlight how individual-level consequences of completing cognitively-demanding tasks influence choice, suggesting that individually-tailored recommendations may be important considerations when promoting PA and exercise.

4.4. Strengths and limitations

The present study builds on previous work and provides fresh evidence of factors that may affect people's decisions to exercise or not and there are a number of strengths and limitations that should be noted. Moving beyond group-based analyses and investigating psychological factors as mediators between mental fatigue and exercise choice helps to further our understanding of the mechanisms and intricacies affecting choice. Group-based analyses examine overall group effects associated with an experimental manipulation and thus, do not account for individual differences in mental fatigue that may also account for variation in motivation and behavior. We argue that analysis strategies accounting for individual-level ratings of mental fatigue may be an important complement to group-based analyses in future work.

Additionally, having the experimenter blinded to experimental group should be noted as a methodological strength, as it minimizes the potential for experimenter bias. Drawing evidence from an insufficiently active sample helps further understanding of the decision-making processes of people who are motivated enough to do some exercise, but not at a level that meets public health recommendations. A greater understanding of these processes should ultimately lead to the design of strategies that support people's decisions to engage in exercise despite experiencing thoughts and feelings that might otherwise lead to non-exercise choices. Lastly, using a mixed-methods design allows for a more holistic understanding of the effects of mental fatigue on exercise decision-making.

Among the study limitations is the fact that people's preferred mode of physical activity was not accounted for in the choice paradigm used. It is possible that one's choice between an exercise and non-exercise task would differ if they were offered a variety of exercise options other than cycling continuously on a stationary ergometer at a moderate-to-vigorous intensity. Future studies should investigate the effects of mental fatigue on motivation and exercise choice allowing people to select their preferred form of exercise, which may more closely resemble decision-making experiences in naturalistic contexts. Additionally, although in-lab studies are advantageous for controlling external factors, in order to better understand what factors influence people's exercise choices in their daily lives, future work should consider incorporating ecological momentary assessment (EMA) techniques to understand exercise behaviors by sampling people's real-time experiences (Shiffman, Stone, & Hufford, 2008). Among the potential ways this approach would be informative is that it could help explain how daily fluctuations in fatigue and other factors affect the choice to exercise in a 24-h period as opposed to a one-hour, in-lab, session.

Although the qualitative analysis in the study provided novel, participant-derived perspective, a limitation likely inherent to those data is attribution bias, given people are motivated to explain and draw inferences from their behavior (Tetlock & Levi, 1982) and may have been introduced when participants were asked to retrospectively justify their decisions during the qualitative interview.

5. Conclusion

This mixed-methods study showed the relationship between mental fatigue and exercise choice is sequentially mediated by subjective perceptions of anticipated effort and benefit vs. cost valuations. Quantitative results demonstrate how experiencing higher levels of mental fatigue may lead to increased perceived effort in anticipation of the exercise task and subsequent reductions in benefit vs. cost valuations which decrease the likelihood of choosing to exercise. Qualitative results added important contextual relevance to interpreting quantitative findings, illustrating the roles of fatigue and other factors influencing motivation to exercise or not.

Author statement

The manuscript has been read and approved by both authors, requirements for authorship have been met by both authors, and each author believes this manuscript represents honest work. There are no conflicts of interest for either of the authors.

Declaration of competing interest

The authors have no competing interests to declare.

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Appendix A. Supplementary data

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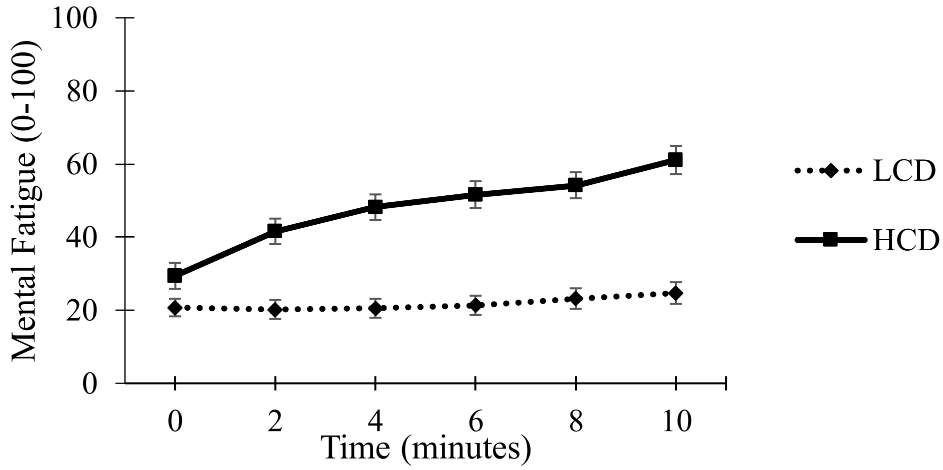

Figure S1. Mental fatigue over time by group. Bars represent standard error. HCD = high cognitive demand; LCD = low cognitive demand.

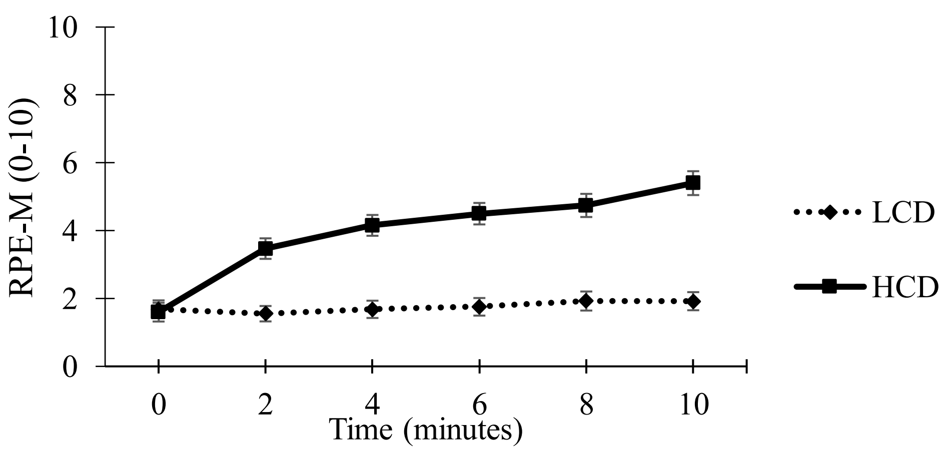

Figure S2. RPE-M (rating of perceived exertion – mental) over time by group. Bars represent standard error. HCD = high cognitive demand; LCD = low cognitive demand.

Appendix

Question guide for interview

Main question	Specific follow-up questions
How much did the 10-minute cognitive task affect your perceived advantages, disadvantages, and decision?	Please describe the effect of the cognitive task on your decision.
	Was it something you felt or thought about the task?
	Was it something you felt or thought about yourself?
	Was it something else?

CHAPTER 3

Is it really worth the effort? Examining the effects of mental fatigue on physical activity effort discounting

Preamble

Is it really worth the effort? Examining the effects of mental fatigue on physical activity effort discounting is the second study in the dissertation series. This study examined the role of intensity and duration on motivation to engage in physical activity using an online effort discounting paradigm among a sample of university students. A secondary objective of this study was to examine whether effort discounting was influenced by levels of mental fatigue.

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<u>Contribution of Study 2 to overall dissertation</u>
Study 2 builds on the findings of Study 1 by investigating how parameters such as intensity and duration used to define physical activity guidelines and prescriptions influence motivation for engaging in physical activity. Using an effort discounting paradigm, we were able to extend experimental work from Study 1 by examining changes in motivation not assessed using a binary choice outcome. In addition, choice outcomes included different types of physical activities based on people’s preferences. Results provide partial support indicating higher levels of mental fatigue are associated with greater discounting of vigorous-intensity physical activity. Findings suggest mental fatigue makes physical activity feel more costly, consistent with findings from Study 1.

Abstract

Physical activity (PA) guidelines are informed by epidemiological evidence but do not account for people's motivation for exerting physical effort. Previous research shows people are less motivated to engage in moderate-to-vigorous intensity PA when fatigued. In a two-study series we investigated how intensity and duration affected people's willingness to engage in PA using an effort discounting paradigm. A secondary purpose was to examine whether effort discounting was affected by mental fatigue. Both studies revealed a significant intensity X duration interaction demonstrating a reduced willingness to engage in PA of higher intensities across increasing duration levels. Study 1 demonstrated greater effort discounting for vigorous-intensity PA with increasing mental fatigue, however, this effect was not observed in Study 2. Findings provide novel insight towards people's motivation for engaging in PA based on the properties of the task and some evidence suggesting feelings of fatigue may also influence motivation to exert physical effort.

Keywords: behavioral economics; motivation, decision-making; exercise

Is it really worth the effort? Examining the effects of mental fatigue on physical activity effort discounting

Current physical activity (PA) guidelines recommend adults engage in at least 150 minutes of moderate-to-vigorous intensity physical activity (MVPA) and two muscle-strengthening activities each week, in addition to several hours of light intensity physical activity (LPA) within a 24-hour day (Ross et al., 2020). These guidelines are based on evidence showing a dose-response relation between MVPA and risk of chronic disease and all-cause mortality (Warburton et al., 2010) as well as recent evidence suggesting positive effects of LPA on health and mortality (Chastin et al., 2019). While guidelines are developed to inform the public's decisions about to their PA behaviors, they are not designed to persuade or motivate people to become more active (Latimer-Cheung et al., 2013). Recent estimates suggest the majority of Canadian adults do not accumulate the recommended amounts of MVPA each week and 3% of adults engage in no MVPA at all (Clarke et al., 2019). While it is necessary for epidemiological evidence to inform the development of PA guidelines, it is also important to consider people's motivation for engaging in the intensities and durations of PA recommended in those guidelines.

Many traditional assessments of motivation rely on questionnaire-based measures such as the Intrinsic Motivation Inventory (McAuley et al., 1989; Ryan, 1982) which are potentially subject to biases. For example, social desirability bias may cause participants to respond in a way they believe is more favourable for their self-esteem or social impression management (Paulhus, 1991). In addition, when responding to traditional questionnaire-based measures, people may be likely to respond in relation to their close friends and peers rather than relative to society at large (Odum, 2011). Thus, alternate methods for measuring people's motivation, indirectly, may provide novel insights.

As an alternative to traditional questionnaire-based assessments of motivation, value discounting methodologies have been developed. One form: *delay discounting* measures the extent to which an outcome (e.g., a reward) decreases in subjective value as the time to its receipt increases (Green et al., 1994; Johnson & Bickel, 2002; Odum, 2011). For example, Rachlin et al. (1991) showed people who are offered a monetary reward are willing to accept a smaller amount of money immediately rather than a larger amount later in the future. Another form of discounting: *effort discounting*, assesses people's willingness to exert effort to obtain rewards (Sugiwaka & Okouchi, 2004). One method of assessing effort discounting involves making a series of choices between engaging in an effortful behavior for a higher reward or a non-effortful behavior for a lower or equivalent reward. For example, offering $5 for physically climbing two flights of stairs vs. taking an elevator to the same level for $1. By offering a series of effortful and non-effortful choices with varying reward options, the subjective value of a reward can be determined based on one's choice patterns and used as an indicator of motivation towards the effortful behavior. Behaviors and rewards may be real or hypothetical and both discounting methodologies have revealed similar findings (Odum, 2011).

Responding to one's preference for effortful versus non-effortful alternatives offers an alternative approach to assessing motivation that may alleviate some biases associated with more transparent, or obvious, question and answer measures (Odum, 2011). Although discounting methods also rely on self-report, when choosing between effortful versus non-effortful options in a series of responses, people are not being asked to report something about themselves, but rather what their preferences are between two alternatives. Further, in responding to a series of choices, since a socially desirable answer is less obvious, people are less likely to be influenced by others or respond based on conscious or unconscious biases. In addition, people make choices between options based on what they prefer in the moment, which allows insight into transient personal and situational factors that may influence their motivation to exert effort. While effort discounting has not yet been widely used in sport and exercise psychology, this innovative and novel method is a promising avenue for assessing people's motivation for engaging in effortful tasks such as PA that are subject to a variety of personal and situational barriers such as lack of time, poor weather, and fatigue (Salmon et al., 2003).

Previous research utilizing effort discounting paradigms to investigate motivation for physical tasks demonstrates decreases in the subjective value of a given reward as the effort required to obtain the reward increases (Hartmann et al., 2013; Ostaszewski et al., 2013; Sugiwaka & Okouchi, 2004) indicating a reduced willingness to exert greater amounts of effort. However, the physically-effortful tasks represented in these studies, such as household cleaning (Sugiwaka & Okouchi, 2004) and stair-climbing (Ostaszewski et al., 2013), are not consistent with the types of PA people might engage in during their leisure time. Effortful tasks in these studies are also not defined by parameters such as duration and intensity which are commonly used for PA prescription and can be contextualized within public health PA guidelines. Furthermore, these studies do not account for variations in physiological or psychological states which may situationally bias motivation for engaging in effortful tasks.

In one study addressing these limitations, Iodice et al. (2017) investigated the effects of fatigue on effort discounting. In this study, participants made a series of choices between exercising at a submaximal intensity or not exercising for various durations. Specifically, participants responded to a series of choices between cycling at 70% of their VO_{2max} for 10, 15, 20, 25, 30, or 40 minutes or exerting no physical effort for the same durations of time. Participants were offered varying amounts of money for choosing to exercise (i.e., 15€, 20€, 25€, 30€, 35€, or 40€ for each duration, respectively) or 10€ for not exerting any physical effort. Participants responded to the same choice pairings under two conditions - one in which they were physically fatigued from having exercised vigorously beforehand and another in which they were not fatigued, having not exercised beforehand. Overall, results showed people's preference (choice) of the non-effortful option increased linearly as the durations of exercise increased, indicating discounting of the subjective value of rewards with increasing levels of effort. Furthermore, at every level of effort, participants choices revealed a lower subjective value of the same reward when they were fatigued compared to a rested state.

Although Iodice et al.'s (2017) research illustrates fatigue may negatively biases choices to exert physical effort, it is important to acknowledge the context in which their study was conducted. That is, assessing the effect of physical fatigue on motivation to exercise after people have already performed a lengthy bout of vigorous exercise stands in contrast to how fatigue may generally manifest as a de-motivator or barrier to physical activity. More specifically, given the majority of the population is not physically active (Clarke et al., 2019), fatigue due to having previously exercised provides little information about the potential role of fatigue in most people's decisions to exercise or not in the first place. Similarly, while being physically fatigued may negatively affect motivation to exercise, fatigue sensations other than those manifested by physical exertion may influence people's choices.

Mental fatigue refers to a psychobiological state experienced during or after prolonged and challenging activity (Boksem & Topps, 2008). Performing physically demanding tasks when mentally-fatigued has been shown to impair subsequent performance of tasks requiring muscular and cardiovascular endurance (Brown et al., 2020). Recent evidence also indicates mental fatigue biases decision-making in favour of sedentary tasks over PA (Harris & Bray, 2021). However, to the best of our knowledge the effects of mental fatigue on effort discounting of physical tasks have not been investigated. Further, investigating effort discounting for PA of varying intensities and durations stands to provide novel and valuable information about people' willingness to engage in PA based on characteristics of activities that are recommended by current PA guidelines.

The primary purpose of the present study was to examine the effects of varying levels of PA intensity and duration on people's subjective valuations of PA using an effort discounting paradigm. A secondary purpose was to investigate the potential moderating effect of mental fatigue on subjective valuations of PA. We present two studies in which participants, who self-reported not currently engaging in recommended levels of MVPA, made a series of hypothetical choices between engaging in PA of varied intensity levels (light, moderate, vigorous) and durations (10, 20, 30, 40, 50, 60 minutes) versus a sedentary behavior for the same durations. Since PA of higher intensities and longer durations require a greater volume or quantity of energy/effort expenditure (Howley, 2001), it was hypothesized that greater effort discounting would be observed for PA of higher intensities and longer durations. Further, based on research showing: 1) decreases in the subjective value of PA when fatigued (Iodice et al., 2017) and 2) mental fatigue negatively biases choice away from PA (Harris & Bray, 2021), it was hypothesized that mental fatigue would moderate the effects of intensity and duration on effort discounting such that higher levels of subjective mental fatigue would be associated with greater effort discounting.

