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Effects of mental fatigue on exercise decision-making

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ABSTRACT

Objectives: The study investigated the effects of exerting high cognitive effort on people's decisions to engage in an acute bout of exercise through a serially-mediated process involving mental fatigue and benefit vs. cost evaluations. We also examined the relationship between perceived mental fatigue, perceived exertion and behavior among participants who chose to exercise. *Design.* Randomized, experimenter blind to group.

Method: Participants ($N = 55$, $M_{age} = 19.04 \pm 1.04$ years) completed either a 10-min, high cognitive demand (incongruent Stroop) task or low cognitive demand (video documentary monitoring) task. Participants then made a choice between engaging in either a 22-min self-paced moderate-to-vigorous intensity exercise task or a 22-min non-exercise task. Prior to making their choice, participants rated their mental fatigue and perceived benefits and costs of engaging in the exercise task.

Results: Approximately half the sample chose to exercise ($n = 30$). There was no direct effect of experimental group on choice. However, serial mediation analyses revealed significant indirect effects, indicating the high cognitive demand task causes increased mental fatigue, which in turn led to lower benefit vs. cost scores, and decreased likelihood of choosing to exercise (95% C.I. = −1.03 to −0.01). Among participants who elected to exercise, mental fatigue was not associated with the amount of work performed, but positively correlated with ratings of perceived exertion while exercising.

Conclusions: Findings suggest mental fatigue affects exercise decision-making by elevating subjective evaluation of the costs of engaging in exercise as opposed to sedentary alternatives.

1. Introduction

Current physical activity guidelines recommend adults engage in at least 150 min of moderate-to-vigorous intensity physical activity (MVPA) each week to accrue important physical and psychological benefits (Haskell et al., 2007; Tremblay et al., 2011). However, data indicate the majority of North American adults do not meet these guidelines, posing a major threat to public health and raising questions as to why more adults are not active (Colley et al., 2011; Norris, Clarke, & Schiller, 2018).

Most people possess the physical capabilities to engage in recommended levels of physical activity, yet many barriers have been identified in the literature, including: work commitments, prioritizing other behaviors, lack of time, and feeling tired or fatigued (Salmon, Owen, Crawford, Bauman, & Sallis, 2003). Brawley, Martin, and Gyurcsik (1998) have pointed out that "barriers" can be actual constraints that limit people's abilities to engage in physical activity. However, in many instances, perceived "barriers" are excuses or reasons that are reflective of people's motivation to be physically active. Thus, people's perceptions of barriers in concert with perceived benefits present people with information they may use to make decisions about whether to engage in physical activity or not. In order to better understand and more effectively promote physical activity, research investigating processes underlying decision-making about exercise is needed.

Traditional economic theory posits that human beings are rational, unemotional, and have unlimited information processing capabilities to allow for ideal decision-making (Mullainathan & Thaler, 2000). However, people frequently make choices to consume foods that exceed their necessary caloric intake, spend more money than they budget for, and procrastinate rather than complete important tasks they need to carry out. These decisions are usually made despite being fully aware that alternative behaviors are more beneficial to one's long-term objectives. Thus, actual decision-making fails to adhere to the predictions of traditional economic theory. Consequently, the field of behavioral economics was developed to integrate research from the disciplines of learning, cognitive psychology, decision-making, and economics to better attempt to understand the factors that influence choices between two or more behavioral alternatives (Epstein, 1998).

As noted above, data indicate people's choices regarding physical

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activity often do not align with beneficial long-term outcomes (i.e., the majority of people are not sufficiently active to accrue health benefits). Epstein (1998) highlighted the complexities of decision-making to help explain why most people do not exercise regularly. He identifies key contributing factors affecting the choice between engaging in physical activity or a sedentary alternative are people's evaluations of the perceived costs (or cons) and benefits (or pros) of each behavior. As an illustration of this effect, a meta-analysis of data from 71 studies based on the Transtheoretical Model (TTM; Prochaska, 1983) found a relationship between stages of change and perceived pros and cons of exercising (Marshall & Biddle, 2001). Consistent with the TTM predictions, perceived pros of engaging in physical activity increased and perceived cons decreased across each of the stages of change (precontemplation, contemplation, preparation, action, maintenance). In other words, regular exercisers reported greater pros than cons of exercising, while people who were not engaging in regular exercise reported greater cons than pros.

Although the findings from Marshall and Biddle's (2001) meta-analysis demonstrate a relation between people's pros vs. cons evaluations of exercising and their behaviors, those data are informative for general or habitual patterns of behavior but not the acute decisions people make about whether to engage in exercise or not. To the best of our knowledge associations between people's acute valuations of engaging in exercise and their decisions to engage in exercise or not have not been investigated. Further, there has been little development in the literature relating to people's acute choices whether or not to engage in exercise or the extent to which their personal valuations can be affected by momentary variations in psychological or physiological states.

