EFFECTS OF ATTENTIONAL FOCUS AND MENTAL FATIGUE ON PERFORMANCE AND PERCEIVED EXERTION DURING EXERCISE

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ABSTRACT

Mental fatigue impairs performance of physically-demanding tasks and increases rating of perceived exertion (RPE) while performing. However, there may be ways of overcoming such performance decrements. One possible method includes the use of attentionally focused instructions. Motor learning research has shown that externally focused instructions can lead to improved performance in comparison to internally focused instructions. The purpose of the present study was to investigate the moderating effect of attentional focus on the mental fatigue – endurance performance relationship as well as the mental fatigue – perceived exertion relationship. Undergraduate students ($N = 78$) completed two wall sit tasks to volitional failure, one before and one after the completion of a cognitive task. Half the participants were randomly assigned to complete a high cognitive demand task to induce mental fatigue (incongruent Stroop; HMF), while the other half performed a low cognitive demand task (documentary viewing; LMF) before the second wall sit. Immediately prior to the second wall sit, half the participants in each cognitive task group also received instructions to focus their attention either internally (INT) or externally (EXT) during the second wall sit. The main effect of mental fatigue ($p < .001$, $d = .873$) during the cognitive task and the main effect of attentional focus ($p < .001$, $d = .883$) during the wall sit task were significant, indicating effective manipulations. Results found no moderating effect of attentional focus on wall sit performance ($p > .500$) or RPE ($p = .724$). However, between-group analyses were conducted to probe the differences in performance between each group. Results indicated the HMF/INT group performed significantly worse than the LMF/EXT ($p = .032$) and trended towards performing worse than the HMF/EXT and LMF/INT groups (ps $< .090$). Significant differences in RPE were also seen between trials for the HMF/INT group ($p = .009$, $d = .592$) alone, suggesting detrimental effects of both mental fatigue and internal focus combined. Overall, the data indicate a potential moderating effect of internal attentional focus that may exacerbate the detrimental effects of mental fatigue on performance and RPE.

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LIST OF ABBREVIATIONS

AF	Attentional Focus
AX-CPT	AX- Continuous Performance Task
b	Moderation coefficient
d	Cohen's d
EXT	External
g	Hedge's g
HMF	High Mental Fatigue
INT	Internal
LMF	Low Mental Fatigue
M	Mean
MF	Mental Fatigue
MVPA	Moderate to Vigorous Physical Activity
MVC	Maximal Voluntary Contraction
RPE	Ratings of Perceived Exertion
TTF	Time to Failure

DECLARATION OF ACADEMIC ACHIEVEMENT

Ashley Flemington's role:

- Amended ethics application at McMaster University
- Designed study protocol and chose measures
- Recruited participants
- Organized visits and set up lab equipment and materials
- Supervised volunteers assisting with data collection
- Responsible for manuscript preparation

Role of co-authors:

- SB assisted AF with ethics application
- SB assisted AF with study design and selection of measures
- SB assisted AF with data interpretation
- SB obtained study funding

INTRODUCTION

In sport and exercise settings, people set goals and strive to improve; to be more physically active, to be better at a sport, and to be able to compete at various levels of recreational sport and activities. A common barrier to participation in physical activity is fatigue (Salmon, Owen, Crawford, Bauman, & Sallis, 2003). Mental fatigue that can be present throughout the day (Aritake et al., 2015) can also impair performance of a variety of physical tasks including motor skills and endurance performance (Brown et al., 2020). Indeed, Russell, Jenkins, Rynne, Halson, and Kelly (2019) show that coaches and athletes report many transient factors that cause mental fatigue in the sport practice and competition environments. However, the detrimental effects of mental fatigue on physical performance may also be mitigated by strategies utilized during performance (e.g., Brown & Bray, 2019; Seeley & Gardner, 2003). In this thesis, I explore the idea that attentional focus may be manipulated in ways that enable people to overcome the negative effects associated with mental fatigue or combine with mental fatigue to exacerbate performance outcomes.

Mental fatigue, self-control depletion, and physical performance

Among the first to postulate about and investigate the effects of mental fatigue on physical performance was Angelo Mosso (1906). He observed many negative effects of what he called ‘intellectual fatigue’ (p. 220), including physiological symptoms such as increased body temperature and dizziness. He also observed psychological symptoms such as thoughts becoming confused, performing cognitive work becoming more challenging, and experiencing difficulty re-engaging in a mental task after a short break. An observation that surprised him; however, was a decrease in the ability to complete muscular contractions after engaging in mentally-demanding tasks. That is, Mosso reported several case studies involving his colleagues where giving their lectures and examinations served as cognitively-demanding manipulations and repeated finger flexion exercise was the physical outcome task. For these studies, a small weight was placed on the subject's middle finger, which was lifted every two-seconds and a graph was made showing their fatigue curve using an apparatus known as an "ergograph". These procedures were completed at different time points (e.g., prior to lectures starting, directly after a lecture, and the day after a lecture). The general phenomenon observed was the amount of muscular work subjects were able to complete was diminished after lecturing compared to performance prior to the task or performance sometime later (such as the following day). Mosso went on to suggest that the brain affects muscular strength and needs time to recover its strength because the exhaustion occurs within the nervous system.

More than a century after Mosso's (1906) original writings, Boksem and Topps (2008) also addressed the topic of mental fatigue. Their description of mental fatigue coincides with that of Mosso, including such symptoms as tiredness and decreased motivation to continue performing demanding tasks. Boskem and Topps further explained mental fatigue as arising from prolonged periods of cognitively-demanding activity resulting in impairment of further cognitive or behavioural performance.

In the first modern study to investigate the effects of mental fatigue on physical performance, Marcora, Staiano, and Manning (2009) looked at the effect of engaging in a cognitively-demanding AX-Continuous Performance Task (AX-CPT) on performance of a cycling task. In that study, participants completed two maximum endurance cycling trials at a resistance equivalent to 80% of their individual peak power on separate days in a randomized order. Using a randomized crossover protocol, during one visit they completed a 90-minute AX-CPT prior to the cycling trial and on the other they watched a documentary film for 90 minutes prior to cycling, as a control task. After the cognitive task, participants completed a constant load, time to failure task, on a cycle ergometer. Results showed that time to failure was significantly (p = .003) shorter for the mental fatigue trial (M = 640 ± 316 s) compared to the control trial (M = 754 ± 339 s). Despite this significant change in time to failure, physiological variables such as heart rate, stroke volume, cardiac output, oxygen consumption, and blood lactate, were not different between conditions throughout the trial. However, as discussed later, perceptions of effort, assessed as ratings of perceived exertion (RPE; Borg, 1998), were found to be significantly higher in the mental fatigue trial compared to the non-fatigue trial (p =.007).