General Method

Procedures

Data collection was conducted online using LimeSurvey (http://www.limesurvey.org). Participants were eligible to participate in the study if they were between the ages of 17 and 30 years and self-reported engaging in less than 150 minutes of MVPA weekly over the past six months. Researchers provided participants a link to the study website, where they gave informed consent and completed questionnaires assessing demographics, habitual MVPA, and their PA participation during the day prior to completing the survey. Next, participants were familiarized with Borg's (1998) CR-10 rating of perceived exertion (RPE) scale ranging from 0 (no exertion at all) to 10 (maximal exertion) using text instructions (see Appendix A in supplemental file). Participants were then informed that the different PA intensities they would respond to questions about throughout the study would be defined using four different ratings on the RPE scale. Specifically, an RPE of 0 (verbal anchor of "*nothing at all*") was used to define sedentary activities such as sitting on a chair, sleeping, or watching TV. An RPE of 2 (verbal anchor of *"weak"*) was used to define light-intensity PA including activities they would be able to perform without an increase in breathing rate, be able to carry on a conversation while performing, and feel they can maintain for hours (e.g., easy walking, yoga, bowling, or fishing). An RPE of 4 (between the verbal anchors of "*moderate*" and "*strong*") was used to define moderate-intensity PA including activities that are somewhat comfortable but becoming noticeably more challenging where they are breathing heavily but can still engage in a brief conversation (e.g., fast walking, easy bicycling, volleyball, or baseball). An RPE of 7 (verbal anchor of *"very strong"*) was used to define vigorous-intensity PA including activities that are borderline uncomfortable where they are continuously short of breath but can speak a sentence (e.g., running, hockey, soccer, or fast swimming).

Following their familiarization to the RPE rating system, participants were provided with the following instructions adapted from Ostaszewski et al., (2013):

> Our study involves making a series of choices between specific behaviours that are linked to different amounts of money. Although the choices are hypothetical, we ask that you indicate your preference as if you were actually going to engage in the behaviour and receive the money. We are interested in your preferences. There are no right or wrong answers. We

> do not have any expectations regarding your behaviour other than we ask you to choose according to your own preferences. The more honest you are about your decisions, the greater scientific value our results will have! On the following pages, you will see "Option A" on the left and "Option B" on the right. Option A offers you an amount of money that requires you to engage in physical activity at a specific intensity for a certain period of time to receive. Option B will offer you an amount of money that you could receive with no effort, and this amount changes with every choice. You will make a series of choices by checking the box beside one of the two options – A or B. We ask that you do not go back to change decisions that you have already made. Please make sure to respond to each choice. Ratings of perceived exertion (RPEs) will be used to describe the different physical activity intensities. Please note that there are 180 questions in total, which are divided into 3 sections. Once you begin this survey you will not be able to go back to previously answered questions.

Participants were then randomly assigned to complete one of six versions of the EDQ in which the order of presentation of intensity was counterbalanced (i.e., light-moderate-vigorous; light-vigorous-moderate, etc…) across the sample. Each version of the EDQ was separated into three, discrete sections consisting of 60 items. Prior to responding to each 60-item section, participants rated their level of mental fatigue.

Tasks and Measures

Effort discounting questionnaire (EDQ). The EDQ was developed for this study based on the methodology described by Ostaszewski et al. (2013), with additional questions to capture the specific intensity-duration combination parameters. The EDQ included 18 conditions based on a 3 (intensity; light, moderate, vigorous) X 6 (duration; 10, 20, 30, 40, 50, 60 minutes) design. Each intensity level was presented as an entire section of 60 questions and duration was presented within each section in ascending order (i.e., 10 questions per duration, beginning with 10 minutes).

The effortful (PA) option in each choice pairing was associated with a fixed reward of $20.00 Canadian dollars (CAD) and the non-effortful (sedentary) option was associated with rewards presented from $2.00 CAD to $20.00 CAD, ascending by $2.00 CAD increments. Choice pairings were presented in two adjacent columns and participants were asked to record their preference between the effortful-reward combination (presented on the left-hand column) and corresponding non-effortful-reward combination (presented on the right-hand column) for each pairing.

All choices were hypothetical such that participants were not expected to perform any chosen option and received no money for their choices. Previous research has found no difference in discounting rates when people were offered hypothetical and real rewards for their choices (Johnson & Bickel, 2002). Point of indifference (POI) scores were obtained by averaging the reward values associated with the sedentary option for the last choice pairing when the PA option was chosen and the first choice pairing when the sedentary option was chosen for each intensity-duration condition. For example, if a participant selected the $20 CAD reward to engage in moderate-intensity PA for 40 minutes rather than the sedentary option when offered $2 CAD through $10 CAD then switched over to select the sedentary option when offered $12 CAD, their POI value for that condition would be $11 CAD (i.e., $10+$12 / 2). This calculation reflects the monetary amount needed to be offered for the sedentary task for choice to be equivalent (indifferent) between the PA and sedentary options. Thus, a lower POI score is reflective of less motivation to exercise (i.e., participants are more willing to accept less money to forego exercise).

Participants who always selected the PA option within a given intensity-duration condition were assigned a POI value of $20, while those who always selected the sedentary option for a given intensity-duration condition were assigned a POI value of $2. These values were chosen to reflect the maximum and minimum reward possible, respectively, within the range of rewards offered in this study. POI scores were normalized by expressing their value as a proportion of the maximum, $20, reward value (e.g., if a POI for an intensity-duration combination was $3, the proportional score was $3/$20 = .15).

Subjective mental fatigue. Participants were instructed to: *"Please indicate the point that you feel represents your perception of your current state of mental fatigue"* on a scale ranging from 0 (energetic/no fatigue) to 10 (worst possible fatigue) prior to completing each section of the EDQ. Mental fatigue ratings reported at the beginning of each survey section were similar (Study 1, light: *M* = 5.65, *SD* = 2.28, moderate: *M* = 5.64, *SD* = 2.19, vigorous: *M* = 5.51, *SD* = 2.34; Study 2, light: *M* = 5.57, *SD* = 2.23, moderate: *M* = 5.63, *SD* = 2.29, vigorous: *M* = 5.64, *SD* = 2.30). The intraclass correlation coefficient (ICC) demonstrated strong reliability with an ICC of .94 (95% C.I = .91 to .95) and .95 (95% C.I = .94 to .96) for Study 1 and Study 2, respectively, based on a multiple measurement, absolute agreement, two-way mixed-effects model (Koo & Li, 2016). Thus, for each study a single measure: mean mental fatigue was calculated by averaging the three ratings.

Covariates.

MVPA. Given the EDQ required participants to choose between PA and sedentary activities, we felt it was important to control for habitual MVPA as people who engage in more regular MVPA may be more likely to choose to engage in PA. MVPA was assessed using four items selected from the International Physical Activity Questionnaire (IPAQ; Craig et al., 2003). Participants reported how many days per week and minutes per day they spent engaging in each of moderate and vigorous intensity activity during a typical 7-day period in the past three to five months. Minutes / day were multiplied by number of days / week for each intensity and summed to yield an overall score of MVPA (minutes / week).

DPA. In order to control for the possibility that people who already participated in PA during the day, prior to completing the EDQ, may have been less motivated to choose to engage in hypothetical PA on the EDQ, daily PA (DPA) participation was assessed. Participants reported the number of minutes they spent engaging in each of moderate and vigorous intensity PA, previously in the day, on the day the survey was completed, which were summed to create an overall DPA score (minutes / day).

Physical activity enjoyment. In order to control for the possibility that people who enjoy PA more may be more motivated to choose to engage in hypothetical PA on the EDQ compared to people who enjoy PA less, physical activity enjoyment was assessed using the Physical Activity Enjoyment Scale (PACES; Kendzierski & DeCarlo, 1991). Consistent with other studies (Williams et al., 2006), the wording of the original scale was altered from "Please rate how you feel *at the moment* about the physical activity you have been doing," to "Please rate how you feel *while* engaging in physical activity," to represent participants' overall enjoyment of PA. The PACES consists of 18 bipolar statements scored on a 7-point scale. Items were summed to create a composite score.

Data Analysis

Data were summarized as means and standard deviations for continuous variables and frequencies were summarized for sex. Outliers for MVPA and DPA were recoded using Winsorization (Leys et al., 2019). Winsorization at the 90th percentile was chosen based on recommendations from Liao et al. (2016) suggesting a relatively larger percentile of Winsorization is sufficient to accommodate the effects of outliers to achieve an acceptable Type I error rate with large sample sizes. Six mental fatigue values from Study 2 were excluded for being outside of the possible range (0 – 10) and were omitted from mean calculations.

Marginal models were computed to examine the effects of intensity, duration, and mental fatigue on POI scores when controlling for covariates. Intensity level was coded as categorical and included light, moderate and vigorous intensities. Duration and mental fatigue were coded as continuous. To achieve the best model fit, independent and exchangeable covariance structures were evaluated and tested using the Akaike information criterion (AIC). Significant interactions were deconstructed by examining slope estimates (i.e., rates of change) of POI scores. Residuals were visually assessed to verify the assumptions of normality. The alpha criterion was set to 0.05. Data management and analyses were conducted using IBM SPSS Version 26.0 and STATA version 14.2.

Study 1

Participants

One hundred and fifty undergraduates provided informed consent to participate in the study. Six participants provided incomplete responses to the EDQ questionnaire and three participants selected the same option for all 180 EDQ questions and were excluded, allowing analyses of data from a total of 141 participants (n = 22 males, M_{age} = 18.72, SD = 1.22 years). The study was reviewed and approved by an institutional research ethics board prior to any recruitment and data collection. Participants received partial course credit for participation.

Results

Descriptive statistics for variables included in the model are presented in Table 1. The first model included intensity, duration, mental fatigue, and all 2-way and 3-way interactions. The model was statistically significant ($\chi^2(14) = 989.76$, $p < .001$); however, since the 3-way interactions were not significant (ps > .26) they were removed and the model was re-computed without them. The subsequent model including up to only the 2-way interactions was significant ($\chi^2(12) = 988.03$, $p < .001$) and the likelihood ratio test confirmed it was not different from the previously tested model ($\chi^2(2) = 1.22$, $p = .54$). The second model was used as it was the most parsimonious model and an independent covariance structure best fit the data.

Model coefficients and 95% confidence intervals are presented in Table 2. Findings showed lower POI scores across greater durations and intensities (Figures 1A and 2A), however, these results were not significant. Results showed significant intensity X duration and intensity X mental fatigue interactions (see Figures 3A and 4A, respectively). Total MVPA and PA enjoyment were significant covariates. Slope estimates for light, moderate, and vigorous intensities across duration were -.002, -.004, and -.007, respectively. Slope estimates were all significantly different from zero (all *p*s < 0.001), indicating a decrease in POI scores with increases in duration. Post-hoc comparisons, decomposing the intensity X duration interaction, revealed that POI scores decreased at a greater rate for vigorous intensity PA over longer durations compared to light ($p < .001$) and moderate ($p = .0002$) intensity PA, and that POI scores decreased at a greater rate for moderate compared to light intensity PA ($p = .002$). Thus, in support of our first hypotheses, results demonstrate greater discounting across duration given increases PA intensity, indicating reduced willingness to engage in PA of higher intensity and longer duration.

Post-hoc decomposition of the intensity X mental fatigue interactions revealed that as mental fatigue increases, slope estimates for POI scores of light (.007) and moderate intensity (.003) PA were no different from 0 (*p*s > .09). However, there was a significant negative slope for vigorous intensity PA (-.01, $p = .008$) indicating POI scores for vigorous intensity PA decreased with increasing levels of mental fatigue. Comparisons of slope parameters between intensities showed no difference between light and moderate intensity PA (p = .52) whereas the slope for vigorous intensity PA was significantly different from both light (p = .002) and moderate intensity PA (p = .01). Overall, results provide partial support for the hypothesized effects, showing no effect of mental fatigue on effort discounting for light and moderate-intensity PA. However, for vigorous-intensity PA, significant discounting was observed, suggesting not only a reduced willingness to engage in vigorous-intensity PA compared to moderate and light intensity PA, but a greater aversion with higher levels of mental fatigue.

Study 2

Participants

Two hundred and eighty-one undergraduate students provided informed consent for the study. Thirty-eight participants provided incomplete responses to the EDQ questionnaire and eleven selected the same option for all 180 EDQ questions and were excluded, allowing analysis of data from a total of 232 participants (n = 38 males, M_{age} = 18.58, SD = .97 years). The study was reviewed and approved by an institutional research ethics board prior to any recruitment and data collection. Participants received partial course credit for participation.

Results

Descriptive statistics for variables included in the model are presented in Table 1. The first model including intensity, duration, mental fatigue and all 2- and 3-way interactions was statistically significant ($\chi^2(14) = 1726.10$, $p < .001$), however, the 3-way interactions were not significant (*p*s > .67) and removed from the model. The subsequent model including up to only the 2-way interactions was also significant ($\chi^2(12) = 1725.81$, $p < .001$) and the likelihood ratio test confirmed that it was not different from the fully saturated model ($\chi^2(2) = .20$, $p = .91$). The second model was used as it was the most parsimonious model and an independent covariance structure best fit the data.

Model coefficients and 95% confidence intervals are presented in Table 3. Results showed significant main effects of duration and intensity (Figures 1B and 2B, respectively) and a significant intensity X duration interaction (see Figure 3B). Total MVPA, DPA, and PA enjoyment were significant covariates. Slope estimates for light, moderate, and vigorous intensities across duration were -.002, -.006, and -.007, respectively and were all significantly different from zero (all *p*s < .001) indicating POI decreased with increasing PA durations. Post-hoc comparisons, computed to decompose the intensity X duration interaction revealed that POI scores decreased at a greater rate for vigorous intensity PA compared to both light and moderate intensity PA, and that POI scores decreased at a greater rate for moderate compared to light intensity PA (all *p*s < .001). Consistent with Study 1, results demonstrate POI scores decrease at a steeper rate across duration given increased PA intensity. Unlike Study 1, there was no interaction of mental fatigue X intensity (Figure 4B).

General Discussion

The purpose of this two-study investigation was to examine the effects of PA intensity and duration on subjective valuations of PA as well as the potential moderating effect of mental fatigue using an effort discounting paradigm. Results from both studies demonstrated greater effort discounting across duration with increases in PA intensity, providing overall support for the first hypothesis. Results from Study 1 provided partial support for the second hypothesis, demonstrating greater discounting for vigorous-intensity PA with higher levels of mental fatigue, however, this effect was not observed in Study 2.

Using an effort discounting paradigm, this study applied a novel methodology to examine people's motivation to engage in physical activities of varying intensities and durations. Main effects of intensity and duration were significant in Study 2 suggesting an overall reduced willingness to engage in tasks requiring greater effort. Although these findings were not observed in Study 1, the model estimates of the main effect of duration and intensity are similar to those of Study 2 (see Figures 1 and 2) suggesting Study 1 was underpowered to detect a significant effect. However, the intensity X duration interaction found in both studies demonstrates how the rate of discounting differs between PA of different intensities across increases in duration. Specifically, PA of higher intensities is discounted at a greater rate than lower-intensity PA suggesting people are more willing to engage in PA at lower intensities for prolonged durations. These results also make sense in terms of the energy requirements of lower vs. higher intensity activities, which enable people to plan and engage in light-moderate activities such as brisk walking or hiking for extended durations.

Findings are consistent with previous research from cognitive and physical effort discounting (Ostaszewski et al., 2013) demonstrating a reduced willingness to engage in tasks requiring greater effort. This finding is not surprising considering evidence of effort's aversiveness (Hull, 1943; Kurzban, 2016), however, to the best of our knowledge, this is the first study to show the interactive effects of different types of effort parameters (i.e., intensity and duration) on effort discounting. Findings may also be contextualized within the theory of effort minimization in PA (TEMPA; Cheval & Boisgontier, 2021) which suggests the effort associated with PA is perceived as a cost to be avoided or minimized. In these studies, we saw a greater preference for engaging in sedentary tasks in response to increases in effort requirements of the PA task such as intensity and duration. The TEMPA also suggests that expected effort influences people's decisions to initiate a behaviour which can lead to one's preference for a lower-effort alternative which is consistent with study findings as well.