In support of evidence identifying fatigue as a perceived barrier to being physically active (Salmon et al., 2003), recent laboratory-based research shows prior exposure to physically demanding tasks influence decision-making regarding subsequent tasks that require physical effort. In one study, Iodice et al. (2017a) demonstrated that non-fatigued rodents chose to pursue a high-reward activity requiring high physical effort more frequently than a low-reward activity requiring low physical effort. However, when they were fatigued following a bout of wheel running, rodents chose to engage in the low-reward/low-effort activity more frequently than the high-reward/high-effort activity. Similarly, Iodice et al. (2017b) found human participants showed a greater preference for "low effort" physical activity over "high effort" activity when they were physically fatigued from an earlier bout of exercise compared to when they were not fatigued.

Together the aforementioned findings support an interpretation that fatigue can alter motivation to engage in effortful behavior such as exercise. However, in terms of understanding the role of fatigue in relation to people's physical activity behaviors, it is important to consider that exercise-induced fatigue is not likely to be the type of fatigue that is perceived as a barrier to being physically active. On the contrary, given the majority of the population does not engage in regular physical activity, fatigue attributable to activities that do not involve physical energy expenditure may be a major factor affecting people's exercise decision-making.

Mental fatigue is a psychobiological state experienced during or following prolonged and challenging cognitive activity, which manifests as tiredness, exhaustion and decreased motivation (Boksem & Tops, 2008). When mentally-fatigued, people frequently report higher perceptions of exertion while performing physical tasks (e.g., Marcora, Staiano, & Manning, 2009; Zering, Brown, Graham, & Bray, 2017) and exhibit performance decrements such as shorter time to exhaustion when performing at a fixed workload (Brown & Bray, 2017; Marcora et al., 2009), increased time to complete a fixed-distance time trial (MacMahon, Schücker, Hagemann, & Strauss, 2014), and reductions in self-selected power output while exercising (Brownsberger, Edwards, Crowther, & Cottrell, 2013). Additionally, people have been shown to lower their intended exercise intensity in studies involving aerobic exercise suggesting they deliberately plan to invest less effort when they are feeling mentally-fatigued (Brown & Bray, 2019; Martin Ginis & Bray, 2010).

Despite a well-established literature showing mental fatigue has detrimental effects on exercise performance or people's intentions to exert effort while exercising, there has been little progress made in determining the mechanisms underlying these effects. Given there appears to be a conscious decision about effort exertion that precedes people's actions, one potential mechanism contributing to changes in intentions and behavior when people are mentally-fatigued is their subjective valuation of the behavior, specifically their cost/benefit evaluations. However, to the best of our knowledge, the effects of mental fatigue on perceived benefits and costs related to engaging in an acute bout of exercise have not been investigated.

The purpose of the present study was to investigate the effects of performing a high cognitive demand task on people's decisions to engage in an acute bout of MVPA or a non-exercise, leisure task and whether this decisional relationship was mediated by perceived mental fatigue and subjective benefit-cost evaluations. It was hypothesized that people would be less likely to choose the exercise option following the high cognitive demand task. Further, it was hypothesized that following a high cognitive demand task people would report higher levels of mental fatigue, which would be associated with greater perceived costs of exercising and lead to a greater likelihood of choosing to engage in a non-exercise task rather than engaging in MVPA. A secondary objective was to investigate the effect of mental fatigue on exercise behavior and perceived exertion during exercise among the participants who chose to engage in MVPA. Based on findings from the mental fatigue-exercise literature (Brownsberger et al., 2013; Van Cutsem et al., 2017), it was hypothesized that people who were more mentally-fatigued would experience higher levels of perceived exertion while exercising and have poorer physical performance, represented by less work performed while exercising.

2. Method

2.1. Participants and design

Participants were 55 ($n = 27$ women) recreationally-active university students ($M_{age} = 19.04 \pm 1.04$ years) who self-reported engaging in ~150 min of MVPA per week ($M = 148.89 \pm 127.12$ min/week). Sample size was determined based on results from Iodice et al. (2017b) that demonstrated a medium-large effect size ($\eta_P^2 = 0.30$) of physical fatigue on exercise decision-making. According to G*Power (Faul, Erdfeller, Lang & Buchner, 2007) calculation for a sequential mediation analysis with three independent variables, a sample size estimate based on a η_P^2 of 0.30, $\alpha = 0.05$ and $\beta = 0.80$, yielded a sample size estimate of 31. Given, the sample size-estimate was considerably smaller than other estimates for regression analyses, which recommend an N of $50 + 8(x)$, when $x =$ the number of predictor variables (Green, 1991), the sample size was increased to 55 participants. Participants were screened for non-normal vision (color-blindness) using self-report, health-related contra-indicators of performing moderate-vigorous intensity exercise using the Physical Activity Readiness Questionnaire (PAR-Q; Thomas, Reading, & Shephard, 1992), and provided informed consent. The study was reviewed and approved by an institutional research ethics board prior to any recruitment and data collection. Participants received either a $20 honorarium or course credit for their contributions to the study.