Another illustrative study investigating the effects of mental fatigue on physical performance was carried out by Boat and Taylor (2017). In this study, a modified Stroop task was used to manipulate mental fatigue and assess its effects on performance of an endurance wall sit task. Using a within-subjects design, participants completed a wall sit on two separate days, holding the position with their back against the wall and hips and knees at 90 degrees until volitional failure. Prior to each wall sit, cognitive tasks were administered in a counterbalanced order: an incongruent Stroop (1935) task inducing mental fatigue on one day and a congruent Stroop task as a control on the other day. In alignment with Marcora et al.'s (2009) finding, when participants were mentally fatigued, they had significantly (p = .01) shorter times to failure on the wall sit task (M = 130.16 ± 70.01) than when not mentally fatigued (M = 147.31 ± 73.01).

Although the study by Marcora et al. (2009) was the first to investigate the effect of mental fatigue on physical performance, it should also be acknowledged that cognitive tasks requiring cognitive self-control have been widely investigated in terms of their effects on a variety of tasks requiring physical stamina and motor control. In a recent review by Brown et al. (2020), the conceptual and methodological overlap between the literatures investigating mental fatigue and self-control (ego) depletion were discussed and a systematic review of the two literatures was carried out.

The concept of self-control depletion comes from the limited strength model, which proposes the ability to enact self-control is governed by a limited resource and when these resources are depleted, there is a tendency for self-control to falter (Baumeister, Bratslavksy, Muraven, & Tice ,1998; Muraven, Tice, & Baumeister, 1998). Although the limited strength perspective proposes sequential performance effects across all tasks involving self-control, the aftereffects of exerting cognitive control on physical self-control have been investigated most frequently in sport and exercise science (Brown et al., 2020). Researchers and theorists have argued the conscious effort required to use self-control can lead to increased feelings of subjective mental fatigue (Hagger, Chatziserantis, Wood & Stiff, 2010). Indeed, Francis and Inzlicht (2016) have proposed that self-control depletion may be considered a "form of mental fatigue" (p. 4), calling this the shifting-priorities process model. The model further suggests that willingness to complete a task is derived from balancing long-term needs with short-term enjoyment. Thus, ego-depletion increases mental fatigue and reduces the motivation to continue a task for long-term gain when the task could switch or end to satisfy short-term enjoyment.

In sport and exercise psychology, the most common method of investigating the effects of mental fatigue or depleted self-control on physical performance has been the dual- or sequential-task paradigm. This method involves the completion of two or more tasks, one after another, that require cognitive or physical effort (Hagger et al., 2010). In studies that use a within subject design, participants complete two study visits. One study session involves performing a cognitively-demanding task prior to a physically-demanding task then a task that does not require high cognitive demands precedes performance of the same physically-demanding task is used in the alternate session. For a between-subjects design, participants are randomly assigned to perform either a demanding cognitive task (experimental condition) or a non-demanding task (control condition) after which all participants perform the same physically-demanding task.

In both the mental fatigue and self-control literatures, researchers have used the same, or highly similar, cognitive tasks to induce mental fatigue and investigate the aftereffects of performing those tasks on physical performance and feeling states experienced during exercise. Tasks requiring executive functions such as sustained attention, working memory, and response inhibition require the use of self-control resources for successful performance, and, thus increase feelings of mental fatigue (Pageaux & Lepers, 2018). Cognitively-demanding tasks that reliably increase mental fatigue have a negative effect on performance outcomes. Based on meta-analysis, the overall magnitude of the effect has been shown to be small-to-medium (g = -.38, p < .001) (Brown et al., 2020). However, several factors were found to moderate the effect including study design and physical performance indices (i.e., aerobic, isometric resistance, or motor skill tasks). Thus, the magnitude and, possibly, the direction of the effects of mental fatigue on physical performance may depend on characteristics of the physical task and the task performance environment.

What is Attentional Focus (AF)?

When engaging in a task, an individual may think about a variety of things such as how their body is feeling, the direction they are moving, or even what they will be having for dinner that night. The locus of one’s thoughts or concentration is referred to as attentional focus and can be directed towards different aspects of a movement relating to either within or outside one's body through the use of instructions (Wulf & Prinz, 2001). Attention that is directed towards the body: how it feels or how it is moving, is referred to as internal. Attention directed outside the body on an implement or the outcomes of movements is referred to as external (Wulf, 2013). This two-dimensional classification of internal and external attention is often used in the literature; however, it can be further broken down into associative and dissociative thoughts (Stevinson & Biddle, 1998). Associative thoughts are those that are relevant to the movement or task. For example, an internal associative thought may be about how one is breathing when they are exercising or the feelings they are experiencing such as muscle soreness. In contrast, an external associative thought may be about the performer's movement strategy or lap time. Dissociative thoughts on the other hand are those that are not relevant to the movement or task. For example, an internal dissociative thought may be about a song or daydream about a fictitious event and an external dissociative thought may be about spectators or sceneries that are within the visual field of the performer (Stevinson & Biddle, 1998).

Theoretical basis for the effect of AF on physical performance

A theoretical framework that has been proposed to explain the effects of different attentional foci on performance is the constrained action hypothesis (McNevin, Shea, & Wulf, 2003; Wulf, Tollner, & Shea, 2007). The hypothesis suggests that an external focus allows for automated processes to control movement. In contrast, an internal focus increases conscious control of movement, disrupting automatic processes (Kal, van der Kamp, & Houdijk, 2013). This perspective suggests that while an external focus may facilitate more efficient movement and better performance, an internal focus puts constraints on the system reducing efficiency of movement leading to worse performance.

Kal, et al. (2013) conducted a study to test the constrained action hypothesis using a cyclic leg extension-flexion task. To assess the effects on automaticity of movement, trials were done as single-task and dual-task. In dual-task trials, participants were asked to complete a secondary cognitive task while simultaneously completing the physical task. Conscious control of movements (hypothesized to occur with internal instructions) would require more demand on working memory than automized control of movements (external instructions). Thus, performance on the secondary cognitive task is hypothesized to be superior when the movement is controlled by automatic processes (i.e., the external instructions condition). For the cognitive task in this study, participants were asked to verbally provide as many Dutch words as they could recall that started with a given letter from the alphabet (e.g., "k"). Participants completed eight trials in total: single- and dual-task trials, with internal and external attentional instructions for each, and for both the dominant and non-dominant legs. Findings showed the movement was performed better with externally focused instructions ($p < .01$, $\eta^2_p = .32$) and the dual task was performed worse while following the internal compared to external instructions ($p < .05$, $\eta^2_p = .20$). Thus, conscious cognitive processes were disrupted when focusing internally, but not when focusing externally, providing support for the constrained action hypothesis.