Importantly, quantifying effort level by parameters that are commonly used to define exercise prescriptions and public health guidelines extends previous effort discounting work. For example, investigating both intensity and duration provides insight into people's decision-making specific to hypothetical leisure time PA behaviors rather than more general forms of physical effort expenditure. Accordingly, the present findings lend practical relevance compared to the existing discounting literature as PA prescriptions are typically defined using Frequency, Intensity, Time, and Type of exercise (FITT principle; Riebe et al., 2018) with recent recommendations to also consider enjoyment in PA prescriptions (Burnet et al., 2019). In this study, participants were encouraged to consider their preferred type of PA for each intensity level which is comparable to decision-making they would be faced with when actually making these decisions to act or not. Thus, results from this study further our understanding of PA-related decision-making contextualized within important parameters that are considered when choosing between engaging in PA versus competing sedentary alternatives.

The secondary objective of this study was to examine the effects of mental fatigue on subjective valuations of PA. Results from Study 1 showed a decrease in POI scores as self-reported mental fatigue increased for vigorous intensity PA. These results are consistent with findings from Iodice et al. (2017) showing physical fatigue makes people less likely to choose to exercise in the presence of a sedentary alternative. Since the vigorous intensity level used in this study (RPE = 7/10) is comparable to the intensity level used in the study by Iodice and colleagues (70% of one's VO_2 max), these findings collectively show people experiencing greater levels of fatigue are less willing to choose to engage in vigorous intensity PA. However, this is the first study to show that motivation to engage in PA of lower intensity levels is unaffected by fatigue. An important difference to note is that participants in the study conducted by Iodice et al. (2017) were purposely fatigued using strenuous exercise prior to completing the discounting questionnaire whereas participants in these studies were asked to report their mental fatigue in the absence of any experimental manipulation. Thus, the effects of mental fatigue observed in these studies may be smaller than effects observed by Iodice et al. (2017) and more reflective of motivation to engage in PA in people's naturalistic environment.

While recent conceptualizations of fatigue constructs have encouraged a holistic approach for measuring fatigue (Micklewright et al., 2017), recent evidence demonstrates mental fatigue is linked to decreased performance on physical tasks (Brown et al., 2020) and makes people less likely to choose to engage in PA when also offered a sedentary alternative (Harris & Bray 2021) warranting further investigation of mental fatigue, specifically, on effort discounting. As noted earlier, Iodice et al. (2017) demonstrated physical fatigue following a vigorous bout of exercise may alter effort discounting; however, as most adults are not sufficiently active, fatigue due to previous physical exertion may not affect PA decision-making to the same extent as mental fatigue that may be experienced independent of any prior physical exertion (e.g., following cognitively demanding activities). Thus, examining how mental fatigue may modify effort discounting extends the work of Iodice et al. (2017) to help account for PA decision-making among the majority of the population who are not meeting PA guideline recommendations and holds practical relevance to understanding current patterns of inactivity.

Although effects of mental fatigue on vigorous-intensity PA motivation was shown in Study 1, this effect was not observed in Study 2. Further inspection of the mental fatigue X intensity interaction from Study 2 showed that when mental fatigue scores = 0 for vigorous intensity PA, the POI estimate was .58 (95% CI = .54 to .62). In contrast, the estimate in Study 1, when mental fatigue = 0 yielded an estimate of .64 (95% CI = .59 to. 69). However, when mental fatigue was at maximum (i.e., 10/10) both studies yielded similar estimated values (Study 1 = .53, 95% CI = .49 to .57; Study 2 = .55, 95% CI = .52 to .58). Together, these findings suggest that at lower levels of mental fatigue, participants in Study 2 were less willing to engage in vigorous-intensity PA than participants in Study 1. One explanation for this difference may be due to lower self-reported levels of habitual PA by participants from Study 2 who reported engaging in 20 minutes less of MVPA each week than those in Study 1. Thus, it seems possible to infer that, for people who are less active, there may be a general aversion to vigorous intensity PA regardless of how much mental fatigue they are feeling. Additionally, participants in Study 2 reported engaging in significantly more DPA prior to completing the survey which could also explain why these participants were less willing to engage in higher-intensity PA, even at shorter durations.

Notably, as participants in both studies self-reported engaging in 150 minutes or less of weekly MVPA, study findings hold practical relevance to PA promotion efforts targeting the large proportion of the population who are insufficiently active or inactive (Clarke et al., 2019). Specifically, changes in one's willingness to engage in PA appear to be dependent on both intensity and duration, with some evidence suggesting motivation may be influenced by current levels of mental fatigue. As PA guidelines are not designed with the aim to persuade people to become more active (Latimer-Cheung et al., 2013), findings from this study highlight the importance of considering how much effort people are willing to invest in PA. Accordingly, messaging designed to promote PA to people who are not active at PA guidelines levels should take into consideration that people's motivation to engage in MVPA may be more sensitive to the duration of recommended activities than lighter intensity PA and that vigorous PA may not be a recommendation for people when they are experiencing higher levels of mental fatigue. In addition to considering epidemiological data, promotion efforts should be mindful of people's general motivation for engaging in PA at different intensities and durations in addition to psychological contexts which may also affect motivation.

To the best of our knowledge this is the first study examining the effects of intensity, duration, and mental fatigue on PA effort discounting and there are several strengths and limitations which should be noted for future research in this area. First, using a novel effort discounting paradigm rather than traditional questionnaire-based measures as an alternate measure of motivation should be viewed as a strength as it is less susceptible to common self-reporting biases. In addition, defining intensity-level with subjective ratings of perceived exertion holds practical relevance to PA in real-world settings where people often select a level of intensity based on their subjective perceptions in the moment. Also, this study has more clear application to real-world PA decision-making than previous examinations of effort discounting for physically effortful tasks by having participants consider tasks they may choose to engage in based on duration and intensity characteristics of the activities as captured by public health PA guidelines. As a result, study findings may have important implications for health promotion efforts.

Study findings hold practical importance for the promotion and prescription of physical activity behaviours. For example, across both studies it was consistently shown that people are more willing to engage in activities of shorter durations at each intensity level. These findings provide some support for the promotion of exercise “snacks” involving several shorter bouts of PA throughout one’s day rather than longer continuous bouts (Francois et al., 2014). Along these lines future work should investigate POI scores for durations shorter than 10 minutes consistent with the "every minute counts" approach to PA (Fan et al., 2013) to support the development of recommendations for exercise "snacks" of varying intensity levels. Encouraging intermittent bouts of shorter duration PA within a day may be an effective way to increase PA of all intensities, but particularly for vigorous-intensity PA that had much lower POI scores at a 10-minute duration than light- and moderate-intensity PA across both studies. Further, when encouraging people to engage in longer-duration PA, practitioners and exercise professionals should consider promoting light-intensity PA which consistently had a higher POI score at each duration level, and it is less likely to be biased by feelings of mental fatigue as demonstrated in Study 1. Consistent with evidence highlighting the health benefits of engaging in light-intensity PA (Chastin et al., 2019) and PA recommendations such as the 24-hour movement guidelines promoting "trading in" sedentary behaviors with light-intensity PA (Ross et al., 2020) further work should continue examining health benefits of light-intensity PA and encourage increased awareness of the value of engaging in PA of any intensity over sedentary behavior.

Purposely sampling participants who self-reported not currently engaging in levels of PA recommended by public health guidelines can be seen as both a strength and limitation. While it is unclear whether findings relate to either the initiation or maintenance of PA, information relating to people's motivation to invest effort towards engaging in PA gained from people who are insufficiently active can be used to inform targeted promotional efforts aimed to increase PA levels in people who are inactive or insufficiently active. However, due to the lack of precision in self-report PA measures, it is also possible that some participants included in the study may have been achieving or surpassing current PA guidelines. Future studies may consider using more objective methods (e.g., accelerometry) to assess PA and include participants who are meeting or exceeding current physical activity guidelines to examine effort-based motivation for PA more comprehensively.

The fact that participants in this study made choices based on hypothetical rewards and were not expected to follow through on any of the choices they made may also be seen as limitations. Since participants did not receive any rewards based on their choices and were not expected to engage in behavior consistent with any of their choices it is unclear how study results may translate to PA decision-making scenarios with real rewards that are contingent on successfully enacting the selected options. However, concerns in these regards should be somewhat tempered in light of previous research showing similar discounting patterns between real and hypothetical choice-dependent rewards (Johnson & Bickel, 2002; Odum, 2011). Future research on effort based decision making should make use of hybrid methods where participants enact a selected behavior based on their choices in order to receive the associated reward (e.g., Iodice et al., 2017). In addition, findings from this study are limited to motivation related to more acute rewards or benefits expected from a single session of PA and do not provide information relating to how delayed benefits of PA, which underlie public health recommendations, may influence motivation.

Further, inconsistent results from Studies 1 and 2 limit the conclusions drawn on the effects of mental fatigue on effort discounting and warrants future investigation.

Finally, the limited demographic information collected from participants is an important limitation to note. Specifically, socio-demographic factors including employment status, living arrangement, gender identity and gender expression may influence people's motivation for engaging in exercise and sport behaviours. For example, factors such as socio-economic status (Griffiths, Moore, & Brunton, 2022) and perceived safety among medically transitioning transgender adults (Jones et al., 2017) have been shown to influence PA behaviours which were not measured in this study.

Despite these limitations, the present study provides a useful framework for examining effort discounting within PA and exercise contexts as well as novel information about people's motivation to engage in various intensities and durations of PA. Future work can continue to explore the effects of intensity, duration, and mental fatigue on motivation for engaging in PA compared to sedentary alternatives. Future research should also investigate strategies to increase motivation for engaging in PA measured using effort discounting to inform the development of interventions aimed to increase PA motivation and ultimately behavior.

This study was the first to examine effort discounting as a measure of motivation for PA involving duration and intensity parameters consistent with current public health guidelines. Study findings demonstrate lower motivation for engaging in PA of longer durations and higher intensities with some evidence suggesting people are less motivated to engage in vigorous intensity PA when experiencing higher levels of mental fatigue.

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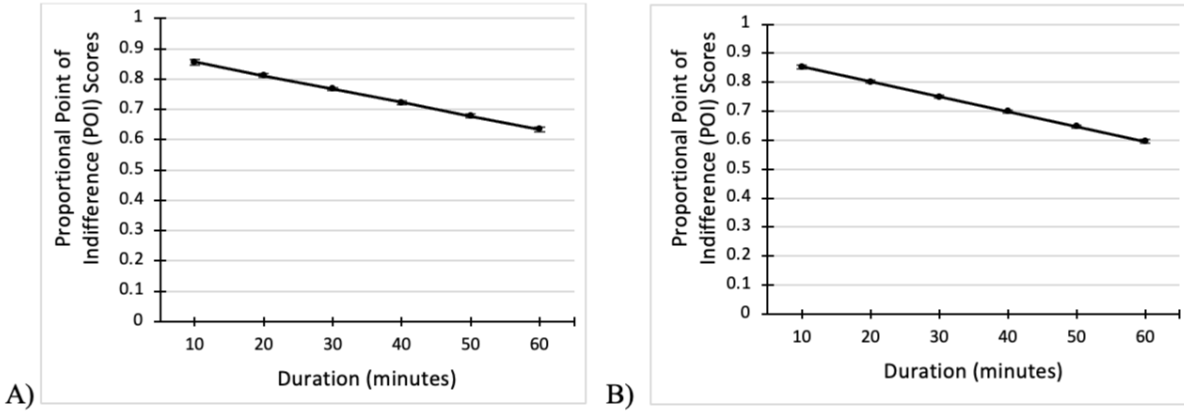


Figure 1. Predictive margin with 95% CIs for PA *Duration* in Study 1 (A) and Study 2 (B).

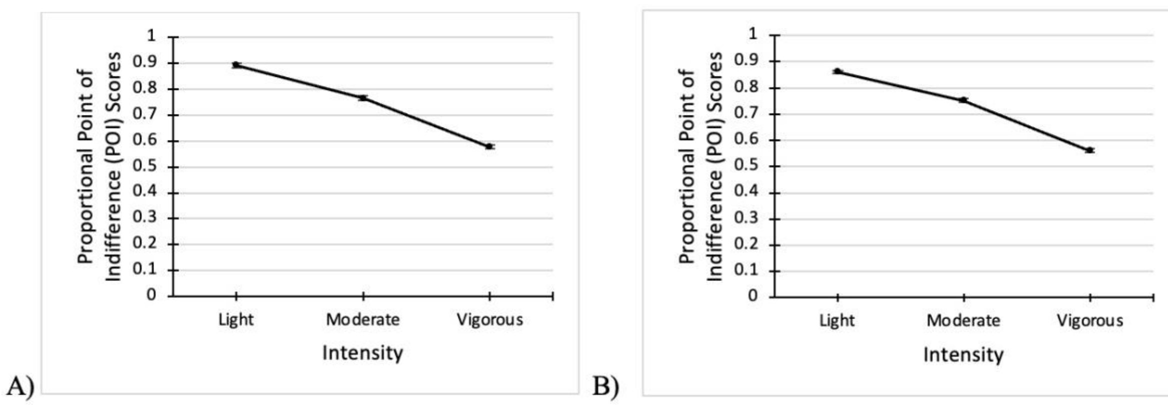
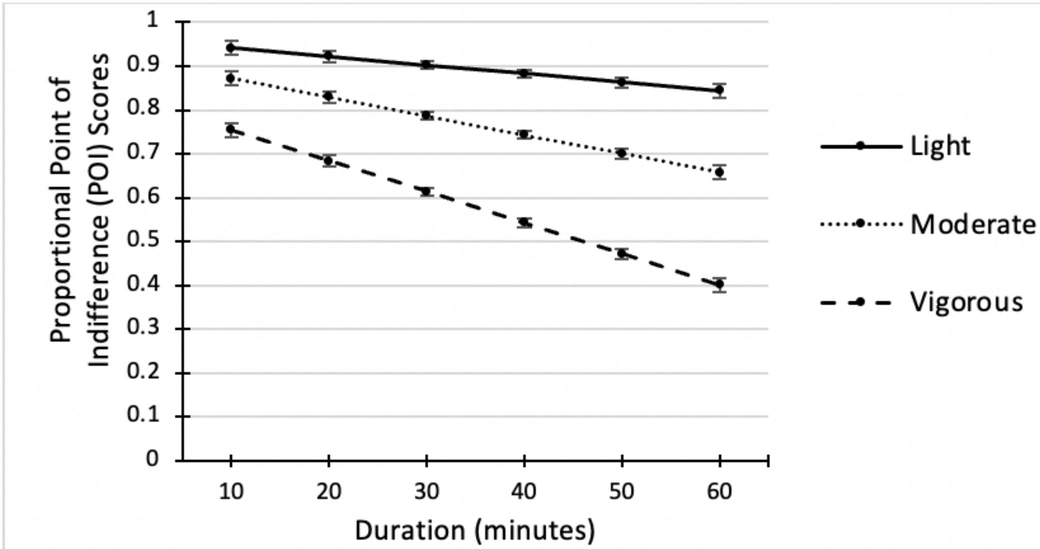
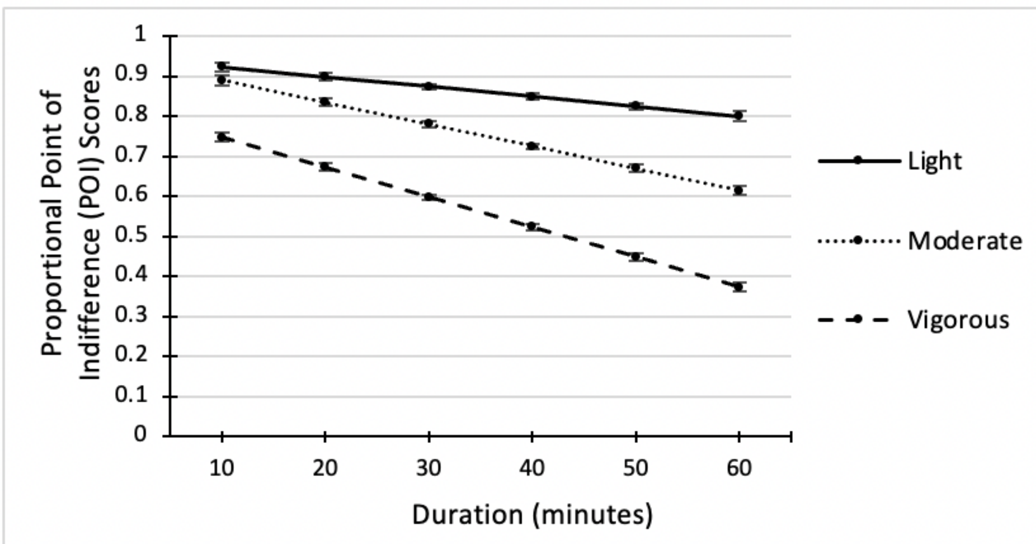


Figure 2. Predictive margin with 95% CIs for PA *Intensity* in Study 1 (A) and Study 2 (B).