The study employed a participant-blind/researcher blind to treatment (cognitive manipulation) allocation, between-groups design. Participants were stratified by sex and randomized to either the high cognitive demand or low cognitive demand group. In order to minimize experimenter effects, a written script was followed throughout the experimental procedure ensuring instructions were presented in the same manner to all participants.

2.2. Procedures

Upon arrival at the laboratory, participants provided informed consent and completed demographic and questionnaire measures. They then completed a modified graded exercise test (M-GXT) protocol on a cycle ergometer (see description below) followed by 10 min of quiet seated rest. Following the 10-min rest period, participants completed their respective experimental manipulation (i.e., high cognitive demand or low cognitive demand task) with perceived mental exertion (RPE-M) and mental fatigue recorded prior to beginning the task and at 2-min intervals during the task. Following the cognitive task, participants were given descriptions of an MVPA exercise task and a non-exercise task. Participants were told that the MVPA task involved cycling on the stationary bike within a RPE range between a three and six which was the range they were asked to focus on during the M-GXT. The non-exercise task was described as "free time" in which they could use their phone, laptop, or the laptop in the lab. Participants were told that both options involved staying in the laboratory space and would take the same amount of time - 22 min. They then completed the subjective evaluation of the MVPA task (benefit/cost measures) and verbally indicated their choice to engage in either the MVPA task or the non-exercise task. Participants then completed the chosen task for 22 min and were debriefed, compensated, and thanked for their participation. Throughout the experimental procedures, the experimenter only interacted with participants to provide instructions, administer measures, and ensure the safety of participants. There was no verbal or motivational encouragement provided at any time.

2.3. Tasks and apparatus

Modified graded exercise test (M-GXT). All 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 think about later on in the study. The protocol began with a 2-min warm-up at a fixed resistance of 50 Watts (W) followed by a progressive ramp 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 a RPE of 3 (verbal anchor of *"moderate")* and a RPE of 6 (between the verbal anchors of "*strong"* and *"very strong"*). Once within the target RPE range, participants were instructed to focus on the sensations they were experiencing while cycling. Once participants rated their RPE = 7, 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.

MVPA protocol. The MVPA protocol consisted of 22-min of stationary cycling on the cycle ergometer. The protocol started with a 2-min warm-up at a fixed workload of 50 W. Following the warm-up, the experimenter switched the ergometer from terminal mode (computer-defined) to manual mode (user-defined) and the experimenter set the ergometer's starting workload to the same intensity as the warm-up (50 W). Participants were then instructed to pedal between 60 and 100 RPM and to manually adjust the workload setting until they were cycling at an intensity within the target range (RPE between 3 and 6). Upon verbal confirmation the participant was within the target range, the experimenter recorded a baseline value for RPE and the 20-min of self-paced cycling began. For the duration of the protocol participants were allowed to adjust the workload in order to maintain their RPE within the target range. RPE was measured at 2-min intervals to ensure compliance with these instructions. If reported RPE dropped or increased outside of the target range, participants were instructed to adjust the workload setting until they were within the target RPE range. Participants were blinded to time elapsed and workload throughout the exercise protocol.

Non-exercise protocol. The non-exercise option involved 22-min of seated, non-exercise behavior within the lab (i.e., time-matched to the MVPA task). The lab provided internet access and participants were permitted to use personal electronic devices (e.g., smartphone), a laboratory computer, or read from a selection of magazines or newspapers.

2.4. 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). Mean RPE-M rating was calculated by averaging the six ratings taken throughout the 10-min task. 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' to 'maximal'. Scores were calculated by measuring the distance in millimetres that the 'X' was placed from the left side of the scale. Mean cognitive task mental fatigue was calculated by averaging the six ratings taken throughout the 10-min task. Post-cognitive task mental fatigue was the mental fatigue VAS administered immediately following the cognitive task.