AF research and physical performance

Attentional focus and assessing the effects of specific instructions directing ones' locus of attention has predominantly been explored in motor learning research (Wulf, 2013). Much of this research has been done in the context of movement efficiency as well as skill acquisition, retention, and execution (Wulf, 2013). In an illustrative study conducted by Zarghami, Saemi, and Fathi (2012), the authors investigated the effect of different attentional focus instructions on discus performance as measured by distance a discus was thrown. The external attention instructions asked participants to concentrate on the discus and the landing location. The internal instructions asked participants to concentrate on their hand and wrist. Results showed participants in the external condition produced significantly better performance, throwing the discus an average of 1.12 meters farther, than those in the internal condition ($p < .05$, $\eta^2_p = .194$).

Wulf and Su (2007) found similar results investigating the effects of internal and external attention instructions on golf shot accuracy for beginners and experts. The shot accuracy task consisted of hitting a golf ball as close as possible to a target 15 meters away. Accuracy points were awarded based on how close the ball landed to the target, higher scores indicating better performance. In this study, the internal instructions asked participants to concentrate on the motion of their arms, the external instructions were to concentrate on the motion of the club, and the control group did not receive specific attentionally focused instructions. While both groups of beginner golfers improved throughout the practice trials, the external instruction group performed significantly better on a retention test than the internal instruction and control groups ($p < .05$). In the study protocol involving expert golfers, results also showed significantly higher scores for the external instructions compared to the internal instructions ($p = .005$).

Another study comparing attentional focus instruction sets, conducted by Marchant, Greig, and Scott (2009), investigated the effect of attentional focus on force production for an isokinetic elbow flexion task. Participants were instructed to go through the full range of motion and to create as much force as possible. During a single study visit, participants completed a control trial, then internal and external trials in a counterbalanced order. For the internal trials, participants were asked to focus on their arm and muscles and for the external trials they were asked to focus on the curl bar they were holding. Results showed participants produced significantly greater peak net joint torque during the external trials (102.10 ± 2.42 %MVC) than the internal trials (95.33 ± 2.08 %MVC) ($p < .01$, $\eta^2_p = .35$), indicating that at the point of highest force about the joint during the movement, external trials produced the greatest amount of force.

While the literature investigating effects of attentional focus on skill acquisition, retention and performance outcomes is expansive, the studies reviewed above demonstrate a general advantage of adopting an external focus. Yet, despite a consistent overall effect, there remains some heterogeneity in findings throughout the literature. For example, de Bruin, Swanenburg, Betschon, and Murer (2009) investigated the effects of attentional focus instructions on dynamic balance performance. In this study, the Biodex Stability System was used for the balance task, were participants can shift their weight around to control the movement of a dot on a feedback screen in front of them. The task included a moving target on the screen and participants were instructed to follow the target with the dot representing their centre of gravity. The internal instructions asked participants to focus on their belly, while the external instructions were to think about the dot as the air bubble in a spirit level at their feet and to concentrate on that bubble. Results showed no difference in balance performance between the conditions (p =.161, ω^2 = .05).

AF and physical endurance performance

Beyond the motor learning research on skill acquisition, one area where research has also concentrated is on the effects of different attentionally-focused instructions on performance of muscular endurance tasks. The idea that externally focused instructions would be beneficial for endurance performance is also informed by the literature indicating improved movement efficiency is associated with an external focus. For example, physiological indicators such as muscle activation (Vance, Wulf, Tollner, McNevin, & Mercer, 2004), heart rate (Neumann & Brown, 2013), and oxygen consumption (Schücker, Hagemann, Strauss, & Volker, 2009) have been investigated while participants performed physically-demanding tasks under different attentional foci. In each of these studies, the physiological correlates of performance were significantly different, such that performance benefits were observed with an external focus compared to an internal focus. These findings suggest movement may occur more efficiently, either requiring lesser resources for the same output or producing greater output for the same resources, depending on the experimental task paradigm. Importantly, these findings suggest that tasks requiring submaximal exertion such as holding or repeatedly lifting a submaximal load or running at a submaximal pace could be sustained longer under an external attentional focus compared to an internal focus.

In a study examining the effect of attentional focus on endurance performance, Marchant, Greig, Bullough, and Hitchen (2011) investigated the effects of internally and externally focused instructions on the number of repetitions performed to failure for bench press and squat exercises. The results showed participants performed significantly greater numbers of repetitions before failure during the external compared to internal attentional focus condition for the bench press ($M_{external}$ = 30.70 ± 2.23, $M_{internal}$ = 27.57 ± 2.28, p = .001, r = .43) and the squat ($M_{external}$ = 11.06 ± .18, $M_{internal}$ = 10.06 ± .18, p = .001, r = .98) exercises.

Lohse and Sherwood (2011) also investigated the effect of attentionally-focused instructions on submaximal performance, operationalized as time to failure for a wall sit task. Consistent with Marchant et al. (2011), they found that an external focus of attention was associated with better performance as assessed by longer times to failure in comparison to trials when participants were instructed to apply an internal attentional focus (p = .03, η^2_p = .12).

A third and more recent example of the effects of different attentional focus instructions on endurance performance was conducted by Schücker and Parrington (2019). In this study, participants ran on a treadmill for six minutes under each of the three attentional focus conditions. Instructions included 1) internal focus on breathing, 2) internal focus on body movements, and 3) external focus on a video of an outdoor running track. It was found that the external condition demonstrated improved running economy assessed as a lower VO_2 than the internal breathing condition (p =.015, d = -.77) and the internal body movement condition (p =.018, d = -.73).

Together, the research examples provided above support the growing literature showing endurance performance benefits with the use of externally-focused compared to internally-focused instructions. However, there is again some discrepancy in the literature regarding the benefits of an external attentional focus on endurance performance. More specifically, some studies have found no significant effect of external attentional focus over internal (Emanuel, Jarus, & Bart, 2008; Lawrence, Gottwald, Hardy, & Khan, 2011) and others have found internal attentional focus more beneficial to performance than external in some instances (e.g., Perkins-Ceccato, Passmore, & Lee, 2003). These discrepancies have been discussed as being attributable to methodological limitations in a review by Wulf (2013) where it was suggested that one of the key methodological limitations in many studies that may lead to inconsistent findings is the specificity of the instructions being used. That is, to ensure specificity, the instructions should be task-relevant with each instruction set (internal and external) referring to the same component of the task. Importantly, there also needs to be a clear distinction between the two sets of instructions, with as little ambiguity between the internal and external focus as possible. For example, if the task is a golf swing, internal instructions may include focusing on the smooth movement of the arms while external instructions may include focusing on the smooth movement of the club. This example clearly distinguishes between a focus on the body (internal) and a focus on an implement (external), while both instructions are related to the movement of the golf club swing.