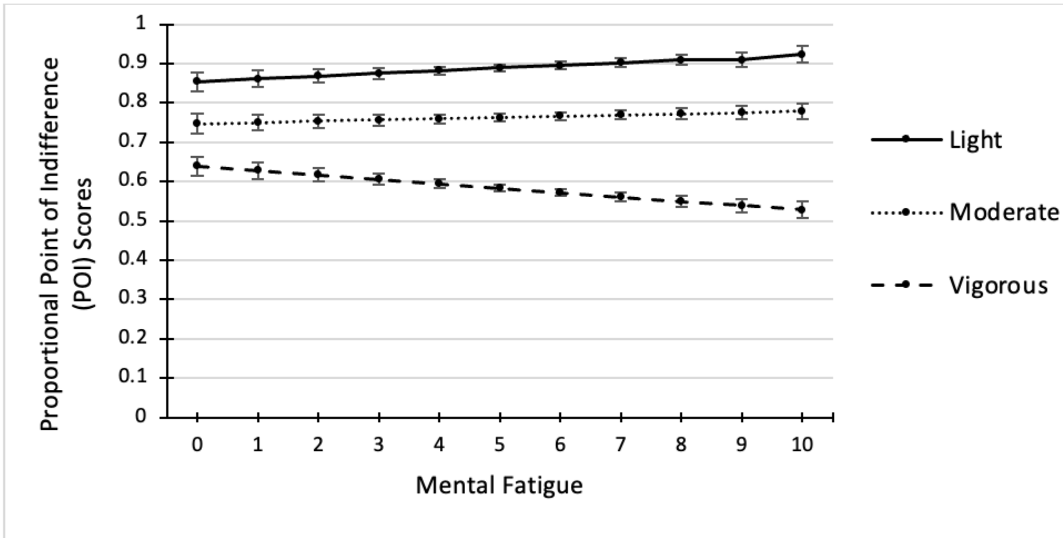


A)

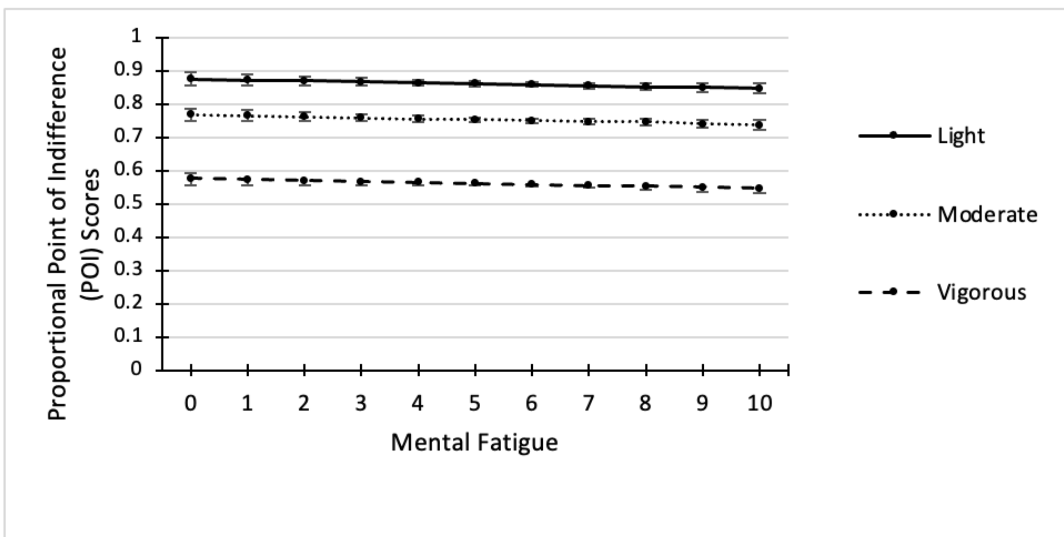


B)

Figure 3. Predictive margin with 95% CIs for the PA *Intensity* X PA *Duration* interaction in Study 1 (A) and Study 2 (B).



A)



B)

Figure 4. Predictive margin with 95% CIs for the PA *Intensity* X *Mental Fatigue* interaction in Study 1 (A) and Study 2 (B).

Table 1.

Descriptive Statistics Demographic Variables and Potential Covariates by Study

	Study 1 *n* = 141 (22 males) *M* (*SD*)	Study 2 *n* = 232 (38 males) *M* (*SD*)	*p*	*d*
Age	18.72 (1.22)	18.58 (.97)	.12	.13
MVPA	165.35 (129.70)	143.54 (107.23)	.02	.19
DPA	13.06 (15.69)	18.01 (21.18)	< .001	.26
PA enjoyment	101.62 (18.29)	96.78 (20.16)	.13	.25
Mental fatigue	5.60 (2.14)	5.60 (2.17)	.48	.00

Note. *M* = mean, *SD* = standard deviation, MVPA = moderate-to-vigorous physical activity. DPA = daily physical activity.

Table 2.

Study 1 Model coefficients

Variable	Coefficient	SE	95% C.I	*p*
Duration	-.001	.0009	-.003 to .0005	.16
Intensity				.70
Moderate	-.03	.04	-.11 to .06	*.56*
Vigorous	-.04	.04	-.12 to .05	*.41*
Mental fatigue	.01	.006	-.002 to .02	.09
Intensity X Duration				< .001
Moderate	-.002	.0007	-.004 to -.0009	.002
Vigorous	-.005	.0007	-.007 to -.004	< .001
Duration X Mental fatigue	-.0001	.0001	-.0004 to .0002	.40
Intensity X Mental fatigue				.005
Moderate	-.004	.006	-.02 to .008	.52
Vigorous	-.02	.006	-.03 to -.007	.002
MVPA	.0002	.00004	.0001 to .0003	< .001
DPA	.0005	.0003	-.0002 to .001	.15
PA enjoyment	.002	.0003	.001 to .002	< .001
Constant	.67	.05	.57 to .77	< .001

Table 3.

Study 2 Model coefficients

Variable	Coefficient	SE	95% C.I	*p*
Duration	-.002	.0007	-.003 to -.0003	.017
Intensity				< .001
Moderate	-.001	.03	-.07 to .07	.98
Vigorous	-.12	.03	-.19 to -.06	< .001
Mental fatigue	.002	.005	-.008 to .01	.76
Intensity X Duration				< .001
Moderate	-.003	.0006	-.004 to -.002	< .001
Vigorous	-.005	.0006	-.006 to -.004	< .001
Duration X Mental	-.0001	.0001	-.0003 to .00009	.25
fatigue				
Intensity X Mental				.99
fatigue	-.0002	.004	-.009 to .009	.97
Moderate	-.00005	.004	-.009 to .009	.99
Vigorous				
MVPA	.0002	.00004	.0001 to .0003	< .001
DPA	.0007	.0002	.0003 to .001	.001
PA enjoyment	.0017	.0002	.0001 to .002	< .001
Constant	.73	.04	.66 to .81	< .001

Appendix A

RPE familiarization script

The Borg Rating of Perceived Exertion (RPE) scale is a way of measuring how much effort or exertion you are experiencing when you are exercising. It is based on the physical sensations a person experiences during physical activity, including increased heart rate, increased respiration or breathing rate, increased sweating, and muscle fatigue. This scale is subjective in nature meaning that it will vary between individuals. When referring to this scale what is important is that you refer to your own feelings of effort or exertion, and not how it compares to other people's. The scale we will be using ranges from 0 – "nothing at all" to 10 – "absolute maximum," but we will be using intensities in between (as shown in the picture above). When answering the following questions, please answer them based on your own perceptions of exertion.

After reading the familiarization script for the RPE scale, participants were presented with a list of five activities and asked to provide an RPE score, based on their personal experiences of engaging in each activity. Descriptive statistics are presented in Table S1. Results show participants utilized a range of scale responses and scaled RPE similarly between samples (studies) as well as in a manner consistent with the RPE demands of the various activities.

Table S1. Descriptive Statistics for RPE scores for five sample activities.

	Study 1	Study 2
Easy walking	1.61 ± 1.09	1.51 ± 1.18
Fast walking	3.32 ± 1.20	3.24 ± 1.44
Volleyball	4.27 ± 1.52	4.57 ± 1.59
Running	6.56 ± 1.43	6.61 ± 1.68
Soccer	6.49 ± 1.61	6.80 ± 1.72

Note. *M* ± *SD*. Study 1 *N*=141, Study 2 *N*=232.

CHAPTER 4

Investigating real-time physical activity decision-making using ecological momentary assessment: Effects of mental fatigue and benefit-cost valuations

Preamble

Investigating real-time physical activity decision-making using ecological momentary assessment: Effects of mental fatigue and benefit-cost valuations is the third study in the dissertation series. This study examined associations between real-time variations in mental fatigue, perceived costs/benefits of engaging in MVPA, and MVPA using ecological momentary assessment and accelerometry.

The manuscript has been submitted (currently under review) for publication in the journal *Annals of Behavioral Medicine* and has been formatted for this dissertation.

Contribution of Study 3 to overall dissertation

Study 3 builds on the findings of Studies 1 and 2 by showing that greater mental fatigue was associated with lower benefit vs. cost scores and fewer minutes of MVPA and lower benefit vs. cost scores were associated with engaging in fewer minutes of MVPA in real-time, ecologically valid settings. Findings demonstrate a relation between mental fatigue, motivation, and subsequent physical activity behavior in people's authentic everyday experiences.

Abstract

Background: Current research investigating the relationship between mental fatigue and physical activity behaviours relies on laboratory-based, experimental studies which lack ecological validity. *Purpose:* This study used ecological momentary assessment (EMA) to assess feelings of mental fatigue and subjective evaluations (benefits and costs) as predictors of moderate-to-vigorous intensity physical activity (MVPA) in the everyday lives of young adults. *Methods:* One hundred participants (n = 22 males, M_{age} = 20.60 years) responded to digital survey prompts up to four times a day and wore an accelerometer for seven consecutive days. MVPA in the 180-minute time window following each survey prompt was recorded. Data from the 28 survey-MVPA epochs were analyzed using hierarchical linear modeling. *Results:* Higher levels of mental fatigue were associated with lower benefit vs. cost scores ($p < .001$) and fewer MVPA minutes ($p = .043$). Higher benefit vs. cost scores were associated with engaging in more minutes of MVPA ($p < .001$). A multilevel mediation model revealed a non-significant ($p = .053$) indirect effect of mental fatigue on MVPA through benefit vs. cost valuations. *Conclusions:* Results are the first to demonstrate outside the lab, that mental fatigue experienced in everyday life may amplify the perceived costs of MVPA, with both factors playing a potential role in MVPA decision-making. Future research may apply insights gained from this study in design and testing of real-time interventions promoting MVPA.

Investigating real-time physical activity decision-making using ecological momentary assessment: Effects of mental fatigue and benefit-cost valuations

Current physical activity guidelines recommend adults engage in at least 150 minutes of moderate-to-vigorous intensity physical activity (MVPA) each week [1-3]; however, the majority of adults are not achieving these recommended amounts [4-5]. Engaging in regular physical activity (PA) has been shown to reduce the risk of several chronic diseases including cardiovascular disease, depression, cancer, and diabetes [6] and physical inactivity has been estimated to carry an economic cost of $53.8 billion worldwide [7]. To encourage regular participation in PA and minimize these negative outcomes, there is a need to explore factors influencing people's choices to engage or not engage in PA.

According to behavioral choice theory, one principle consistent across decision-making scenarios is that choices people make depend on their assessments of behavioral costs [8] such that people are less motivated to engage in behaviors perceived to be more costly. For PA, behavioral costs may include the energetic cost of engaging in the behavior, the effort required in processes of planning and scheduling PA around alternate priorities such as caregiving or work, or the opportunity costs associated with engaging in a lower-effort task such as watching TV at the end of a long day [9-10]. In this way, the behavioral cost of engaging in PA may be an important factor predicting one's motivation and ultimately choice to engage or not engage in PA behaviors.

Motivation has been conceptualized as a subjective trade-off between the perceived benefits and perceived costs associated with engaging in a behavior [10, 11].

According to this conceptualization, people make choices in favour of behaviors they perceive maximize benefits and minimize costs. Conceptualizing motivation as a decisional balance between perceived benefits and costs may help explain population-level decision-making related to PA. Specifically, despite universal knowledge that regular PA is beneficial [12, 13], current rates of physical inactivity suggest there are many factors that may amplify cost perceptions of PA and shift decisional balances away from PA and towards competing sedentary tasks.

A recent study examining barriers to engaging in PA found structural factors including: lack of facilities/equipment/space, as well as personal factors such as lack of time and laziness or fatigue as barriers to PA [14]. Fatigue has been defined as "*a symptom in which physical and cognitive function is limited by interactions between performance fatigability and perceived fatigability*" [15, pp. 2236] suggesting fatigue encompasses both physical and psychological elements. Previous research has demonstrated people experiencing greater physical fatigue have a greater preference for engaging in lower-effort tasks than when making decisions in a non-fatigued state [16] indicating fatigue may amplify cost perceptions and bias choice in favour of lower-effort behaviors. However, given widespread evidence that most adults do not regularly engage in PA, fatigue caused by prior *physical* exertion seems an unlikely PA impediment. Rather, other sources or manifestations of fatigue may determine people's decisions to engage in PA or not.

Mental fatigue refers to a psychobiological state experienced during or following prolonged and challenging cognitive activity [17]. Mental fatigue experienced after prior cognitive exertion has been shown to impair physical performance and amplify ratings of perceived exertion during endurance tasks [18, 19]. In addition, previous research has shown reductions in self-selected intended exercise intensity for endurance [20] and resistance exercise [21] following completion of cognitively demanding tasks. Collectively, these investigations illustrate the negative impact of mental fatigue on exercise intentions and subsequent performance; however, these findings are limited insofar as participants were given no choice other than to engage in PA and to modify their motivation or behaviour in light of that eventuality. An area that has received less attention is examining how mental fatigue influences people's decision-making when given choices between engaging in PA or alternative behaviours.

An emerging body of research has examined the role of mental fatigue on decision-making between engaging or not engaging in exercise or MVPA. Van As et al. found completing a mentally fatiguing task beforehand did not affect the likelihood of choosing to engage in a physically effortful task or not [22]. However, the task participants were presented with was a hand-grip exercise task, which, while designed to be physically-effortful, may not represent the types of activities people choose to engage in for exercise or MVPA. In contrast, two experiments found mental fatigue decreased the likelihood of engaging in MVPA when a sedentary alternative was readily available [23, 24]. Importantly, the effect of mental fatigue on choice was mediated by motivation represented by a benefit vs. cost valuation, consistent with theorizing by Chong et al. [11] and others [10, 25].

Although the above studies demonstrate the influence of mental fatigue and benefit vs. cost valuations on MVPA choices, the MVPA task consisted of continuous cycling on a stationary ergometer which also fails to represent the broad range of MVPA options people may choose to engage in throughout their day. In addition, participants choices regarding MVPA were confined to a single study session and did not account for fluctuations in psychological or feeling states that may affect choices people make during their everyday lives. Thus, while previous research has demonstrated effects of mental fatigue and subjective valuations on MVPA in principle, methods with stronger ecological validity and better application to real-world decision-making scenarios are needed.

Ecological Momentary Assessment (EMA) is a real-time data capture methodology which involves sampling psychological and contextual experiences using digital software applications to deliver surveys to personal electronic devices requesting immediate responses. This methodology accounts for dynamic changes in real-time to examine cognitions, feelings, and behaviour across time and contexts, minimizing recall bias and maximizing ecological validity [26] which results in greater accuracy when evaluating associations between psychological experiences and subsequent behaviour. Further, EMA can be paired with activity monitoring devices (e.g., accelerometers), which can provide accurate estimates of PA within discreet time windows, rather than relying on self-report measures that are subject to social desirability, over-reporting, and recall biases [27]. A major strength of using EMA is that it can better account for the complex and dynamic patterns of change that occur in real-world, real-time scenarios than more traditional methods (e.g., one-time questionnaire assessments) applied in PA research [28].