Subjective evaluation of exercise. A 2-item measure was developed by the researchers to assess each of the perceived costs and benefits of engaging in the MVPA task. Participants completed this measure following the 10-min experimental manipulation. For the perceived costs measure, participants were presented with the statement "For the exercise option, there are:…" and responded by circling a number on a 1–10 scale anchored at 1) "no disadvantages" and 10) "many disadvantages". For the perceived benefits measure, participants were presented with the statement "For the exercise option, there are:…" and responded by circling a number on a 1–10 scale anchored at 1) "no advantages" and 10) "many advantages". The items were assessed separately as "costs" and "benefits" and these items were also converted into a composite measure: "benefits vs. costs", which was simply the reported "costs" value subtracted from the reported "benefits" value. Greater positive values represent a greater benefit - cost valuation and greater negative values represent greater cost - benefit valuations.

2.5. Potential covariates

Given the decision task would offer participants opportunities to engage in either a session of MVPA or non-exercise activity, we felt it was important to assess and control for any potential group differences in habitual MVPA and physical activity enjoyment based on the possibility that people who engaged in greater amounts of physical activity or enjoyed physical activity more would be more likely to choose to engage in MVPA. Participants completed these measures at the beginning of the study session.

MVPA. MVPA prior to the study 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 physical activity. Internal consistency was acceptable (Cronbach's $\alpha = 0.93$).

2.6. Experimental manipulations

High cognitive demand task. Participants in the high cognitive demand group performed a computerized version of the incongruent Stroop color word task (Stroop, 1935). The task consisted of five, 2-min blocks of 135 trials (900 ms per trial), 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″ flat screen computer monitor for 800 ms on a white background in 48-size, Times New Roman font, followed by a 100 ms 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 "black" presented in "green" font, the correct response was to say aloud the word "green").

Low cognitive demand task. Participants in the low cognitive demand 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 when they heard the word "water".

3. Data analysis

Descriptive statistics were computed for all study variables. Independent samples *t*-tests were computed for MVPA and physical activity enjoyment. Independent samples *t*-tests were computed to evaluate between-group differences for mean cognitive task RPE-M and mean cognitive task mental fatigue during the cognitive experimental manipulations, as well as post-cognitive task mental fatigue and subjective evaluation scores. In addition, separate 2 (group) X 6 (time) mixed ANOVAs were conducted on mental fatigue and RPE-M scores throughout the cognitive tasks. To assess the direct effect of experimental group on exercise choice, a binary logistic regression was computed with exercise choice (coded 0 = non-exercise, 1 = exercise). To assess the hypothesis that post cognitive task mental fatigue and a benefit vs. cost evaluation mediated the effect of high cognitive demand on exercise choice, a serial mediation analysis was conducted using Model 4 in the *PROCESS* software macro (Hayes, 2017). Bootstrap procedures utilizing 10,000 simulations were computed, as recommended by Hayes and Scharkow (2013). In this analysis, a 95% confidence interval that does not include zero indicates a significant ($p < .05$) indirect (mediation) effect.

To assess the secondary hypothesis that mental fatigue would be negatively associated with work and positively associated with RPE during exercise, mean workload was calculated by averaging the self-selected workload throughout the 20-min exercise task for participants who chose the MVPA task. Further, in order to normalize workload across individuals, the mean workload during the exercise task was divided by the workload setting from the M-GXT corresponding to each participant's RPE of 6, which was then multiplied by 100 to yield a relative workload score (%/100). For example, if a participant cycled at a mean workload of 80 W during the MVPA task and at 135 W at RPE of 6 on the M-GXT, their relative workload score was: $80/135 \times 100\% = 59.26\%$. Mean RPE during exercise was calculated by averaging the 11 RPE scores recorded while exercising. Separate Pearson's correlations were computed to test the associations between post-cognitive task mental fatigue, mean RPE, and normalized workload performed during the 20-min self-paced bout of exercise. All data analyses were carried out using IBM SPSS Version 20.0.

4. Results

4.1. Data screening

Data were screened for normality using the Shapiro-Wilk test. Positively skewed variables (mental fatigue, RPE-M) were transformed using a square root transformation and a "reflect and square root" transformation was used for the negatively skewed variable (perceived exercise benefits). Analyses were computed with transformed and non-transformed data and, in all cases, produced identical results. For ease of interpretation, the results of the analyses using the non-transformed values are reported. Outliers were defined as cases with standardized scores in excess of 3.29 standard deviations from the mean (Tabachnick & Fidell, 2001). One outlier from the low cognitive demand group was identified for the MVPA variable and was excluded from the *t*-test assessing differences between groups in that variable but included in all other analyses. RPE during the exercise task was screened to ensure that task instructions were followed for those selecting the MVPA task. Two participants who chose to exercise reported RPE < 3 while exercising despite repeated instructions to adjust their workload setting and were removed from analyses pertaining to exercise behaviors. All results are presented as $M \pm SD$.