A second methodological limitation noted by Wulf (2013) relates to factors that may confound instructions. Some examples of potential confounding variables include visual feedback that may interfere with locus of the attentional instructions (e.g., needing to visually follow a moving target throughout the task) or providing a different amount of information in one instruction set compared to the other. As such, it is suggested that the instructions be kept as similar as possible, with only key words changing to distinguish the focus of attention from the body to an implement or outcome. An example of such instructions provided by Wulf and Su (2007) in relation to a golf swing are to “focus on the swing of your arms" versus "focus on the swing of your club”. Although there is some discrepancy within the attentional focus literature, careful examination of methodology and construction of appropriate instructions in future research may reconcile divergent findings.

Perceptions of effort

Perceived exertion refers to “the effort expended in performing a physical activity” (Marcora, 2009, p. 2060; Oxford Dictionary of Sports Science and Medicine) and is measured in terms of the strength or intensity of the rating of perceived exertion (RPE) with Borg's (1998) 6-20 or CR-10 scales being the most widely-used measures of perceived exertion (Borg & Kaijser, 2006). Thus, RPE is a subjective measure based on the individual’s experiences, not based on absolute workload or intensity of the exercise.

Endurance Tasks

A commonly observed phenomenon with perceived exertion is a continuous increase in RPE occurring over time while performing physical endurance tasks. According to Tenenbaum (2001) there are many individual factors that contribute to the perception of exertion including the individual's dispositional personality traits, the type of task, intensity of the task, environmental conditions, and coping strategies. How perceived exertion is experienced is based on the interplay of these factors, but a consistent relationship is seen such that perceived exertion increases as the duration of an endurance task increases (Taylor & Gandevia, 2008).

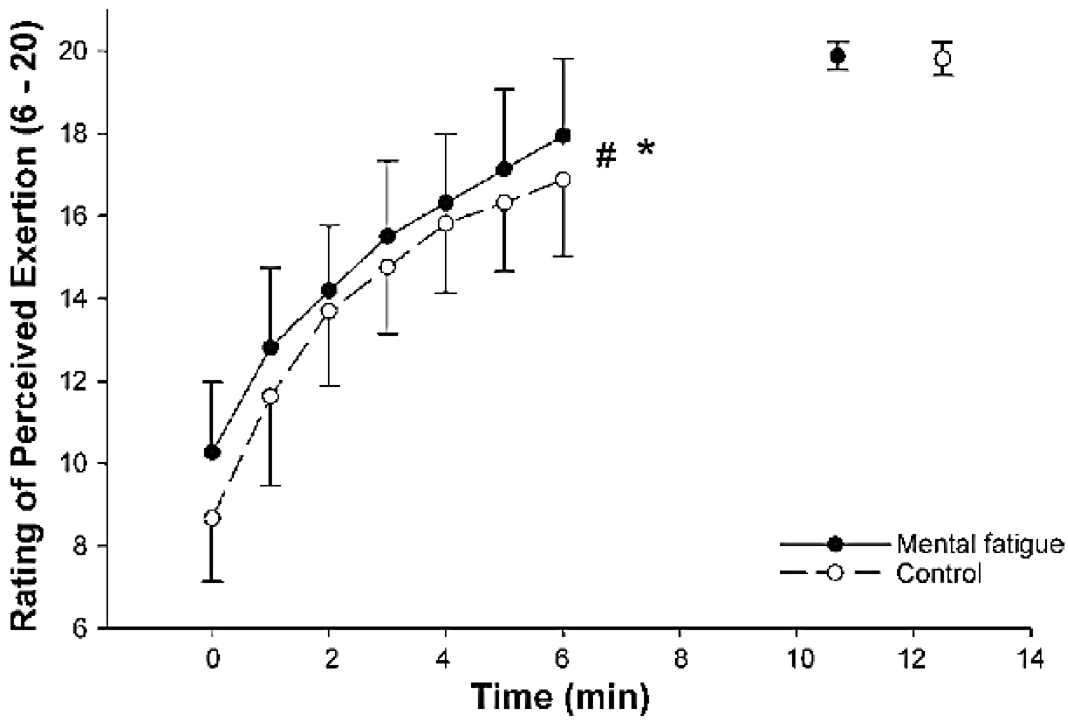
Mental Fatigue and RPE

Mental fatigue has been previously discussed in relation to its detrimental effects on physical performance and one mechanism that has been hypothesized to account for the negative effects of mental fatigue on performance is perceived exertion (Van Cutsem et al., 2017). Specifically, it has been shown that increases in mental fatigue can influence perceptions of exertion, particularly for endurance tasks that require maintenance of a constant workload over an extended duration.

In the study by Marcora, et al. (2009) discussed previously, the researchers also recorded ratings of perceived exertion (RPE) when they investigated the effects of mental fatigue on a cycling time to exhaustion task at 80% of peak power output. It was found that perceived exertion increased the same amount throughout the trial in both the mental fatigue and control conditions and was not significantly different at the time of task failure. However, as illustrated in Figure 1, RPE was found to be greater for the mental fatigue condition compared to control (p = .007) and times to failure were significantly shorter in the mental fatigue condition (p = .003). Thus, while the change in RPE over time was the same, when time to failure for the cycling task is taken into account, this finding suggests mental fatigue causes the same work to be perceived as more effortful and leads to disengaging from the work task sooner.

Figure 1

Ratings of Perceived Exertion across Time of Cycling task by Experimental Condition



Note. Line graph from Marcora et al. (2009), used with permission from the American Physiological Society

Pageaux, Marcora, Rozand, and Lepers (2015) also investigated the effects of mental fatigue on whole-body endurance exercise involving a cycling task at 80% peak power output. Participants completed three study visits with initial cycling tests on the first visit to determine peak power output. On subsequent study visits participants completed the cycling task after performing a cognitively-demanding Stroop task to induce mental fatigue or a control task, in a counterbalanced order. Ratings of perceived exertion (RPE) were taken throughout the cycling task at one-minute intervals. It was found that RPE increased significantly throughout the physical task for both the mental fatigue and control trials ($p < .001$). However, RPE was significantly higher during the mental fatigue trials compared to the control trials ($p = .044$) at the same time intervals, thus while both trials had a similar increase in RPE across time, the mentally fatigued trials remained higher at all time points.

Attentional Focus and RPE

Locus of attentional focus has also been associated with changes in perceived exertion during physical performance in several ways. For example, as perceived exertion increases there is a tendency to shift towards a more internal focus of attention. In a study conducted by Hutchinson and Tenenbaum (2007), an endurance hand-grip task was used to investigate attentional focus throughout a fatiguing endurance trial. Participants held a hand-grip squeeze at 25% of their maximum voluntary contraction for as long as they could and were asked to continuously, verbally express their thoughts during the task. It was found that thoughts about the body occurred most frequently during the end stage of the task ($p < .001$, 95% of all thoughts) and the middle of the task ($p < .01$, 64% of all thoughts). Conversely, thoughts outside of the body occurred most frequently during the beginning of the task ($p < .001$, 71% of all thoughts).