In an illustrative study using EMA, Rebar et al. [29] investigated associations between ego depletion (a construct similar to mental fatigue [30]), intentions, and MVPA. In the study, participants completed one, daily, EMA survey on each of seven consecutive days. Results showed when people reported higher ego depletion, their exercise intentions were significantly lower than when they reported lower ego depletion. Further, when ego depletion was high, intentions were a good predictor of MVPA the following day; however, MVPA levels were low (i.e., people intended and engaged in less MVPA). These findings provide evidence that within-day levels of ego depletion predict intentions and next-day behaviour such that higher ego depletion prompts intentions to engage in less MVPA. Given the similarities between ego depletion and mental fatigue, these findings may be extended to support a prediction that mental fatigue may play a similar role in shaping motivation and engagement in MVPA; however, to the best of our knowledge no study has examined the relationships between mental fatigue, motivation, and MVPA using real-time data capture and device-assessed activity.

The purpose of this study was to examine associations between real-time variations in mental fatigue, perceived costs/benefits of engaging in MVPA, and MVPA using EMA and accelerometer methodologies. Building on research by Rebar and colleagues [29], this study utilized four, within-day, EMAs from: morning, late morning/early afternoon, mid/late afternoon, and evening on seven consecutive days. Based on findings from Harris and Bray [23, 24], it was hypothesized that (1) higher levels of mental fatigue would be associated with engaging in fewer minutes of MVPA in the 180-minutes following the EMA survey, (2) higher levels of mental fatigue would be associated with lower benefit vs. cost scores, (3) higher benefit vs. cost scores would be associated with engaging in more minutes of MVPA in the 180-minutes following the EMA survey, and (4) benefit vs. cost scores would mediate the relation between mental fatigue and MVPA minutes.

Methods

Participants

One hundred and twelve participants provided informed consent to participate in the study. Ten participants did not complete the study protocol and accelerometer data was inaccessible for two participants who did not return the accelerometer following the study period, allowing analyses of data from a total of 100 participants (n = 22 males, M_{age} = 20.60, SD = 2.61 years). See Figure 1 for flow diagram of study participants. Participants were eligible to participate if they were (a) between 17-30 years of age, (b) fluent in English, and (c) owned a personal smartphone device. Participants received a $20 CAD honorarium and pro-rated compensation up to a maximum of $50 CAD for completing EMA surveys. The study was reviewed and approved by an institutional research ethics board prior to recruitment and data collection.

Sample Size Calculation

The study methodology involved collection multiple measures from participants on multiple occasions, resulting in “nesting” of data and application of multilevel analyses. Simulation studies show multilevel models reach optimum efficiency with 50-

60 observations at the highest level of the hierarchy (in this study, the individual) [31]. Similar EMA studies in the field of exercise psychology have used sample sizes around 100 (e.g., *N* =121 [32]; *N* = 114 [33]; *N* = 103 [29]). Thus, to be consistent with other studies in the field, we aimed to collect data from 100 participants.

Procedures

Following local/institutional COVID-19 restrictions, all research procedures were carried out remotely. Participants conducted one phone screening session with a study researcher confirming study eligibility and providing informed consent. Baseline data collection was managed through an online survey platform: LimeSurvey (http://www.limesurvey.org) which participants accessed via a hyperlink to the study website where they completed questionnaires assessing demographics (age, sex) and habitual MVPA. Next, participants were familiarized with the different measures they would respond to during each EMA survey prompt during the study period and were instructed to contact study researchers with any questions or concerns regarding the EMA survey instruments. After completing the online questionnaire, a study researcher delivered a wrist-worn accelerometer (ActiGraph GT9X Link) to the participant. Participants were instructed to wear the accelerometer on their non-dominant wrist for as much time as they could over the 10-day study period; apart from water-based activities (e.g., showering, swimming). The study period started the day after the accelerometer was provided to the participant. Days 1-3 were used as a device habituation period in which activity was monitored, but not analyzed for study purposes. On Day 3 of the study, participants were sent instructions via email for downloading a smartphone application (Lumedi: Webility Solutions Inc.) with a customized EMA survey platform, developed for this study, and provided with a unique code to activate a secure, personal, account. Participants were also provided a study reference document outlining the EMA questions. The EMA survey prompts commenced at 8am EST on study Day 4 and ended at 8pm EST on Day 10 (See Figure 2 for study procedure timeline). Upon completion of the study, participants returned the accelerometer and received the honorarium/compensation.

Measures

Habitual MVPA. Habitual MVPA was assessed using four items from the International Physical Activity Questionnaire (IPAQ; [34]). Participants reported how many days per week and minutes per day they spent engaging in each of moderate and vigorous intensity activity during a typical 7-day period in the past three to five months. Minutes / day were multiplied by number of days / week for both intensities and summed to yield an overall score of habitual MVPA (minutes / week).

Ecological momentary assessment (EMA) measures

Electronic EMA surveys were delivered through a smartphone app (Lumedi) downloaded to participants' personal smartphone device. Four EMA surveys were distributed each day for seven consecutive days (up to 28 total surveys) to assess participants' current psychological state and perceptions related to engaging in physical activity. Surveys were designed to take 2-3 minutes to complete. Each EMA prompt was delivered at a random time within four pre-programmed timepoint windows (1) 8:00-9:30am, (2) 11:30am-1:00pm, (3) 3:00-4:30pm, and (4) 6:30-8:00pm daily. Participants were alerted when a survey was available to complete through a notification on their smartphone from the Lumedi app. If a survey was not completed at the time of the initial prompt, the app sent up to three reminder notifications 10-minutes, 20-minutes, and 25-minutes after the initial prompt. If a response was not logged within 30-minutes of the initial prompt, the survey became inactive. Each EMA survey was coded for day of the week (i.e., Monday through Sunday) and time-of-day (i.e., timepoint 1 through timepoint 4).

Subjective mental fatigue. A horizontal sliding scale, similar to a Visual Analogue Scale (VAS; [35]), was used to assess mental fatigue. Participants were instructed to: *"Please use the sliding scale to indicate what you feel represents your perception of your current state of MENTAL FATIGUE"* with the anchors ranging from 'None at all' on the far left to 'Maximal' on the far right. The scale was calibrated to 101 increments ranging from 0 on the far left of the line to 100 on the far right. Participants used their fingertip to move a cursor along the sliding scale to the point on the line representing their current state of mental fatigue.

Subjective evaluation of exercise. A 2-item measure was used to assess each of the perceived costs and perceived benefits of engaging in exercise. For perceived costs, participants were presented with: "*In general, I think exercising for 10+ minutes sometime within the next few hours has:...*" and responded on a 1-10 scale anchored at 1) "No disadvantages" and 10) "Many disadvantages". For perceived benefits, participants were presented with: "*In general, I think exercising for 10+ minutes sometime within the* *next few hours has:...*” and responded on a 1-10 scale anchored at 1) “No advantages” and 10) “Many advantages”.

To represent the perceived costs relative to perceived benefits, responses were converted into a composite measure: “benefits vs. costs”, calculated by subtracting the perceived costs value from the perceived benefits value. Scores for the composite measure range from -9 to +9, with greater positive values representing greater benefit – cost valuations and greater negative values representing greater cost – benefit valuations. This measure has been previously used to examine perceived costs and benefits of engaging in MVPA [23, 24].

Accelerometer-based physical activity. Moderate-to-vigorous intensity PA was measured passively using an ActiGraph GT9X Link device on participants’ non-dominant wrist for seven consecutive days. Data were collected in three axes at a sampling rate of 30 Hz. Data were uploaded from each accelerometer to the ActiGraph CentrePoint platform once returned to study researchers. The CentrePoint platform was used to calculate and record wear time as well as MVPA during 180-minute time window following each EMA survey. MVPA cut points were based on the Troiano et al. [36] criteria. A 180-minute time window has been previously used in EMA research examining PA in adults [37].

Data Analysis

Descriptive data from the baseline questionnaire were summarized as means and standard deviations for age and habitual PA and frequencies were summarized for sex.

Summary descriptive information was also computed for the EMA sampling data. Descriptive analyses were conducted using IBM SPSS (Version 28.0).

Analyses of missing data were conducted using logistic regression models (coded 0 for not missing and 1 for missing) to examine whether EMA responses differed by age, sex, habitual MVPA, time-of-day (timepoint 1 through 4), and day-of-week (Monday through Sunday).

Multilevel Modelling. The data collected form a three-level hierarchy with observations (Level 1) nested within day-of-week (Level 2) or time-of-day (Level 2) nested within people (Level 3). Three separate unconditional models were initially generated by entering MVPA as the dependent variable and each of the nesting variables to establish whether there was systemic variation in data recorded at Level 1, within-people (Level 3), within-day-of-week (Level 2), and within-time-of-day (Level 2) on MVPA engaged in within the 180-minute time window.

A multilevel mediation model was computed in STATA (Version 14.2) to assess the hypothesized relationships between (1) mental fatigue and MVPA, (2) mental fatigue and benefit vs. cost scores, (3) benefit vs. cost scores and MVPA, and (4) mental fatigue and MVPA, controlling for benefit vs. cost scores. All data were analyzed for MVPA observations with a non-zero wear time value in the 180-minute time window following the EMA survey prompt. The alpha criterion was set at 0.05.

Multilevel mediation modeling allows for the test of mediational effects at the lowest level of the multilevel hierarchy in clustered data [38]. Essentially, this analysis tests mediation of the mental fatigue – MVPA relationship by benefits vs. costs at each of the 28 Level 1 observations (4 timepoints * 7 days) in the dataset adjusting for the "nesting", or intercorrelation, of Level 1 observations within higher levels of the hierarchy. Bootstrap procedures utilizing 10,000 simulations were computed based on recommendations by Hayes & Scharkow [39] to determine 95% confidence intervals. Residuals were visually assessed to verify assumptions of normality.

Results

Descriptive statistics

The sample was, on average, 20.60 (*SD* = 2.61) years old and self-reported engaging in 290.00 (*SD* = 267.27) minutes of MVPA per week. On average, participants answered 72% of EMA prompts (range = 14% – 100%) and most (63%) participants wore the accelerometer for ≥ 12 hours/day, on 7/7 days during the EMA period and 80% wore the accelerometer for ≥ 12 hours/day on 5/7 days or more.

Missing Data

The likelihood of answered vs. unanswered mental fatigue ratings did not vary as a function of age, sex, habitual MVPA, or day-of-week. However, mental fatigue scores were more likely to be missing for prompts later in the day (coef. = -.27, SE = .039, $p < .001$, 95% C.I. = -.35 to -.19). The likelihood of answered vs. unanswered benefit vs. cost scores did not vary as a function of age, habitual MVPA, or day-of-week. However, benefit vs. cost scores were more likely to be missing from male participants (coef. = .35, SE = .12, $p = .003$, 95% C.I. = .12 to .58) and for prompts later in the day (coef. = -.33, SE = .043, $p < .001$, 95% C.I. = -.42 to -.25).

Descriptive statistics and percentages of missing data for mental fatigue, benefit vs. cost score, and MVPA minutes during the 180-minute time window after each EMA survey are presented in Table 1. As shown in the table, mental fatigue scores were moderate (*M* = 41.00, *SD* = 26.47), based on a possible range of 0-100; benefit-costs scores were +2.72 (*SD* = 4.03) demonstrating a general bias in favour of perceived benefits over perceived costs, based on a possible range of -9 to +9; and participants spent on average 16.56 (*SD* = 16.49) minutes engaging in MVPA during the 180-minutes following each EMA survey.

Preliminary Analyses

The likelihood ratio test comparing the unconditional model to a linear model was significant when examining nesting of Level 1 observations within-people ($\chi2(1) = 156.11$, $p < .001$) and within-time ($\chi2(1) = 31.60$, $p < .001$) indicating significant between-people and between-time-of-day variation, thus supporting use of multilevel modeling. However, there was no difference between the unconditional model examining nesting within-day-of-week and a linear model ($\chi2(1) < 1.00$, $p = 1.00$) indicating no significant variation based on days of the week (e.g., scores for measures taken on Monday were not statistically different from scores taken on Wednesday, etc.) deferring the use of multilevel modeling of within-day variance.

Because multilevel mediation models can only accommodate 2-level data structures [38], separate multilevel models were initially computed for the 3-level data structure (i.e., observations nested within time-of-day nested within individuals) to assess the x-y, x-m, and m-y (controlling for x) relationships. For each model, a random intercept model was first generated to fit the data and consequently compared to a random intercept, random slope model to achieve the best fit for the 3-level data structure. A random intercept, fixed slope model best fit the data assessing the x-y relationship. For the x-m and m-y relationships, random intercept, random slope models provided the best fit.

Results from each 3-level model were compared with the results of a random-intercept multilevel mediation model using only the 2-level structure (i.e., observations nested within individuals) to determine if multilevel mediation was statistically appropriate. In all cases, the 3-level multilevel models produced identical results to the 2-level multilevel mediation model. Thus, given there was no observable effect associated with nesting within time-of-day, results from the 2-level multilevel mediation model including nesting of observations within individuals were considered appropriate for the primary analyses.

Primary Analyses

The first multilevel model included MVPA minutes as the dependent variable and mental fatigue as the independent variable. Higher levels of mental fatigue were associated with less MVPA (coef. = -.032, SE = .016, p = .043, 95% C.I. = -.062 to -.00099, ICC = 9.5%). The multilevel model including benefit vs. cost score as the dependent variable and mental fatigue as the independent variable indicated higher levels of mental fatigue were associated with lower benefit vs. cost scores (coef. = -.013, SE = .0034, $p < .001$, 95% C.I. = -.019 to -.0062, ICC = 42.2%). The final multilevel model included MVPA minutes as the dependent variable and benefit vs. cost score and mental fatigue as independent variables. Higher benefit vs. cost scores were associated with engaging in more MVPA (coef. = .40, SE = .11, $p < .001$, 95% C.I. = .18 to .61, ICC = 9.7%). The unadjusted model including MVPA as the dependent variable and benefit vs. cost score as the independent variable revealed a significant association (coef. = .45, SE = .10, $p < .001$, 95% C.I. = .24 to .65, ICC = 11.8%). See Electronic Supplemental Material 1 for model coefficients for fixed and random effects.

Mediation Analysis

In the mediation analysis, (see Figure 3), MVPA minutes during the 180-minute time window was specified as the dependent variable, mental fatigue as the independent variable, and benefit vs. cost score as the mediator. The overall results revealed a non-significant indirect (mediation) effect (coef. = -.005, SE = .0026, $p = .053$, 95% C.I. = -.010 to .00007); however, it is noteworthy that this effect barely exceeded the conventional $p = .05$ level. Further, the strength of the direct effect of mental fatigue to MVPA was weakened from -.032 to -.026 when benefit vs. cost score was included in the model (coeff = -.026, SE = .016, $p = .092$, 95% C.I. = -.057 to .0043) showing the relationship between mental fatigue and MVPA minutes is partially mediated by benefit vs. cost scores. As recommended by Shrout and Bolger ([40], pp. 434), P_M: an estimate of the “effect proportion mediated”, was calculated to assess the strength of the partial mediation effect attributable to benefits vs. costs using the ratio of the indirect effect over the total effect. The resulting P_M value indicated 16.2% of the effect between mental fatigue and MVPA was accounted for by benefits vs. costs.

Discussion

In this study we examined associations between real-time variations in mental fatigue, perceived costs/benefits of engaging in MVPA, and MVPA using EMA and accelerometry. Building on previous lab-based research using an acute decision-making paradigm, we investigated the association between mental fatigue and MVPA and whether that association was mediated by benefit vs. cost valuations of engaging in MVPA over seven consecutive days. Results demonstrated greater mental fatigue was associated with significantly lower benefit vs. cost scores and significantly fewer minutes of MVPA, while higher benefit vs. cost scores were significantly associated with engaging in more minutes of MVPA. Results of the mediation analysis were not significant, however, an estimate of the strength of the effect indicated a partial mediation such that benefits vs. cost valuations accounted for 16.2% of the effect between mental fatigue and MVPA minutes.

The effects of mental fatigue on physical performance is a burgeoning topic of interest in the fields of sport and exercise psychology. However, existing evidence is largely based on data from controlled experimental methods which limits applicability to real-world contexts. Previous research examining the role of mental fatigue on PA decision-making has been mixed, with some studies demonstrating higher mental fatigue leads to greater likelihood of selecting a sedentary task rather than engaging in MVPA [23, 24] and other studies showing the probability of choosing to engage in an effortful hand-grip exercise task was not reduced with higher mental fatigue [22]. In this study, we set out to extend results from studies using lab-based experimental methods and examine the mental fatigue – PA relationship using methods with stronger ecological validity. Thus, this study acts as an important step to further our understanding of the effects of mental fatigue on PA decision-making based in people's real-time lived experiences.