4.2. Preliminary analyses

Descriptive statistics for potential covariates and manipulation effects are presented by group in Table 1. Results of the independent samples *t*-tests investigating the effectiveness of the randomization procedures in terms of the potential covariates revealed no significant between-group differences in MVPA or physical activity enjoyment ($ps > .68$, $ds < 0.12$). As shown in the table, the means for both RPE-M and mean cognitive task mental fatigue were higher in the high cognitive demand group than the low cognitive demand group. These

Table 1
Descriptive statistics for potential covariates and measured variables by high cognitive demand and low cognitive demand group.

	Group		*t*	*p*	*d*
	Low Cognitive Demand *n* = 29 (13 females)	High Cognitive Demand *n* = 26 (14 females)			
	M ± *SD*	*M* ± *SD*			
Age	19.31 ± 1.20	18.73 ± .72	2.14	.04	.58
MVPA	150.89 ± 108.89	146.73 ± 146.38	.12	.91	.03
PA enjoyment	100.31 ± 16.13	102.12 ± 15.55	-.42	.68	.11
Mean RPE-M	1.57 ± 1.07	4.62 ± 1.87	−7.32	< .001	2.03
Mean mental fatigue	22.25 ± 17.36	50.37 ± 22.68	−5.19	< .001	1.40
Post-task mental fatigue	24.24 ± 20.30	62.15 ± 27.49	−5.86	< .001	1.58
Costs	3.38 ± 1.78	4.38 ± 2.14	−1.90	.06	.51
Benefits	7.38 ± 2.03	7.54 ± 2.14	-.28	.78	.08
Benefit vs. cost	4.00 ± 3.02	3.15 ± 3.41	.98	.33	.27

Note. M = mean, *SD* = standard deviation, *d* = Cohen's *d*, MVPA = moderate-to-vigorous physical activity, RPE-M = rating of perceived exertion - mental. Mean mental fatigue = Mean of mental fatigue ratings during the cognitive task. Post-task mental fatigue = mental fatigue rating reported immediately following the cognitive task. Benefit vs. cost = benefit - cost.

differences were significant: RPE-M, $t(38.86) = -7.32$, $p < .001$, $d = 2.03$; mean cognitive task mental fatigue, $t(53) = -5.19$, $p < .001$, $d = 1.40$. Post-cognitive task mental fatigue scores were also significantly higher in the high cognitive demand group, $t(53) = -5.86$, $p < .001$, $d = 1.58$. There was a very strong positive relationship between mean cognitive task mental fatigue and post-cognitive task mental fatigue ($r = .95$, $p < .001$), so the post-cognitive task mental fatigue scores were used in the analyses as they are, temporally, the most proximal to the outcome measures.

A significant group X time interaction was found for mental fatigue scores reported throughout the cognitive task ($F(5, 260) = 28.18$, $p < .001$), $\eta_P{}^2 = 0.35$). There were no between groups differences prior to beginning the task ($p = .75$, $d = 0.09$), however, the high cognitive demand group reported significantly higher mental fatigue at each time point during the cognitive task compared to the low cognitive demand group ($ps < .006$) with effect sizes ranging from $d = 0.79$ after 2 min to $d = 1.58$ after 10 min. The group X time interaction for RPE-M scores was also significant ($F(5, 265) = 32.47$, $p < .001$, $\eta_P{}^2 = 0.38$). There were no differences between groups prior to beginning the task ($p = .54$, $d = 0.17$), however RPE-M scores were significantly higher in the high cognitive demand group compared to the low cognitive demand group throughout the cognitive task (all $ps < .001$, $ds > 1.45$).

Descriptive statistics for the main study variables are reported, by group, in Table 1. The mean perceived cost rating of engaging in MVPA was higher in the high cognitive demand group, representing a medium-sized effect that approached statistical significance, $t(53) = -1.90$, $p = .06$, $d = 0.51$. There were no differences between groups for perceived benefits of engaging in MVPA, $t(53) = -0.28$, $p = .78$, $d = 0.08$, or overall benefit vs. cost score, $t(53) = 0.98$, $p = .33$, $d = 0.27$. Since there was a very strong positive relation between perceived costs and benefits vs. cost score ($r = -0.78$, $p < .001$) and perceived benefits and benefits vs. cost score ($r = 0.80$, $p < .001$), benefits vs. cost scores were used in the mediation analysis to avoid multicollinearity.

4.3. Primary analyses

Frequencies of choice between the exercise and non-exercise options are presented, by experimental group, in Figure 1. As shown in the figure, similar proportions from each group chose each of the MVPA and non-exercise options. The binary logistic regression model assessing the differences in frequencies of choice by group was not statistically significant, $\chi^2(1) = 0.20$, $p = .66$, $d = 0.12$, and explained .01% of the variance in choice (Nagelkerke R^2).