In a second study by Hutchinson and Tenenbaum (2007), a similar methodology was followed using a cycling task involving increasing intensities. Specifically, participants were asked to cycle for five minutes at 50% of their VO_2 max, then five minutes at 70% of their VO_2 max, and finally to volitional failure at 90% of their VO_2 max. Once again thoughts about the body were most prominent at the high ($p < .001$, 93% of all thoughts) and moderate ($p < .01$, 61% of all thoughts) intensity cycling, while thoughts outside the body were most prevalent at low intensity ($p < .001$, 78% of all thoughts). Together these studies illustrate the natural shift in attentional focus towards more prominent internal thoughts as exercise intensity increases during a physical task.

Research shows a shift in attentional focus relative to exercise intensity; however, the ability to adjust or manipulate attentional focus also appears to decrease as physical task intensity increases. Tenenbaum (2001) hypothesized that due to increases in perceived exertion and naturally shifting attention toward the prevailing sensations within the body, it becomes more challenging to consciously direct attention away from those sensations. This change in voluntary control of attention is derived from the parallel processing model (Leventhal & Everhart, 1979), which suggests the aversiveness of a pain signal is related to the amount of attention focused on the emotional aspect of it. Within this model it is suggested that internal thoughts influence the pain sensation, whereas external thoughts use up attentional resources with thoughts not focused on the sensations. This concept was further developed by Rejeski (1985) to extend from pain to perceived exertion, suggesting that exertion would also be influenced by attentional focus. From this perspective, an internal focus increases awareness of negative sensations and may allow an emotional appraisal of these sensations that occur at high levels of exertion (Brewer & Buman, 2006). On the other hand, external focus reduces the emotional appraisal of negative stimuli and occupies the attentional resources. However, when the negative sensations become the most prevalent, as can be the case at higher levels of exertion, attention is moved towards the most relevant stimuli and will not be as easily adjusted away.

Attentional focus and perceived exertion have also been proposed to interact in such a way that, upon manipulation of attentional focus, internally focused instructions lead to increased perceived exertion in comparison to externally focused instructions. This hypothesis was supported by a study conducted by Hill, Schücker, Hagemann, and Strauss (2017) where an endurance running task was used to investigate the differential effects of attentionally focused instructions on running economy and perceived exertion. It was found that ratings of perceived exertion were significantly higher for the internal-instruction condition compared to the external-instruction and control conditions ($p < .02$, $d = .53$-$.83$).

A similar pattern of results was also found in the study by Lohse and Sherwood (2011), previously discussed, where an endurance wall sit task was used to investigate the effects of attentional focus instructions on performance and perceived exertion. It was found that an external focus of attention led to a significantly longer time to failure than an internal focus of attention ($p = .03$, $\eta^2_p = .12$). It was also found that ratings of perceived exertion were significantly lower for the external condition compared to the internal condition ($p < .05$).

Mental Fatigue, Attention, Performance, and RPE

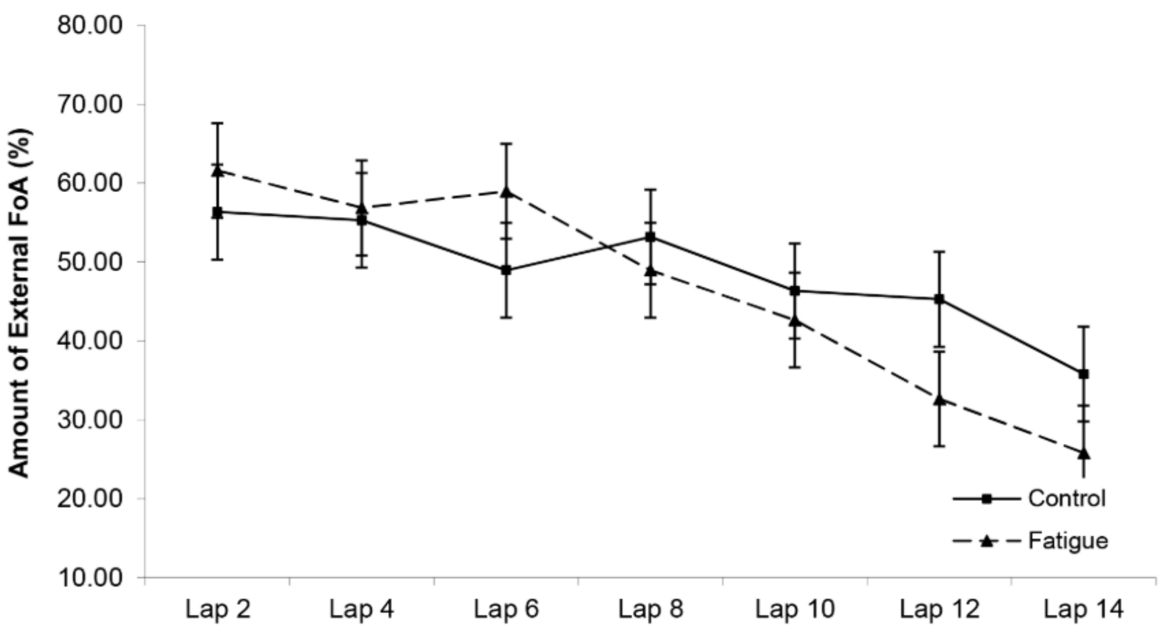
To this point, the literature review has illustrated that mental fatigue and an internal attentional focus have detrimental effects on performance and inflate RPE while performing physical endurance tasks. Although the effects of attentional focus and mental fatigue manipulations have not been studied in combination, research suggests the two effects may interact to some extent. In the only study to investigate the effect of mental fatigue manipulations on physical performance and also include a measure of attentional focus, MacMahon, Schücker, Hagemann, and Strauss (2014) investigated these effects on performance and RPE during a running time trial, where participants ran 15, 200-meter laps for a total of 3,000 meters as fast as possible. To investigate the effects of mental fatigue on physical performance and assess potential shifts in attentional focus that occurred across progressive laps, runners reported perceived exertion or attentional focus after each 200-m lap, alternating the scale (RPE on odd laps, AF on even laps). In a counterbalanced order, participants completed the time trial after a cognitively demanding task (90 minutes of an AX-CPT) and after a control task (6 minutes of the AX-CPT and 84 minutes of documentary viewing). Performance was better for the control group compared to the mentally fatigued group such that the control group had shorter times to completion (p =.009, η^2_p = .31). Consistent with other studies investigating attentional focus while performing endurance tasks, attention shifted from external to predominantly internal over time (p <.001, η^2_p = .29). The results also showed a main effect of lap on RPE scores (p < .05, η^2_p = .89), such that RPE increased significantly throughout the laps (p < .001) for both conditions. However, there were no significant differences in perceived exertion between groups (p >.05) over the 15 laps, which suggests runners were engaging in pacing strategies based on their RPE and adjusting pace to run slower in the mental fatigue condition, resulting in equivalent RPE. Thus, when participants ran under the mental fatigue condition, they perceived greater levels of exertion and adjusted to this sensation by running slower, compared to when they ran under the no mental fatigue condition.