Study findings demonstrate greater mental fatigue is associated with engaging in fewer minutes of MVPA in naturalistic, everyday environments. While previous research has demonstrated a small-to-medium sized negative effect of mental fatigue on subsequent physical performance [18], these results do not explain the effect of mental fatigue on people's decisions to engage or not engage in PA. Previous cross-sectional studies show feeling tired/fatigued is a barrier to engaging in PA in the general population (Farah et al., 2021; Salmon et al., 2003) and lack of sleep is a barrier in first-year university students [41]. Findings are consistent with these observations as they demonstrate people engage in less MVPA when feeling fatigued in their everyday lives. To the best of our knowledge, this is the first study to demonstrate the negative effect of mental fatigue on physical activity in people's regular day-to-day experiences.

As predicted, higher benefit vs. cost valuations were associated with engaging in more minutes of MVPA, but are perhaps better contextualized in terms of lower benefit-cost valuations being associated with fewer minutes of MVPA. This relationship is consistent with theorizing using cost/benefit valuations to represent motivation for engaging in effortful tasks [10, 11, 25] and previous research demonstrating cost/benefit valuations predict PA decision-making between a MVPA and sedentary task in experimental settings [23, 24]. Importantly, cost/benefit valuations are constructs in some models of health behavior (e.g., Health Belief Model; [42, 43]), however, these models have focused on the benefits and costs of the health outcomes rather than those associated with engaging in the behaviours themselves. The present study extends these ideas in a novel way by showing cost/benefit valuations predict MVPA in people's daily lives.

According to the framework proposed by Müller and Apps [10], fatigue leads to a decline in motivation to exert effort and reduced performance on subsequent physical tasks which is consistent with effects observed in the *a* and *b* mediation model pathways in this study. More specifically, this study's results suggest under conditions of higher mental fatigue there is a bias of cost/benefit valuations in favor of amplified cost perceptions, which in turn predicts engagement in fewer minutes of MVPA. This finding also extends findings from previous laboratory-based work [23, 24], being the first to demonstrate this effect outside of controlled, laboratory settings.

The indirect mediation effect of mental fatigue on MVPA through benefit vs. cost valuations was not significant; however, findings indicate partial mediation at a probability of $p < .06$, in which benefits vs. cost valuations accounted for 16.2% of the overall effect of mental fatigue on MVPA. Given the significant independent pathways observed, the non-significant indirect effect may be due to model misspecification as described by Shrout and Bolger [42]. Specifically, if groups exist within the data in which different mediation mechanisms apply to different groups, the mediator may mediate the relation for one group but not the other. For example, there are many potential moderators that may influence people's ability or opportunity to engage in MVPA which were not measured in this study. Contextual factors such as what participants were doing at the time of the prompt (e.g., eating, watching TV/movies, socializing, etc…), where participants were at the time of the prompt (e.g., at home vs. at work/school; inside vs. outside), and who they were with at the time of the EMA prompt (e.g., alone, with spouse/partner, friends, etc…) have been shown to affect PA engagement [32, 33, 44]. Thus, despite low levels of mental fatigue and high motivation, people may be unable to engage in MVPA within the hours after responding to the prompt if they are not in a behavioral or social context that allows opportunities for PA (e.g., at work/school or with family/peers engaging in alternate behaviors). Therefore, future exploration using additional measures and more complex modeling parameters is needed to understand the dynamic nature of these data in real-world contexts.

In addition to their theoretical relevance, results from this study hold practical relevance towards understanding real-time correlates of PA and can inform health promotional efforts targeting PA behaviors. Specifically, since higher mental fatigue is related to engaging in fewer minutes of MVPA, more emphasis can be placed on encouraging people to engage in PA during times of the day when fatigue is likely to be lower, such as earlier in the day or prior to completing long work shifts [45]. Additionally, PA promotional efforts should target behaviors with lower perceived costs to adjust the effort cost/benefit ratio. For example, considering evidence showing important health benefits of engaging in light-intensity PA [46] and current 24-hour movement guidelines encouraging participating in light-intensity PA [3], promoting light-intensity PA as a lower effort PA option may increase the likelihood that people will choose to engage in PA when experiencing higher levels of mental fatigue.

There are several strengths and limitations of the present research that should be noted. Using real-time data capture methodologies such as EMA and accelerometry builds on previous experimental work by examining the associations and sequential relationships between mental fatigue, motivation, and MVPA in real-time, real-world settings. Notably, mental fatigue, as measured in this study was not experimentally manipulated which has stronger ecological validity than fatigue manipulated using cognitive tasks in laboratory settings. In addition, passive monitoring of MVPA using accelerometers can be seen as a strength as participants were able to engage in PA consistent with their preferences and what they would normally engage in based on parameters including type, duration, and context rather than examining limited PA options in controlled lab settings such as stationary cycling [16, 23, 24] or a hand-grip exercise task [22]. However, use of accelerometry does not distinguish between engagement in planned and purposeful PA which involves a deliberate decision-making process versus incidental bouts of MVPA. To address this, future work should use a combination of tools to assess PA including device-based and self-reported techniques consistent with recommendations by Nigg et al. [47].

The study limitations include the fact that not all contextual factors which may affect one's PA choices were accounted for in the present study. As mentioned above, evidence of partial mediation suggests a more complex statistical model including physical, social, and/or behavioral contextual information may be needed to better understand real-time associations between variables which we were unable to examine in this study. In addition, this study did not control for individual-level factors shown to be significant covariates in other decision-making paradigms such as PA enjoyment and habitual MVPA [48].

Despite these limitations, the present study provides a strong foundation for future research exploring associations between psychological factors and real-time decision-making for PA to provide a holistic view of factors influencing decisions to engage in PA. By identifying psychological factors associated with real-time decisional balances and behavior, future work along these lines should be useful in the development of PA interventions. For example, mental fatigue, cost/benefit valuations, and other variables can inform optimal decision rules for digital interventions known as “just-in-time” adaptive interventions (JITAIs; [49, 50]). JITAIs are individually tailored to a person’s current and unique context and can adapt based on their psychological status to address changing needs. For example, lower-intensity PA such as yoga or light walking may be promoted for someone experiencing higher mental fatigue whereas higher-intensity PA may be promoted for someone experiencing lower mental fatigue. Future research should define other important components of JITAIs including decision points and intervention options [49, 51] to increase the efficacy of real-time interventions targeting PA.

To the best of our knowledge this study is the first to use real-time data capture methods to examine associations between mental fatigue, benefit vs. cost valuations, and MVPA to advance our understanding of conditions influencing PA decision-making in real-time. Results showed greater mental fatigue was associated with fewer MVPA minutes and lower benefit vs. cost valuations, and higher benefit vs. cost valuations were associated with more MVPA minutes. Overall, study findings provide insight into real-time predictors of motivation and PA and highlight the complex relationships between psychological variables and behavioral outcomes in the real world.

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Table 1.

Descriptive Statistics for Demographic Variables, EMA Measures

	M (*SD*)	*% Missing data*
Age	20.60 (2.61)	0
Habitual MVPA	290.04 (267.27)	0
Mental fatigue	41.00 (26.47)	32.48%
Benefit vs. cost score	2.72 (4.03)	25.20%
MVPA	16.56 (16.49)	0

Note. *M* = mean, *SD* = standard deviation, MVPA = moderate-to-vigorous physical activity during 180 minutes post EMA prompt. Scores for Mental fatigue can range from 0-100; scores for Benefit vs. cost can range from -9 to +9.

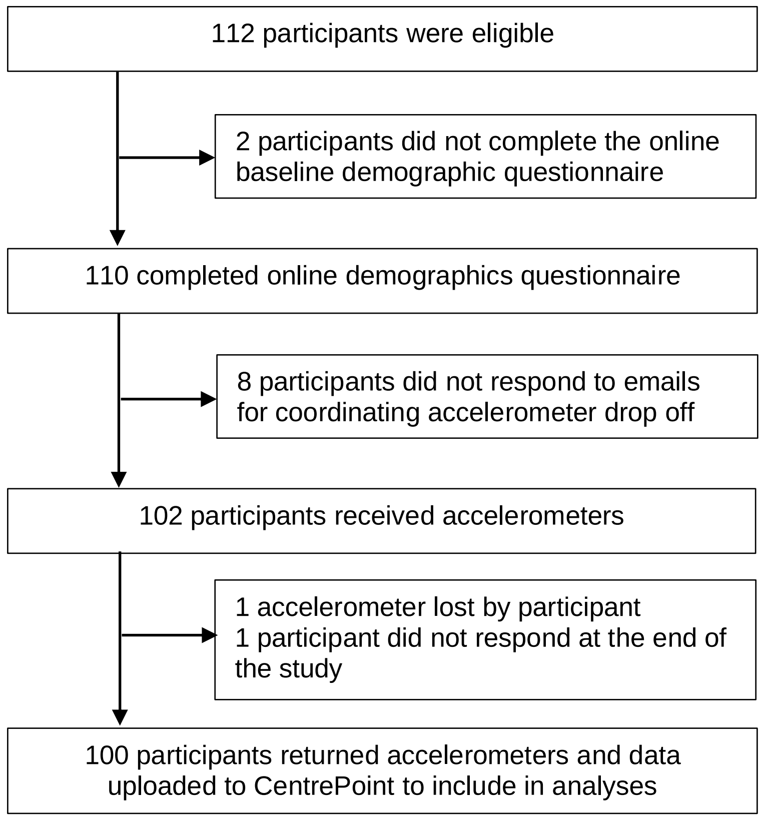

Figure 1. Flow diagram of included participants.

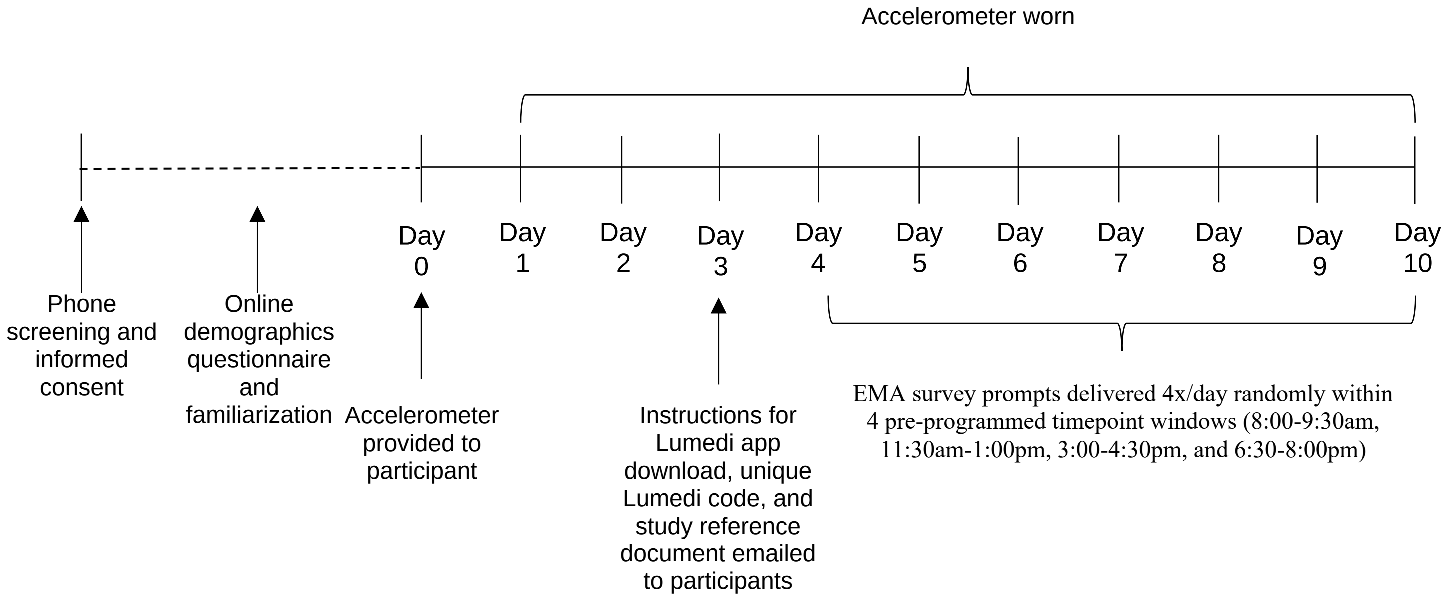

Figure 2. Timeline of study procedures.

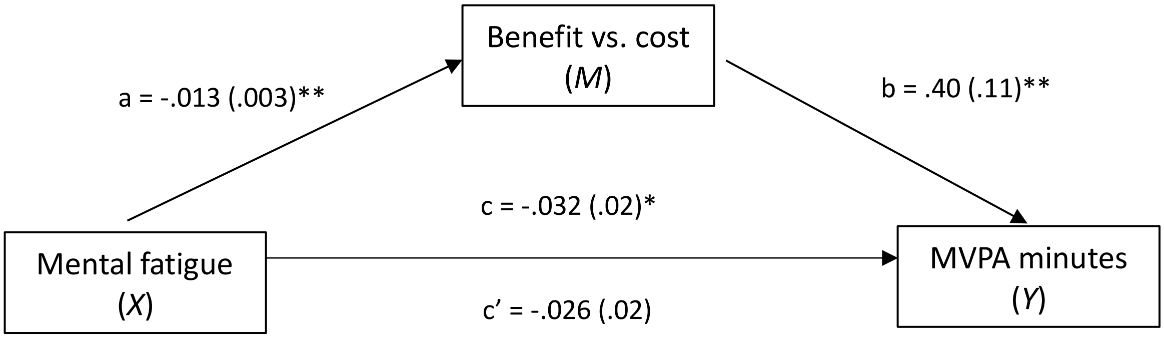

Figure 3. Mediation (indirect effect) analysis results. MVPA = moderate to vigorous physical activity. Values for a, b, c, c' are model coefficients (standard error). *p < .05, ** p < .001.

Electronic Supplemental Material 1

Table A1.

Model coefficients analyzing the fixed effects of mental fatigue on MVPA

	Coefficient	SE	*z*	*p*	95% C.I.
Mental fatigue	-.032	.016	-2.02	.043	-.062 to -.00099
Constant	18.29	.90	20.33	< .001	16.53 to 20.05

Table A2.

Model coefficients analyzing the random effects of mental fatigue on MVPA

	Estimate	SE	95% C.I.
Between-subject SD	4.94	.56	3.96 to 6.18
Within-subject SD	15.11	.27	14.59 to 15.64

Table A3.

Model coefficients analyzing the fixed effects of mental fatigue on benefit vs. cost score

	Coefficient	SE	*z*	*p*	95% C.I.
Mental fatigue	-.013	.0034	-3.82	< .001	-.019 to -.006
Constant	3.15	.31	10.14	< .001	2.54 to 3.76

Table A4.

Model coefficients analyzing the random effects of mental fatigue on benefit vs. cost score

	Estimate	SE	95% C.I.
Between-subject SD	2.62	.21	2.24 to 3.07
Within-subject SD	3.06	.05	2.95 to 3.16

Table A5.

Model coefficients analyzing the fixed effects of benefit vs. cost score on MVPA

	Coefficient	SE	*z*	*p*	95% C.I.
Benefit vs. cost score	.45	.10	4.33	< .001	.24 to .65
Constant	15.70	.71	22.03	< .001	14.31 to 17.10

Table A6.

Model coefficients analyzing the random effects of benefit vs. cost score on MVPA

	Estimate	SE	95% C.I.
Between-subject SD	5.44	6.01	19.91 to 44.09
Within-subject SD	14.89	7.40	207.74 to 236.79

Table A7.

Model coefficients analyzing the fixed effects of mental fatigue and benefit vs. cost score on MVPA

	Coefficient	SE	*z*	*p*	95% C.I.
Benefit vs. cost score	.40	.11	3.66	< .001	.18 to .61
Mental fatigue	-.026	.016	-1.68	.09	-.057 to .0043
Constant	17.04	.96	17.69	< .001	15.15 to 18.93

Table A8.