4.4. Indirect (serial mediation) analysis

In the serial mediation analysis, (see Figure 2), choice (MVPA/non-exercise) was specified as the dependent variable with experimental group (high cognitive demand/low cognitive demand) serving as the independent variable, and subjective mental fatigue (M_1) and benefit vs. cost score (M_2) as the mediators. As hypothesized, the overall results revealed a significant indirect (mediation) effect (95% C.I. = −1.03 to −0.01). To summarize: there was a significant direct effect of experimental group on mental fatigue, 95% C.I. = 24.93 to 50.89, SE = 0.02, $p < .001$; a significant direct effect of mental fatigue on benefit vs. cost score, 95% C.I. = −0.08 to −0.01, SE = 02, $p = .02$; and the direct effect of benefit vs. cost score on choice approached significance, 95% C.I. = -0.001 to 0.40, SE = 0.10, $p = .05$. The direct effects of group on benefit vs. cost score, 95% C.I. = −1.35 to 2.92, SE = 1.07, $p = .46$, and mental fatigue on choice, 95% C.I. = −0.04 to 0.02, SE = 0.01, $p = .45$, were not significant.

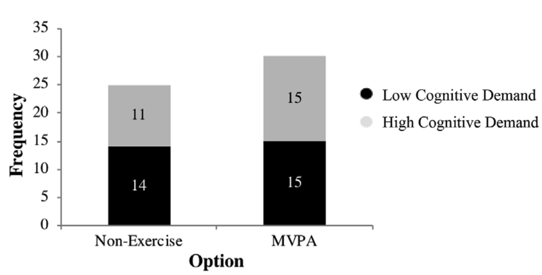

Fig. 1. Frequencies of selection of non-exercise and MVPA options by group.

4.5. Secondary analyses

From the sample of 55 participants, 30 (55%) selected the MVPA exercise option. Pearson's correlations between post-cognitive task mental fatigue, mean RPE during exercise, and percent average workload are presented in Table 2. Mean self-selected intensity ranged from 4.04 to 5.75 on the RPE scale during the 20-min cycling task. There was a moderate relationship between mental fatigue and mean RPE ($r = 0.38$, $p = .05$) indicating participants who reported greater mental fatigue reported greater perceived exertion while exercising. There was a small, non-significant, negative relationship between mental fatigue and workload ($r = -0.11$, $p = .59$) suggesting people who were more mentally-fatigued performed less work while exercising.

5. Discussion

In this study we investigated the effects of performing a high cognitive demand task on people's decisions to engage in an acute bout of MVPA and whether the effect is mediated by subjective mental fatigue and benefit vs. cost evaluations. We also examined the effects of mental fatigue on perceptions of exertion and exercise behaviors during a self-paced bout of exercise among those who made the decision to exercise. Results indicated performing the high cognitive demand task caused significantly greater mental fatigue, but did not directly predict exercise choice. However, ratings of mental fatigue and subjective benefit vs. cost evaluations serially mediated the relationship between the experimental group and participants' choice of whether to exercise or not. Among participants who elected to exercise, higher levels of mental fatigue were associated with higher ratings of perceived exertion while exercising.

The primary hypothesis was that people would be less likely to choose to exercise after performing a task requiring high cognitive demands. To the best of our knowledge, this is the first study to examine the effects of performing a cognitively demanding task on exercise decision-making. Drawing from previous research showing people reduce their intentions to expend effort in a subsequent exercise session after expending high levels of cognitive effort (Brown & Bray, 2019; Martin Ginis & Bray, 2010), it seemed logical to predict they might also withdraw from exercising if given the chance to do so. Contrary to predictions, the direct effect of the experimental manipulation was not significantly associated with the choice to exercise. Rather, people chose the exercise and non-exercise options in almost equal proportions in both experimental groups.

Although the absence of a direct effect of cognitive demand group on exercise choice did not support our main prediction, the absence of a direct effect between the independent and dependent variable does not preclude mediation (Hayes, 2017; Rucker, Preacher, Tormala, & Petty, 2011). Further analyses were carried out to test whether effects associated with mental fatigue and subjective evaluations could predict decisions to exercise or not. Results of that serial mediation model (Figure 2) showed high cognitive demand led to a biasing of choice towards the non-exercise option through a process wherein greater mental fatigue was associated with lower subjective benefit vs. cost evaluations (See Figure 2: coefficient $d_{21} = -0.04$) and, in turn, lower benefit vs. cost evaluations were associated with the choice to not engage in exercise (See Figure 2; coefficient $b_2 = 0.20$). In short, results