One additional effect observed in the MacMahon et al. (2014) study was an association between mental fatigue and shifts in attentional focus. As illustrated in Figure 2, the shift from external focus to internal over the duration of the running trial occurred earlier in the trial and at an accelerated rate in the mental fatigue condition compared to control. These data suggest mental fatigue and attentional focus may interact when performing endurance physical activity. However, given attentional focus was observed rather than purposely manipulated, a more potent test of this potential interaction requires manipulation of attentional focus as well as mental fatigue.

The prospect of an interaction between mental fatigue and attentional focus in the context of endurance exercise also invites examination of people's experiences of perceived exertion while exercising. While MacMahon et al. (2014) recorded RPE and attentional focus during the running trials, the two variables were not analyzed in combination. Given there is extensive research regarding greater mental fatigue and internal focus of attention each showing independent effects that increase ratings of perceived exertion while exercising, the interaction between these two effects is also worthy of investigation.

Figure 2

Ratings of Attentional Focus across Running Time by Experimental Condition



Note. Line graph from MacMahon et al. (2014), used with permission from Human Kinetics Publishers.

Statement of the problem

The purpose of the present study was to investigate the effect of mental fatigue on endurance performance in the context of differing loci (internal and external) of attentional focus. Specifically, attentional focus was examined as a moderator of the mental fatigue – endurance performance relationship. A secondary purpose was to investigate the effects of mental fatigue and attentional focus on RPE during exercise, again to examine attentional focus as a moderator of the effects of mental fatigue on RPE during exercise.

Hypotheses

Effects on a) endurance performance and b) RPE

Drawing upon the extensive literature showing negative effects of mental fatigue on endurance exercise performance (Brown et al., 2020), it was hypothesized that participants engaging in a mentally-fatiguing cognitive task prior to performing an endurance exercise task will exhibit shorter times to failure compared to participants that engage in a non-fatiguing cognitive task prior to exercising. It has been shown that an external focus of attention has positive effects on performance of a variety of physical tasks, including times to failure for isometric/constant work endurance tasks, as well as decreased RPE during task performance. On the other hand, an internal focus of attention has been shown to increase perceptions of effort while performing isometric/constant work endurance tasks. In concert, these effects suggest mental fatigue and attentional focus exert independent effects on performance and RPE that may combine to negatively affect performance and RPE feeling states or combine in a way so as to cancel out the negative effect of one variable through the positive effect of the other. Accordingly, attentional focus is predicted to moderate the effect of mental fatigue on performance and RPE such that, relative to performance in the absence of mental fatigue or attentional focus effects:

1) the negative effect of mental fatigue combined with the negative effect of internal focus of attention should lead to a) the shortest time to failure (worst performance) and b) the highest RPE during performance

2) the positive effects of external focus of attention in combination with the neutral effect of the non-fatiguing manipulation should lead to a) the longest time to failure (best performance) and b) the lowest RPE during performance

3) the positive effects of external focus of attention should offset the negative effect of the mental fatigue manipulation, and, negative effect of internal focus of attention should combine with the neutral effect of the non-fatiguing manipulation to result in a) moderate performances and b) RPE levels somewhere between the other two groups.

METHOD

Participants and Design

Participants were 78 (n = 51 females) undergraduates (M_{age} = 19.01 ± 2.46) recruited through posters on McMaster University campus or a Psychology research participation pool (SONA) system. The study was reviewed and approved by the McMaster University Research Ethics Board prior to recruitment and informed consent was obtained prior to beginning each study visit. Participants received either a $10.00 honorarium or course credit for participation in the study. The experimental design was a blinded (experimenter blinded to condition), 2 (high vs. low mental fatigue) X 2 (internal vs. external attentional focus), factorial arrangement. The sample was stratified by sex and assigned to one of the four experimental conditions using a randomization schedule (www.random.org).

Sample size calculations for a 2 X 2 factorial ANOVA were computed using G*Power software. Due to there being no previous studies investigating both mental fatigue and attentional focus to provide an effect size, calculations were computed for each area of research. In the mental fatigue literature, a study by Brown and Bray (2017) used a similar study design and the data was used to calculate an effect size (Cohen's *f*) of .49. Using this effect size, and setting an alpha of .05, power of .80 yielded a sample size estimate of 35. In the attentional focus literature data from Lohse and Sherwood (2011) were used to calculate an effect size (Cohen's *f*) of .22, again setting an alpha of .05, and power of .80, a sample estimate of 165 was yielded. Thus, the present study aimed to collect a large enough sample to satisfy the 165-sample size requirement. However, due to the abrupt closure of lab spaces and indefinite cessation of in person data collection brought on by the COVID-19 pandemic, data collection was halted prior to reaching this sample size.

Tasks

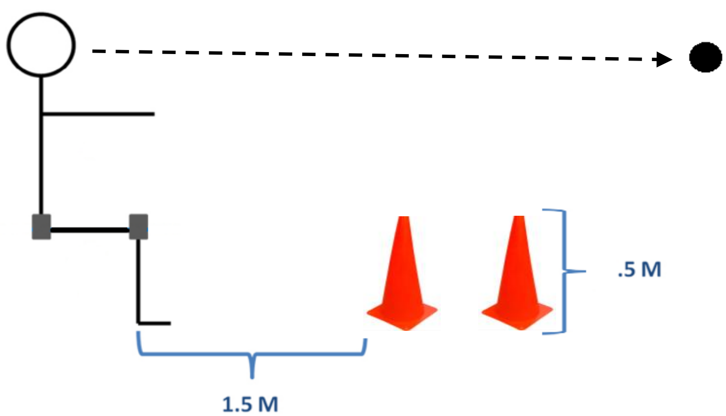
Endurance Wall Sit

The primary dependent variable of interest was time to failure (TTF) for an endurance wall sit task. Endurance wall sit tasks have been used in previous research investigating effects of attentional focus on physical performance (Lohse & Sherwood, 2011) as well as effects of cognitive exertion on physical performance (Boat & Taylor, 2017). Following procedures reported by Lohse and Sherwood (2011), participants were instructed to stand with their backs against a wall and feet hip width apart, then slowly walk their feet out and slide their back down the wall until their knees were at a 90-degree angle as determined by a goniometer. A visual fixation point was implemented for all trials by having participants look straight ahead at an 8 cm diameter black sticker posted on the adjacent wall. Two orange pylons 0.5-meters tall were placed in front of the participants, the first 1.5-metres away, the second 0.5-metres in direct alignment behind it and in line with the visual fixation point (Figure 3). Arm position was also kept consistent by asking participants to relax their arms at their sides to prevent them from pushing their arms into their legs or against the wall, which may alter positioning or task performance. A familiarization task for the wall sit was performed by all participants prior to the first performance trial. Participants practiced the correct positioning, allowing the researcher to place markers for the position. Participants held the position for 10 seconds while the researcher placed markers at their foot position, on their hip and on the wall in line with their hip. The markers on the hip and wall, along with the goniometer at the knee, were used to establish the starting position for each trial and determine when they moved out of position (i.e., a ≥5-degree change in knee angle, determined by the pre-set markers) to signal the end of the trial.