Model coefficients analyzing the random effects of mental fatigue and benefit vs. cost score on MVPA

	Estimate	SE	95% C.I.
Between-subject SD	4.99	.57	4.00 to 6.23
Within-subject SD	15.05	.27	14.54 to 15.58

CHAPTER 5:

GENERAL DISCUSSION

The negative effects of mental fatigue on physical performance outcomes have been widely documented (e.g., Brown et al., 2020). However, effects of mental fatigue on people's choices to engage in PA or not has received limited attention. The overarching objective of this dissertation was to examine the associations between mental fatigue, motivation, and physical activity decision-making using experimental, hypothetical, and real-world decision-making paradigms.

Overall, results from the studies in this dissertation extend prior knowledge in several important areas. Importantly, in addition to consistent evidence demonstrating mental fatigue impairs subsequent performance on a variety of physical tasks, results show people are less likely to engage in PA when reporting higher levels of mental fatigue (Studies 1, 2, & 3). Higher mental fatigue was also shown to decrease the likelihood of engaging in MVPA indirectly through a sequential pathway consisting of psychological mediators: perceived effort and benefit vs. cost valuations (Study 1) and decreased motivation for engaging in vigorous-intensity PA (Study 2). Higher mental fatigue was also associated with fewer MVPA minutes and lower benefit vs. cost valuations assessed in real-world settings (Study 3). In addition, results show motivation measured by one's subjective valuations of perceived costs and benefits of engaging in a bout of MVPA predicts choice in acute experimental (Study 1) and real-world decision-making (Study 3) scenarios. Parameters frequently used to prescribe exercise such as intensity and duration were shown to influence people's subjective valuations and willingness to engage in PA (Study 2).

Qualitative results from Study 1 align with quantitative findings from the dissertation studies which demonstrates higher mental fatigue decreases motivation for engaging in PA (Studies 1, 2, & 3). Finally, qualitative results from Study 1 revealed "*increased feelings of fatigue resulting from the cognitive task*" was most frequently reported in participants who chose not to exercise after engaging in a high cognitive demand task. This finding aligns with results from Study 3 showing higher mental fatigue was associated with engaging in fewer MVPA minutes. In the following sections, the conceptual and theoretical implication of this work will be addressed along with remaining gaps and considerations for future areas of research stemming from this work.

5.1 Conceptual Implications

The studies in this dissertation were conducted to examine and extend theoretical propositions and conceptual frameworks suggesting subjective perceptions of effort, costs, and benefits influence subsequent effort-based decision-making. The emerging body of research examining the role of mental fatigue on physically effortful decision-making has shown mixed findings (Abdel et al., 2021; Harris & Bray, 2019; van As et al., 2021, 2022). Study 1 was the first study to directly examine the mediating role of perceptions of effort on the relation between mental fatigue and effort-based choice between engaging in a physically effortful task or a non-effortful task. Consistent with research demonstrating mental fatigue increases perceptions of effort during a physically demanding task (Marcora, et al, 2009; Smith, et al, 2015; Zering, et al, 2017), this study provides the first evidence that mental fatigue amplifies perceived effort in anticipation of a bout of PA and these increased effort perceptions make people less likely to volitionally engage in MVPA. These findings are consistent with conceptualizations of effort by Shenhav et al. (2017) suggesting effort mediates the relation between one's capacity and ability to successfully perform a task and task performance. According to this conceptualization, effort determines the level of performance that will be achieved based on a person's ability levels. Extending this perspective, results from Study 1 highlight perceptions of effort predict not only performance on a task but also predict one's willingness to engage in a physically effortful task such that greater perceived effort for engaging in an acute bout of MVPA will shift one's decisional balances making them less likely to choose to exercise when less-effortful alternatives are available. Further, results from Study 1 suggest mental fatigue leads to a lower capacity to exert physical effort which aligns with theorizing by Shenhav et al. (2017).

In addition to demonstrating the role of perceived effort on PA decision-making, Study 1 used qualitative methods to examine the conscious reasoning behind participants' subjective perceptions and choices to engage or not engage in MVPA and how their choice was affected by completion of cognitively demanding or non-demanding tasks. Much of the qualitative data mapped, conceptually, onto the hypothesized mediation pathways in Studies 1 and 3 showing increased feelings of fatigue and changes in motivation (i.e., benefits and costs) influenced choice. However, some of the qualitative insights provide perspective into alternative explanations explaining people's decision-making, which challenges the hypotheses of the studies within this dissertation. For example, following a high cognitively demanding task, some participants expressed having a "*desire to switch from mental to physical (task)*" as well as "*increased alertness resulting from cognitive task*" as reasons justifying their choice to engage in a MVPA task. Interestingly, while the low cognitive demand task used in Study 1 has been shown to be affectively neutral (Zering et al., 2017), some participants mentioned "*increased feelings of fatigue/feeling tired*," "*aversive feelings towards the cognitive task*," and experiences of a "*deactivated state following the cognitive task*" as reasons why the low cognitive demand task led to their choice to not engage in exercise.

With these latter findings in mind, it is interesting to note that research has shown participants reported higher levels of fatigue after completing tasks designed to be cognitively boring compared to tasks requiring greater cognitive effort (Milyavskaya et al., 2019), which may help explain some of these contradictory findings. For instance, engaging in the documentary viewing task may have increased feelings of boredom in some participants, resulting in the negative changes in affect/activation mentioned in the qualitative responses. Although boredom was not measured in Study 1, it is possible that the low cognitive demand task may have increased feelings of boredom which is phenomenologically similar to feelings of fatigue (Milyavskaya et al., 2019) leading to the choice to not engage in MVPA. Future work using cognitive manipulations should be mindful of the different psychological or affective states caused by each task (i.e., fatigue, boredom, affect, etc…) and include measures to examine their potential influence on outcomes of interest such as physical performance and decision-making.

Studies 1 and 3 provide evidence supporting the utility of using cost/benefit calculations as an indirect measure of motivation (Chong et al., 2016) and measure of the subjective value of producing effort (Pessiglione, et al 2018). Results showed a positive relation between benefit vs. cost valuations and physical activity decision-making in both laboratory and field settings such that higher benefit vs. cost valuations are associated with engaging in more minutes of MVPA and predict the choice to engage in a MVPA task versus a sedentary task. Importantly, the cost/benefit measure used in Studies 1 and 3 allowed participants to consider the perceived costs and benefits most salient to them rather than existing questionnaire measures developed to evaluate beliefs around specific factors associated with engaging in exercise (e.g., Exercise Benefits/Barriers Scale (EBBS); Sechrist, et al, 1987). For example, the EBBS contains nine items specific to physical performance benefits compared to three items related to family encouragement suggesting a disproportionate role of both factors on cost/benefit valuations. However, some people may weigh both factors similarly when considering PA decision-making which is not reflected by the EBBS. Assessing the perceived costs and benefits using an open-ended measure can account for individual differences in the subjective valuations associated with engaging in PA.

Drawing upon recommendations by Massar, et al (2018) to use insights from the field of effort-based decision-making to examine the influence of fatigue on motivation, Study 2 used an effort discounting paradigm to investigate the effects of two primary characteristics of PA: intensity and duration; on motivation to engage in PA and examine the effect of mental fatigue on PA motivation. While previous research has used effort discounting paradigms to investigate the role of cognitive fatigue on cognitively effortful decision-making (van As et al., 2021) and physical fatigue on physically effortful decision-making (Iodice et al., 2017), Study 2 is the first to examine the crossover effects of mental fatigue on physically effortful decision-making using effort discounting.

Although the conceptual bases for the dissertation and most of the data were collected prior to publication of the theory of effort minimization in physical activity (TEMPA; Cheval & Boisgontier, 2021) evidence from all three studies provide support for the proposition that effort demands involved with engaging in PA is perceived as a cost which leads to effort minimization processes in favour of behaviors that are more cost-effective. Study 1 showed effort perceptions associated with engaging in a MVPA task was a strong predictor of MVPA and mediated the relation between mental fatigue and choice where higher effort perceptions led to a reduced likelihood of choosing to engage in MVPA. In addition, Study 2 demonstrated decreased willingness to engage in PA behaviors as a function of increased effort requirements defined as activities of higher intensities or longer durations. Taken together, results from these studies support the interpretation that effort is costly and people are less likely to engage in tasks with greater physical effort demands and more likely to choose to engage in alternate tasks with lower effort requirements as suggested by TEMPA.

5.2 Practical Implications

While current PA guidelines recommend engaging in at least 150 minutes of MVPA and two muscle-strengthening activities each week, several hours of light intensity physical activity including standing, and muscle strengthening activities at least twice a week (Ross et al., 2020), recent estimates suggest the majority of Canadian adults are not meeting these guidelines (Clarke et al., 2019). The findings from this dissertation highlight many practical implications for contexts which involve decision-making related to physical activity and exercise behaviors and recommendations which aim to increase PA levels in adults.

Findings from this dissertation provide evidence suggesting mental fatigue is a barrier to engaging in PA in a young adult population which is consistent with previous cross-sectional data (Farah et al., 2021; Salmon et al., 2003). Based on findings demonstrating higher mental fatigue leads to decisions to avoid engaging in MVPA and is associated with engaging in fewer minutes of MVPA, people should be encouraged to engage in PA during times of the day when they are experiencing lower fatigue such as earlier in the day (Micklewright et al., 2017). Promoting PA earlier in the day and at times when people are experiencing lower levels of mental fatigue may increase the likelihood people will choose to engage in MVPA. However, there are many factors that may limit a person's ability to engage in PA earlier in the day such as school, work, or family commitments. Thus, strategies shown to attenuate the negative effects of mental fatigue on physical performance such as consuming caffeine (Azevedo et al., 2016), offering financial incentives (Brown & Bray, 2017), providing autonomy supportive instructions (Graham et al., 2014), and use of behavioral monitoring (Brown & Bray, 2019) should be investigated as potential mechanisms to overcome mental fatigue and encourage choices in favour of engaging in MVPA when experiencing high levels of mental fatigue.

Findings from Study 2 demonstrate physical activity enjoyment is a significant predictor of motivation for engaging in PA of different intensities and durations.

Specifically, participants with higher PA enjoyment reported higher motivation than those with lower PA enjoyment. While PA guidelines and exercise prescriptions provide recommendations on important parameters including the frequency, intensity, time, and type of exercise (i.e., FITT principle; Riebe et al., 2018), recent recommendations suggest including a measurement of fun or enjoyment in PA prescriptions which may be an important factor for the initiation and maintenance of PA (Burnet et al., 2019). In addition, people should be encouraged to engage in a wide variety of physical activities (e.g., competitive/recreational/leisure; weight bearing/non-weight bearing) in different environments (inside/outside; home/work/gym facility; alone/with people) and contexts (e.g., leisure/transportation/household) as performing new and challenging exercises could be one strategy to increase enjoyment and interest (Lakicevic et al., 2020). Consistent with findings from this dissertation suggesting people are more willing to engage in PA if they have higher enjoyment, personal trainers, strength and conditioning coaches, qualified exercise professionals, and other health professionals responsible for providing exercise prescriptions should present clients with a diverse range of PA options and consider their personal preferences and enjoyment levels in their recommendations.

Consistent with suggestions to consider fun and enjoyment in PA and exercise prescriptions, PA promotion should continue promoting lower-intensity PA and emphasize an “every minute counts” perspective for engaging in PA (Fan et al., 2013). A growing body of research has identified numerous health benefits of engaging in light-intensity PA (Chastin et al., 2019; Füzéki et al., 2017) demonstrating the importance of engaging in some versus no PA, even at lower intensity levels. Further, current 24-hour movement guidelines highlight the benefits of engaging in several hours of light intensity PA such as standing and recommend trading in sedentary behavior with light-intensity PA (Ross et al., 2020). Findings from Study 2 provide additional support for encouraging people engage in PA of lower intensities as results show greater motivation for light-intensity PA than both moderate- and vigorous-intensity PA at each duration level. Importantly, there were no changes in one's willingness to engage in light-intensity PA with increased mental fatigue. Thus, engaging in lower-intensity PA may be a more realistic expectation than MVPA for people who are currently inactive of insufficiently active, or those experiencing higher levels of mental fatigue. Consequently, encouraging participation in light-intensity PA may increase PA participation and subsequent health benefits.

Based on findings demonstrating the utility of a cost/benefit ratio in predicting PA behavior, strategies which aim to increase perceived benefits and minimize perceived costs should be targeted to encourage decisions to engage in PA. One such strategy for increasing the immediate benefits associated with engaging in PA is the use of incentives. Previous research demonstrates positive effects of modest financial incentives on short-term PA behavior in adults (Mitchell et al., 2013, 2020). Additionally, as financial incentives have been shown to mitigate the negative effects of mental fatigue on physical performance (Brown & Bray, 2019) there may be additional benefits of using incentives to encourage PA decision-making under conditions of mental fatigue. However, as there is limited evidence demonstrating the efficacy of longer-term incentive interventions (Mitchell et al., 2013), future work must continue to investigate the post-intervention effects of incentive interventions and how to maintain PA behaviors once the incentive is no longer being provided.

Another strategy that may increase the salience of perceived benefits for cost/benefit valuations involves the use of message framing. Message framing is a technique used to present factually identical information by highlighting either the gains associated with partaking in a particular behavior or the losses associated with not partaking in the behavior (Tversky & Kahneman, 1981) and has been used for health behaviors including PA (Gallagher & Updegraff, 2012; Latimer et al., 2010). Previous research has shown gain frame messages may be more effective at increasing motivation than loss frame messages at higher levels of mental fatigue (Harris et al., 2022) suggesting gain frame messages may increase perceived benefits and be particularly useful for PA decision-making when experiencing mental fatigue.

Other strategies aiming to decrease the perceived effort/cost requirements involved with planning to engage in a bout of PA include engaging in action and coping planning (Michie et al., 2011) which have been shown to facilitate PA behavior (Carraro & Gaudreau, 2013). Evidence suggests making decisions may impair one's ability to make subsequent decisions and control future behavior through a phenomenon known as *decision fatigue* (Pignatiello et al., 2020). Thus, the effortful decision-making process involved with engaging in PA (e.g., what type of activity to engage in, where, when, for how long, etc…) may factor into one's cost valuations of engaging in PA and decrease the likelihood of choosing to exercise. Automating the process of engaging in PA by developing action and coping plans may minimize cost perceptions involved with engaging in PA to increase the likelihood people will choose to exercise.

Finally, findings from this dissertation demonstrate people have a greater preference for engaging in PA of lower durations and people spent on average 16 minutes engaging in MVPA within a 3-hour time window in real-world settings. These results provide some support for prescribing exercise “snacks” which involve engaging in several shorter bouts of PA throughout the day rather than longer continuous bouts (Francois et al., 2014). Previous work has demonstrated positive health effects of a brief stair climbing exercise “snack” in overweight/obese adults (Rafiei et al., 2021) and modest increases in cardiorespiratory fitness in sedentary young adults over a 6-week intervention (Jenkins et al., 2019). Importantly, shorter bouts of PA may be easier to incorporate within one’s day and require no specialized equipment. Thus, prescribing exercise “snacks” may be of use to encourage engagement in some PA within one’s everyday life.

5.3 Limitations and Future Directions

While this dissertation addresses many gaps in the literature and extends current ways of thinking, there are several limitations which should be noted. First, participants from the current studies consisted of samples of young adults enrolled in a post-secondary institution in Southwestern Ontario. The homogeneity of study participants limits the generalizability of study findings to more diverse populations including children, middle-older adults, pregnant people, and people with chronic conditions. Along these lines, the limited demographic information collected makes it unclear whether factors such as ethnicity, gender identity, gender expression, and disability status may uniquely affect PA decision-making. When considering physical activity in real-world contexts, different demographic groups may experience unique barriers which may influence their motivation to engage in PA such as lack of accessible equipment and programs for people with disabilities (Rimmer et al., 2004), inadequate changing rooms and showering facilities for transgender people (Jones et al., 2017) or perceived safety (Rees-Punia et al., 2018). Future work should collect more demographic data to increase generalizability and examine the effects of these barriers on motivation and decision-making.

Another important limitation from this dissertation is that the measure of perceived benefits and costs was developed specifically for these studies and lacks psychometric development and evaluations of reliability and validity. While benefit vs. cost valuations were calculated based on recommendations by Pessiglione et al. (2018), the evaluation of measurement instruments for reliability and validity is necessary to determine the consistency of a measure and the extent to which the measure accurately represents the variable they are intended to (Price et al., 2015). Future research should examine the psychometric properties of the cost/benefit measure in an adult population.