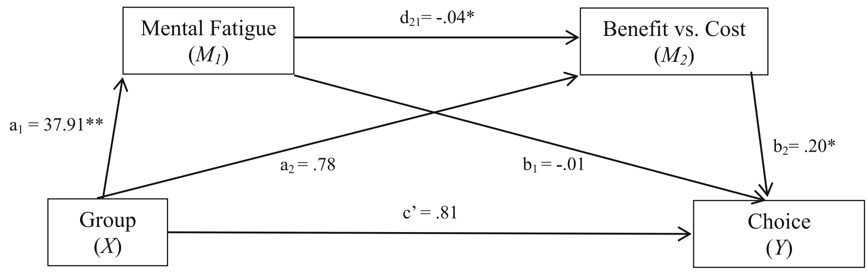

Fig. 2. Serial mediation analysis. Coefficients are presented in unstandardized form. *$p < .05$, **$p < .001$.

Table 2
Bivariate Correlations (Pearson's r) Between Mental Fatigue, Exercise RPE, and Workload During Exercise.

	M ± *SD*	1	2	3
1. Mental fatigue	35.75 ± 28.44	-		
2. Exercise RPE	4.72 ± .49	.38*	-	
3. Workload (%)	61 ± 15	-.11	.27	-

Note: N = 28 participants selecting the exercise option. * = $p < .05$.

support an interpretation that performing cognitively demanding tasks does not reliably predict whether people will avoid exercising on its own, but rather can contribute to a process that is orchestrated by people's feelings of mental fatigue and subjective evaluations of the benefits and costs of exercising.

In addition to the serial mediation effects suggesting an important causal role for subjective (benefit vs. cost) evaluations for exercise decision-making, the results are also interesting to consider in light of the fact that the benefit scores were relatively high and did not differ between the high and low cognitive demand groups (M = 7.54 ± 2.14 and 7.38 ± 2.03, respectively). However, the cost evaluation score showed a medium-to-large effect (d = 0.51) indicating greater perceived costs of exercising among participants in the high cognitive demand group. Further analyses of the correlations between mental fatigue and exercise costs and benefits showed no association between mental fatigue and subjective benefits ($r = -0.18$, $p = .19$), but a medium-sized positive correlation between mental fatigue and subjective costs ($r = 0.35$, $p = .01$). These results suggest people may perceive the effort demands of exercising to be greater when mentally fatigued. As noted earlier, there is consistent evidence that, when mentally fatigued, participants report greater perceptions of exertion while performing a physically-demanding task (Van Cutsem et al., 2017). Therefore, when faced with a decision regarding a physically-demanding task, it seems possible that people who are more mentally-fatigued anticipate having to exert more effort to perform the task. In turn, this anticipation may increase the perceived costs of the activity. Future research should directly assess anticipated effort as a determinant of subjective benefit-cost valuations of exercise.

The interpretation that mental fatigue leads to greater subjective effort-based cost valuations of exercise is also supported by research showing cognitive fatigue causes people to avoid performing cognitively-demanding tasks (Kool & Botvinick, 2014) and choose less effortful tasks over those requiring greater effort (Massar, Csathó, & Van der Linden, 2018). However, an alternative interpretation is the increase in the cost score may be indicative of the opportunity cost of not engaging in the non-exercise task. Theorists in the self-control literature have suggested expending mental effort on a difficult task may signal greater reward, and desire, for leisure (Kurzban, Duckworth, Kable, & Myers, 2013). Although the direct costs of exerting additional effort and the indirect "opportunity costs" of not engaging in a rewarding leisure task may be two sides of the same coin, both possibilities can explain why the perceived costs of exercising were greater in the experimental group that expended greater cognitive effort and experienced greater mental fatigue.

The serial mediation and benefit vs. cost findings are informative in terms of understanding decision-making processes; however, they also raise methodological issues relating to theorized processes by which people's performance of cognitively demanding tasks can influence their exercise behaviors. Specifically, having people perform experimental manipulations involving greater or lesser cognitive demands is designed to alter characteristics of the participants, which in turn, are theorized to cause changes in behavior or other outcomes. However, having one group of people perform a cognitively-demanding task does not ensure that they will uniformly develop mental fatigue. Restricting analyses only to the group level fails to account for the range of mental fatigue symptoms experienced by participants exposed to the experimental manipulations. Our findings suggest mental fatigue exerts effects on subjective evaluations and exercise decision-making at the level of the individual. That is, group manipulations involving tasks with greater and lesser cognitive demands may be useful to create an expanded range of mental fatigue scores experienced within a sample of participants. However, it is the individual's perception of perceived mental fatigue that alters their subjective evaluations and subsequent decision-making.