During the endurance trials, participants were instructed to maintain the wall sit position for as long as possible. Time was started when the participants were in the correct position and ended when participants signalled volitional failure or moved out of position. Volitional failure was signalled by participants verbally indicating 'done' or as visually-observable change in position, defined as a ≥5-degree change in knee angle, determined by the pre-set markers.

Figure 3

Image depicting the wall sit set up for the present study.



Manipulations

Mental Fatigue

To manipulate mental fatigue, a continuous incongruent Stroop colour word task was performed (Stroop, 1935) for the high mental fatigue (HMF) group. Participants were seated facing a computer monitor and were instructed to say aloud the colour of letters the words were written in and not the name of the colour spelled out by the letters (e.g., for the word “Black” appearing in blue lettering the correct response is “Blue”). Stroop word stimuli were presented in five, two-minute blocks consisting of 134 trials, where words appeared for 800 ms followed by a blank screen inter-trial interval for 100 ms. Participants were given a 30-second break between each block, during which measures of mental fatigue and ratings of perceived mental exertion were completed. This task has been used previously and has been shown to reliably induce mental fatigue in healthy young adults (Brown & Bray, 2017).

A documentary titled: “Planet Earth: Fresh Water” (Fothergill, Attenborough, & Fenton, 2007) was used for low mental fatigue (LMF) as a control group. Participants were seated facing a screen and watched five blocks of two-minute clips of the documentary. This manipulation has also been used in previous research (Brown & Bray, 2017; Harris & Bray, 2019) and has been shown to be an affectively-neutral stimulus with minimal effect on mental fatigue (Zering, Brown, Graham, & Bray, 2017). To ensure the participants were engaged in the task, they were instructed to mark down the number of times they heard the word "water" or a compound word containing water (e.g., "waterfall").

Locus of Attentional Focus

Prior to the second endurance trial, participants’ attentional focus was manipulated to either focus externally or internally during the subsequent wall sit task. Specific instructions for attentional focus were provided to participants immediately prior to starting the second endurance wall sit task. The instructions were adapted from scripts reported by Lohse and Sherwood (2011) with minor modifications based on feedback from an attentional focus researcher Dr. Gabriele Wulf (Wulf, G.; personal communication, August 5th, 2019). Participants randomized to the internal attentional focus group received the following instructions: “while performing the wall sit task, please concentrate on your thighs. Try to keep your thighs parallel to the floor”. Those assigned to the external attentional focus group received the following instructions: “while performing the wall sit task, please concentrate on drawing imaginary lines between the pylons in front of you. Try to keep the lines parallel to the floor”.

Measures

Rating of Perceived Exertion (RPE)

Rating of Perceived Exertion (RPE) was measured using Borg’s (1998) CR-10 scale. The scale ranges from 0, indicating no exertion at all to 10, indicating maximal exertion. Using Borg’s instructions (Borg, 1998, p. 47) participants were educated on how to report their RPE and had an opportunity to ask the experimenter clarification questions, if needed. The CR-10 RPE measure has been used extensively in exercise psychology and physiology research (Harris & Bray, 2019; Marcora et al., 2009)

Mental Fatigue (MF)

Mental fatigue was measured using a 100-millimeter visual analogue scale (VAS; Wewers & Lowe, 1990). 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 continuum is anchored at “none at all” to “maximal” and scores, ranging from 0-100, were calculated by measuring the distance in millimeters the ‘X’ was placed from the left of the scale.

Attentional Focus (AF)

Participants provided ratings of their locus of attentional focus using a 10-point bi-polar scale ranging from 0 (0% external thoughts, 100% internal thoughts) to 10 (100% external thoughts, 0% internal thoughts) developed by MacMahon et al. (2014). The AF scale instruction set was adapted from MacMahon et al. (2014). Specifically, given the original instructions were developed for a running task, the instructions were modified to suit an isometric endurance task based on recommendations by Dr. Linda Schücker (Schücker, L., personal communication, October 18th, 2018).

In order to prepare participants for rating AF, clear explanations distinguishing between internal and external loci of attention were provided as well as instructions for the AF scale to be used throughout the wall sit trials at the outset of the experimental session using a script (Appendix G). Participants were asked to provide examples of internally- and externally-focused thoughts they had experienced recently to check clarity and understanding.

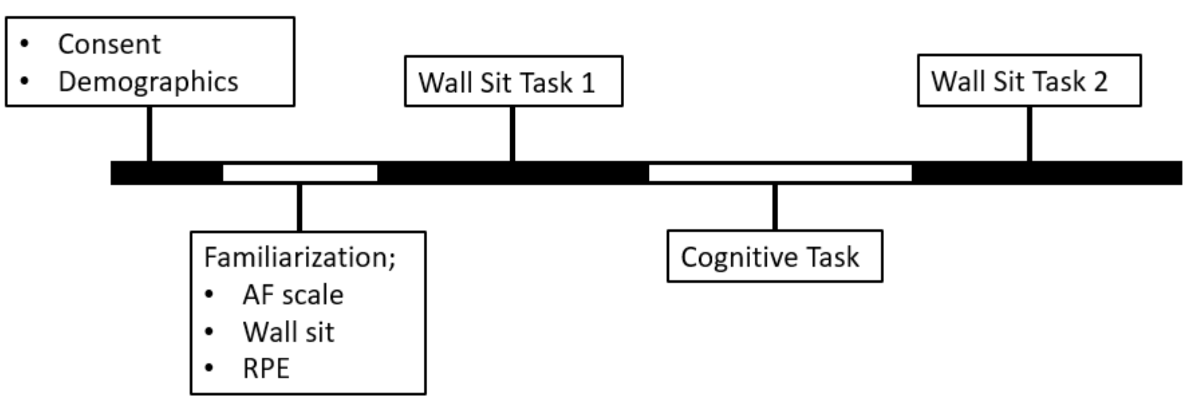
Procedure

All experimenters followed a script, ensuring that instructions were presented to each participant in the same way to reduce potential bias. Upon arrival at the laboratory participants completed informed consent and demographic questionnaires as well as assessments of height, weight, and self-reported footedness (see Appendix A). Participants were then familiarized with the RPE and mental fatigue measures and completed baseline measures of mental fatigue. Next, participants were given instructions, familiarized with, and practiced the wall sit task. After the wall sit familiarization, participants were provided instructions and orientation to the attentional focus measures and tasks. Any questions about attentional focus were answered and understanding was verified to ensure all participants could provide valid responses to the measure. Participants then completed their first endurance wall sit task. RPE and attentional focus scores were reported verbally by participants at 20 second intervals throughout the task in response to verbal prompts by the researcher. Order effects for reporting RPE and attentional focus were controlled for by counterbalancing the order of reporting these measures between subjects. Upon completion of the first endurance trial, participants reported post-task assessments of RPE, attentional focus, and mental fatigue.