In this dissertation we examined perceived effort, costs, and benefits as potential mechanisms (mediators) to explain how mental fatigue affects physical activity decision-making. However, alternate models are also potentially viable and one possibility would be to examine the moderating effects of mental fatigue on the relation between effort, benefit vs. cost valuations, and decision-making. A moderator has been defined as a "*variable that affects the direction and/or strength of the relation between an independent or predictor variable and a dependent or criterion variable*" (Baron & Kenny, 1986, pp. 1174). Thus, an alternative perspective is that higher levels of mental fatigue may moderate the relations between perceived effort, subjective perceptions of costs and benefits, and decision-making. For example, mental fatigue may moderate the relation between perceived effort and benefit vs. cost valuations such that the association would be stronger at higher levels of mental fatigue due to amplified cost perceptions. Future work should examine the potential moderating effects of mental fatigue to explain the relation between variables shown to predict PA decision-making.

In addition to alternative theoretical perspectives that may account for people's PA decision making, there are alternate conceptualizations of perceived effort than the perspective applied in these studies, which warrant future investigation. Specifically, studies in this dissertation assume effort is aversive and costly (Kurzban, 2016) which is supported by quantitative and qualitative results from Study 1. However, in certain instances, effort can be experienced as valuable or rewarding (Inzlicht et al., 2018). Previous work has shown people assign greater value to self-made products that were completed with effort than comparable products requiring no effort to complete (Norton et al., 2011). Further, learned industriousness describes the process in which the sensation of effort is paired with a reinforcer, which over repeated exposures can lead to effort being a secondary reinforcer with its own rewarding properties (Eisenberger, 1992). Based on this theorizing, effort perceptions may increase perceived benefit valuations, leading to choices in favor of engaging in an effortful bout of PA. Future work should try to capture and explain how the rewarding properties of effort and learned industriousness factor into decision-making for PA and exercise behaviors.

Building from the findings from Study 3 demonstrating real-time associations between psychological factors, decisional balances, and decision-making, an exciting area of future research is in the development and evaluation of real-time interventions to encourage decisions to engage in physical activity. "Just-in-time" adaptive interventions (JITAIs; Nahum-Shani et al., 2015; Spruijt-Metz & Nilsen, 2014) are a suite of digital interventions that are individually tailored to a person's current and unique context. By integrating real-time data capture techniques, JITAIs can address an individual's changing need for support to intervene in ways which encourage engagement of physical activity behaviors throughout the day. There are six elements of a JITAI: 1) the distal outcome, 2) the proximal outcomes, 3) decision points, 4) intervention options, 5) tailoring variables, and 6) decision rules (Müller et al., 2017; Nahum-Shani et al., 2015; Nahum-Shani et al., 2018). In this dissertation, the distal (i.e., MVPA) and proximal outcomes (i.e., perceived costs and benefits) have been examined, however, future research should work on operationalizing the other parameters of JITAIs aimed to increase PA in real-time.

5.4 Conclusion

This dissertation furthers current understanding of the associations between mental fatigue, motivation, and effort-based decision-making related to PA behavior using experimental, hypothetical, and real-world decision-making paradigms. Results from this dissertation demonstrate mental fatigue decreases motivation for engaging in

MVPA measured using cost/benefit evaluations (Studies 1 & 3) and vigorous-intensity PA measured using an effort discounting paradigm (Study 2). Further, changes to subjective valuations of perceived costs and benefits of engaging in MVPA in turn makes people less likely to engage in MVPA (Studies 1, 3). Quantitative results from Study 1 demonstrate the relation between mental fatigue and exercise choice is sequentially mediated by increased perceptions of anticipated effort and reductions in benefit vs. cost valuations. In addition, qualitative results from Study 1 demonstrate how completing high and low cognitively demanding tasks influences subsequent choice between engaging in an acute bout of MVPA versus a competing sedentary task. Study 2 found lower motivation for engaging in PA of longer durations and higher intensities. Finally, Study 3 is the first to demonstrate that mental fatigue experienced in everyday life may alter subjective valuations of benefits and costs, with both factors being associated with minutes of MVPA people choose to engage in. Taken together, these studies demonstrate that mental fatigue decreases people's motivation for engaging in physical activity and makes them less likely to choose to engage in exercise behaviors rather than competing sedentary alternatives.

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APPENDIX A: STUDY 1 MATERIALS

A.1 Physical Activity Readiness Questionnaire
A.2 Ratings of Perceived Exertion
A.3 Ratings of Perceived Mental Exertion
A.4 Subjective Mental Fatigue Visual Analogue Scale
A.5 Perceived Effort Visual Analogue Scale
A.6 Subjective Evaluation of Exercise
A.7 International Physical Activity Questionnaire
A.8 Physical Activity Enjoyment Scale

A.1 Physical Activity Readiness Questionnaire

1. Do you have a medical condition that requires you to avoid strenuous exercise?

2. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?

3. Do you feel pain in your chest when you do physical activity?

4. In the past month, have you had chest pain when you were not doing physical activity?

5. Do you lose balance because of dizziness or do you lose consciousness?

6. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?

7. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?

8. Do you know of any other reason why you should not do physical activity?

9. Are you colour blind?

A.2 Ratings of Perceived Exertion

Please report how much **effort** you exerted during the task.

0 Nothing at all

0.3

0.5 Extremely weak

1 Very weak

1.5

2 Weak

2.5

3 Moderate

4

5 Strong

6

7 Very Strong

8

9

10 Absolute Maximum

A.3 Ratings of Perceived Mental Exertion

Please report how much **mental effort** you exerted during the task.

0 Nothing at all

0.3

0.5 Extremely weak

1 Very weak

1.5

2 Weak

2.5

3 Moderate

4

5 Strong

6

7 Very Strong

8

9

10 Absolute Maximum

A.4 Subjective Mental Fatigue Visual Analogue Scale

Please mark (X) on the line the point that you feel represents your perception of your current state of **MENTAL FATIGUE**.

None at all 0 ____ 100 Maximal

A.5 Perceived Effort Visual Analogue Scale

Effort Scale

Effort can be thought of as the "*subjective intensification of either mental or physical activity in the service of meeting some goal.*" Effort is related to, but different from, task demand or task difficulty. We want you to think about effort as representing how hard you will have to work throughout the task.

In thinking about the exercise task, please mark on the 0-100 line, how much effort you feel it would take for you to complete the task.

No effort at all 0 ____ 100 Maximal effort

A.6 Subjective Evaluation of Exercise

Please answer each of the following items as they apply to you by circling the number that best represents your opinions at this moment. Please be honest, there is no right or wrong answer.

1. For the exercise option, there are:

1	2	3	4	5	6	7	8	9	10
no advantages									many advantages

2. For the exercise option, there are:

1	2	3	4	5	6	7	8	9	10
no disadvantages									many disadvantages

A.7 International Physical Activity Questionnaire

How active are you usually? Please consider your usual activity level during a typical 7 day period in the past 6 months and answer the following about moderate and vigorous activity participation.

MODERATE Physical Activity Definition
Moderate physical activity or exercise includes activities such as brisk walking, light swimming, dancing, biking, gardening, and yardwork. You should be able to carry on a conversation when doing moderate activities. Please consider a TYPICAL week for you and answer the following questions about moderate activities.

1. How many days per week are you moderately physically active or do you exercise moderately?	**_____ days per week**
2. Approximately how many minutes are you moderately physically active or do you exercise moderately each day?	**_____ minutes per day**

VIGOROUS Physical Activity Definition:
Vigorous physical activity or exercise includes hard activities such as jogging, aerobics, swimming, and fast biking. You may have a hard time carrying on a conversation when doing vigorous activities. Please consider a TYPICAL week for you and answer the following questions about vigorous activities.

1. How many days per week are you vigorously active or do you exercise vigorously?	**_____ days per week**
2. Approximately how many minutes are you vigorously active or do you exercise vigorously each day?	**_____ minutes per day**

A.8 Physical Activity Enjoyment Scale

Please rate how you feel *while* engaging in your preferred type of physical activity.

*1	2	3	4	5	6	7
I enjoy it						I hate it
1	2	3	4	5	6	7
I feel bored						I feel interested
1	2	3	4	5	6	7
I dislike it						I like it
*1	2	3	4	5	6	7
I find it pleasurable						I find it unpleasurable
*1	2	3	4	5	6	7
I am very absorbed in this activity activity						I am not at all absorbed in this
1	2	3	4	5	6	7
It's no fun at all						It's a lot of fun
*1	2	3	4	5	6	7
I find it energizing						I find it tiring
1	2	3	4	5	6	7
It makes me depressed						It makes me happy
*1	2	3	4	5	6	7
It's very pleasant						It's very unpleasant
*1	2	3	4	5	6	7
I feel good physically while doing it						I feel bad physically while doing it
*1	2	3	4	5	6	7
It's very invigorating						It's not at all invigorating

1

	2	3	4	5	6	7
I am very frustrated by it						I am not at all frustrated by it

*1	2	3	4	5	6	7
It's very gratifying						It's not at all gratifying

*1	2	3	4	5	6	7
It's very exhilarating						It's not at all exhilarating

1	2	3	4	5	6	7
It's not at all stimulating						It's very stimulating

*1	2	3	4	5	6	7
It gives me a strong sense of accomplishment at all						It does not give me any sense of accomplishment

*1	2	3	4	5	6	7
It's very refreshing						It's not at all refreshing

1	2	3	4	5	6	7
I felt as though I would rather be doing something else						I felt as though there was nothing else I would rather be doing

*Item is reversed scored (i.e., 1=7, 2=6, … 6=2, 7=1).

APPENDIX B: STUDY 2 MATERIALS

B.1 Ratings of Perceived Exertion
B.2 Subjective Mental Fatigue
B.3 International Physical Activity Questionnaire
B.4 Daily Physical Activity Questionnaire
B.5 Physical Activity Enjoyment Scale

B.1. Ratings of Perceived Exertion

Please report how much **effort** you exerted during the task.

0	Nothing at all
0.3	
0.5	Extremely weak
1	Very weak
1.5	
2	Weak
2.5	
3	Moderate
4	
5	Strong
6	
7	Very Strong
8	
9	
10	Absolute Maximum

B.2 Subjective Mental Fatigue

On a scale of 0 (*energetic/no fatigue*) to 10 (*worst possible fatigue*), please indicate the point that you feel represents your perception of your current state of mental fatigue.

0	1	2	3	4	5	6	7	8	9	10
energetic/ no fatigue		mild fatigue			moderate fatigue			severe fatigue		worst possible fatigue

B.3 International Physical Activity Questionnaire

How active are you usually? Please consider your usual activity level during a typical 7 day period in the past 6 months and answer the following about moderate and vigorous activity participation.

MODERATE Physical Activity Definition
Moderate physical activity or exercise includes activities such as brisk walking, light swimming, dancing, biking, gardening, and yardwork. You should be able to carry on a conversation when doing moderate activities. Please consider a TYPICAL week for you and answer the following questions about moderate activities.

1. How many days per week are you moderately physically active or do you exercise moderately?	**_____ days per week**
2. Approximately how many minutes are you moderately physically active or do you exercise moderately each day?	**_____ minutes per day**

VIGOROUS Physical Activity Definition:
Vigorous physical activity or exercise includes hard activities such as jogging, aerobics, swimming, and fast biking. You may have a hard time carrying on a conversation when doing vigorous activities. Please consider a TYPICAL week for you and answer the following questions about vigorous activities.

1. How many days per week are you vigorously active or do you exercise vigorously?	**_____ days per week**
2. Approximately how many minutes are you vigorously active or do you exercise vigorously each day?	**_____ minutes per day**

B.4 Daily Physical Activity Questionnaire

Please think about any physical activity that you have done today that was planned and purposeful.

Moderate physical activity or exercise includes activities such as brisk walking, light swimming, dancing, biking, gardening, and yardwork. You should be able to carry on a conversation when doing moderate activities.

Approximately how many minutes of planned and purposeful moderate physical activity have you engaged in today? **_____ minutes**

Vigorous physical activity or exercise includes hard activities such as jogging, aerobics, swimming, and fast biking. You may have a hard time carrying on a conversation when doing vigorous activities.

Approximately how many minutes of planned and purposeful vigorous physical activity have you engaged in today? **_____ minutes**

B.5 Physical Activity Enjoyment Scale

Please rate how you feel *while* engaging in your preferred type of physical activity.

*1	2	3	4	5	6	7
I enjoy it						I hate it
1	2	3	4	5	6	7
I feel bored						I feel interested
1	2	3	4	5	6	7
I dislike it						I like it
*1	2	3	4	5	6	7
I find it pleasurable						I find it unpleasurable
*1	2	3	4	5	6	7
I am very absorbed in this activity activity						I am not at all absorbed in this
1	2	3	4	5	6	7
It's no fun at all						It's a lot of fun
*1	2	3	4	5	6	7
I find it energizing						I find it tiring
1	2	3	4	5	6	7
It makes me depressed						It makes me happy
*1	2	3	4	5	6	7
It's very pleasant						It's very unpleasant
*1	2	3	4	5	6	7
I feel good physically while doing it						I feel bad physically while doing it
*1	2	3	4	5	6	7
It's very invigorating						It's not at all invigorating

1	2	3	4	5	6	7
I am very frustrated by it						I am not at all frustrated by it
*1	2	3	4	5	6	7
It's very gratifying						It's not at all gratifying
*1	2	3	4	5	6	7
It's very exhilarating						It's not at all exhilarating
1	2	3	4	5	6	7
It's not at all stimulating						It's very stimulating
*1	2	3	4	5	6	7
It gives me a strong sense of accomplishment at all						It does not give me any sense of accomplishment
*1	2	3	4	5	6	7
It's very refreshing						It's not at all refreshing
1	2	3	4	5	6	7
I felt as though I would rather be doing something else						I felt as though there was nothing else I would rather be doing

*Item is reversed scored (i.e., 1=7, 2=6, … 6=2, 7=1).

APPENDIX C: STUDY 3 MATERIALS

C.1 International Physical Activity Questionnaire
C.2 Physical Activity Readiness Questionnaire
C.3 Subjective Mental Fatigue
C.4 Subjective Evaluation of Exercise

C.1 International Physical Activity Questionnaire

How active are you usually? Please consider your usual activity level during a typical 7 day period in the past 6 months and answer the following about moderate and vigorous activity participation.

MODERATE Physical Activity Definition
Moderate physical activity or exercise includes activities such as brisk walking, light swimming, dancing, biking, gardening, and yardwork. You should be able to carry on a conversation when doing moderate activities. Please consider a TYPICAL week for you and answer the following questions about moderate activities.

1. How many days per week are you moderately physically active or do you exercise moderately?	**_____ days per week**
2. Approximately how many minutes are you moderately physically active or do you exercise moderately each day?	**_____ minutes per day**

VIGOROUS Physical Activity Definition:
Vigorous physical activity or exercise includes hard activities such as jogging, aerobics, swimming, and fast biking. You may have a hard time carrying on a conversation when doing vigorous activities. Please consider a TYPICAL week for you and answer the following questions about vigorous activities.

1. How many days per week are you vigorously active or do you exercise vigorously?	**_____ days per week**
2. Approximately how many minutes are you vigorously active or do you exercise vigorously each day?	**_____ minutes per day**

C.2 Physical Activity Readiness Questionnaire

1. Do you have a medical condition that requires you to avoid strenuous exercise?

2. Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?

3. Do you feel pain in your chest when you do physical activity?

4. In the past month, have you had chest pain when you were not doing physical activity?

5. Do you lose balance because of dizziness or do you lose consciousness?

6. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?

7. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?

8. Do you know of any other reason why you should not do physical activity?

C.3 Subjective Mental Fatigue

Please use the sliding scale to indicate what you feel represents your perception of your current state of MENTAL FATIGUE

None at all 0 ____ 100 Maximal

C.4 Subjective Evaluation of Exercise

Please answer each of the following items as they apply to you by circling the number that best represents your opinions at this moment. Please be honest, there is no right or wrong answer.

1. In general, I think that exercising for 10+ minutes sometime within the next few hours has:

1	2	3	4	5	6	7	8	9	10
no advantages									many advantages

2. In general, I think that exercising for 10+ minutes sometime within the next few hours has:

1	2	3	4	5	6	7	8	9	10
no disadvantages									many disadvantages

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