Although the results align with an interpretation that mental fatigue biases effort-based decision-making, they may also be contextualized within the behavioral economic concept known as "present-biased preferences," which refers to people's tendency to make choices in favor of immediate rather than future evaluations of costs and benefits (Mitchell et al., 2013; O'Donoghue & Rabin, 1999). In the context of the present experiment, exercise is a behavior for which costs (e.g., effort requirements) are experienced immediately whereas benefits (e.g., improved health) may not be experienced until later on. The greater perceived costs suggest "present-bias" may also be more pronounced when people are more mentally-fatigued and result in decisions to forego exercise for a less costly alternative. Future work should identify whether strategies for attenuating fatigue may counter present-biased decision-making.

The secondary objective of the study was to examine the feelings and behaviors of the participants who elected to exercise. Our interest here was guided by previous research showing mental fatigue causes people to down-regulate how much exercise they perform or experience exercising as more effortful (Brown & Bray, 2019; Brownsberger et al., 2013). The current findings were consistent with these effects insofar as people who rated their mental fatigue higher following the cognitive task also rated perceived exertion as higher while they were exercising ($r = 0.35$, $p = .05$), yet, mental fatigue was not significantly correlated with how much work people performed while exercising. Together, these findings indicate participants who were more mentally fatigued perceived the exercise bout to be more effortful despite working at the same (or lower) relative workloads as people who felt less fatigued.

This study provides the first evidence suggesting benefit vs. cost evaluations function as a mechanism by which mental fatigue affects exercise decision-making. A number of strengths and limitations should be noted. The investigation of psychological variables that mediate the effect of mental fatigue on behavior is a definite strength as it helps identify explanatory mechanisms and potential avenues for intervention development. Analyses of individual levels of mental fatigue in addition to group effects also helps extend research and illustrates how participants' responses to manipulations intended to elevate mental fatigue rather than simple exposure to those manipulations should be the focus of research intending to understand how mental fatigue affects behavior. The single-item measures used to assess subjective evaluation may be a limitation as single item measures are often criticized in the literature (Wanous & Reichers, 1996). However, single-item measures of concepts such as physical activity intentions are both valid and commonly-used (Courneya & McAuley, 1995). Similar to intention measures used in the physical activity literature, the subjective benefits and costs measures have strong ecological validity as the questions allowed participants to holistically evaluate the factors most relevant to them just prior to making their decision, rather than assessing specific examples of physical, health, psychological, or social factors as have been used in previous studies relating to more generalized beliefs (e.g., Marcus & Owen, 1992).

The sample consisting of recreationally-active university students should be noted as a limitation as results may not be generalizable to other age groups. Furthermore, given evidence that cost/benefit evaluations of physical activity vary with different activity levels (Marcus & Owen, 1992), findings may not be generalizable to less active samples. Lastly, offering participants only one exercise option (i.e., cycling at a moderate-to-vigorous intensity for 22 min in the lab) should be recognized as a limitation as it may not have been a desirable mode of activity for some participants. Given the behavioral economic principle that choice, in part, depends on the available alternatives (Epstein, 1998), future studies should examine decision-making when people have opportunities to engage in a variety of physical activity behaviors in varied contexts that could include resistance or interval circuit exercise that can be performed with a partner, friend, or in a group setting. Offering more alternatives to choose from would provide a more complete understanding of decision-making regarding participation in physically-active behaviors.

Despite several limitations, the present study provides a strong starting point for future efforts to explore how mental fatigue may be a factor affecting people's acute decisions to exercise or not as well as physical activity levels in the population. From a practical standpoint, it is interesting to consider the findings in light of what might be considered an epidemic of inactivity in the population at large and the sedentary culture of most university students (Haase, Steptoe, Sallis, & Wardle, 2004). Specifically, all of the participants responded to an advertisement and volunteered for a study in which they expected to engage in exercise, attended the study session dressed in exercise attire, and engaged in a warm-up session to prepare to exercise. Yet, despite being fully prepared to engage in exercise, almost half the sample decided to sit in the lab and remain sedentary for 22 min instead of exercising. We discovered mental fatigue could partly account for these decisions, but there are multiple additional factors at play.

This study is the first to have investigated the effects of mental fatigue on acute exercise decision-making. It was found that mental fatigue and a benefit vs. cost evaluation mediated the relationship between exerting high cognitive demand on an experimental task and people's choice of whether to exercise or not. High cognitive demand led to higher levels of mental fatigue, which were predictive of lower benefit vs. cost scores, and a reduced likelihood of choosing to exercise. Overall, findings indicate that mental fatigue and one's subjective evaluations about exercising contribute to a complex decision-making process related to acute exercise decision-making.

Conflicts of interest

The authors have no competing interests to declare.

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