Following the first endurance wall sit trial, the primary researcher excused herself and was substituted with a secondary researcher who administered the cognitive task. Participants rated mental fatigue prior to the cognitive task, during the 30-second rest breaks between each of the five blocks of trials, and upon completion of the task. Following the cognitive task, the secondary experimenter provided the AF manipulation instructions for the second endurance wall sit task. To ensure understanding, participants repeated the instructions back to the researcher, after which they were instructed to "please keep the instructions I gave you in mind but do not mention anything we talked about or did here to the other researcher." The primary researcher was then substituted with the secondary researcher and participants completed the second endurance wall sit task, again reporting attentional focus and RPE at 20 second intervals. Upon completion of the second endurance trial, participants were thanked, debriefed, and compensated for their time.

Figure 4

Procedural Timeline.



Data analysis

One-way ANOVAs were conducted on baseline measures of height, weight, moderate – vigorous physical activity levels, initial mental fatigue, and initial attentional focus to determine potential differences between groups. One-way ANOVAs were also conducted on the attentional focus scores for each trial based on the order they reported attentional focus and RPE to assess order effects of these measures during the wall sit.

To evaluate the effects of the cognitive manipulation on mental fatigue a 2 (MF group) x 6 (time) ANOVA was computed with the mental fatigue scores collected throughout the cognitive task. To evaluate the effects of the attentional focus manipulation a 2 (AF group) x 5 (iso-time) ANOVA was computed with the difference in attentional focus scores at each 25% iso-time during the wall sit tasks. Iso-times were computed as described in previous research (Blanchfield, Hardy, & Marcora, 2014; Zering et al., 2017), where the start of each trial served as 0% iso-time and TTF score for the shortest of the two trials was used as 100% iso-time. This procedure allowed for relative within-person comparisons at 0%, 25%, 50%, 75% and 100% iso-time.

The study hypotheses relating to the potential moderating effect of attentional focus on the mental fatigue – performance relationship was evaluated using a simple moderation analysis. Model 1 in the PROCESS software macro (Hayes, 2017) was used to test the main and interaction effects. In the model, mental fatigue condition (coded 1, 2 for HMF and LMF, respectively) was the independent variable, change in performance (TTF) was the dependent variable, and attentional focus (coded 1, 2 for INT and EXT, respectively) was the moderator.

Analyses were computed using the raw performance change scores (Trial 2 - Trial 1) as well as residualized time to failure scores as the dependent variable. This was done as residualized change scores control for individual variability in TTF scores from Trial 1. Residualized scores also control for the negative correlation between Trial 1 scores and raw change scores, as participants that persist longer on Trial 1 tend to have larger trial-to-trial changes in time to failure (as was the case in these data; $r = -.671$, $p < .001$). Residualized change scores were computed using SPSS (version 25) by regressing the raw Trial 1 TTF scores on the raw Trial 2 TTF scores and saving the standardized residual values.

For analyses of RPE, iso-times were also used. RPE values reported in closest temporal proximity, to each iso-time were used. There were no cases where iso-times fell exactly at the midpoint between RPE ratings. The analyses evaluating the potential moderating effects of attentional focus on the mental fatigue – RPE relationship were conducting using a 2 (AF group) x 2 (MF group) x 2 (Time) X 5 (0%, 25%, 50%, 75%, 100% RPE iso-time) mixed ANOVA. RPE scores at the five iso-times were treated as a repeated measures dependent variable.

RESULTS

Data Screening

Data were screened for normality by using the Shapiro-Wilk test. Data that were positively skewed were transformed using square root transformation (weight, MVPA, baseline MF, and Trial 1 TTF). Analyses were conducted on the transformed and non-transformed data with similar results. For ease of interpretation, the results using the non-transformed data are presented. Four outliers were identified for time to failure scores based on box plots and 5% trimmed means, the same results were also found using 1.5 times the interquartile range (IQR). These cases were removed for the primary analyses, resulting in a final sample size of 74.

Preliminary Analyses

Descriptive statistics for anthropometrics, activity levels, and baseline measures of the sample are found in Table 1. Analyses were conducted to determine if there were differences between groups regarding height (p = .756), weight (p = .612), habitual moderate-vigorous physical activity (p = .444), baseline mental fatigue (p = .140), baseline attentional focus (p = .563), and initial time to failure (p = .177). No significant differences were found for any of these variables indicating effectiveness of the randomization procedures.

Analyses found no order effects on attentional focus scores throughout Trial 1, $F(1,72)$ = 1.869, p = .176, d = .321 , or for Trial 2, $F(1,72)$ = 1.441, p = .234, d = .282. This indicates that participants did not report different values for attentional focus regardless of whether they reported attentional focus or the RPE scale first. This trend remained true for both the first and second trial of the wall sit task.

Table 1

Descriptive Statistics and Between Group Comparisons

	HMF/INT *n* = 20 *M* (*SD*)	HMF/EXT *n* = 17 *M* (*SD*)	LMF/INT *n* = 18 *M* (*SD*)	LMF/EXT *n* = 19 *M* (*SD*)	*F*	*p*	η^2_p
Height	171.025 (10.632)	167.618 (10.535)	168.472 (9.836)	170.105 (11.027)	.396	.756	.017
Weight	149.350 (23.552)	142.971 (32.768)	139.667 (20.375)	139.737 (25.326)	.609	.612	.025
MVPA	450.250 (408.155)	364.710 (226.719)	500.560 (359.709)	353.420 (212.217)	.904	.444	.037
Baseline MF	35.500 (19.954)	27.240 (18.329)	24.000 (16.414)	24.160 (14.025)	1.886	.140	.075
Baseline AF	3.782 (1.935)	4.621 (2.038)	3.834 (1.810)	4.150 (2.050)	.688	.563	.029
Trial 1 TTF	128.445 (51.481)	112.074 (42.594)	149.706 (47.995)	129.663 (54.900)	1.688	.177	.067

Note. *M* = mean, *SD* = standard deviation, η^2_p = partial eta squared (effect size), MVPA = moderate – vigorous physical activity, MF = mental fatigue, AF = attentional focus, TTF = time to failure, INT = internal focus, EXT = external focus.

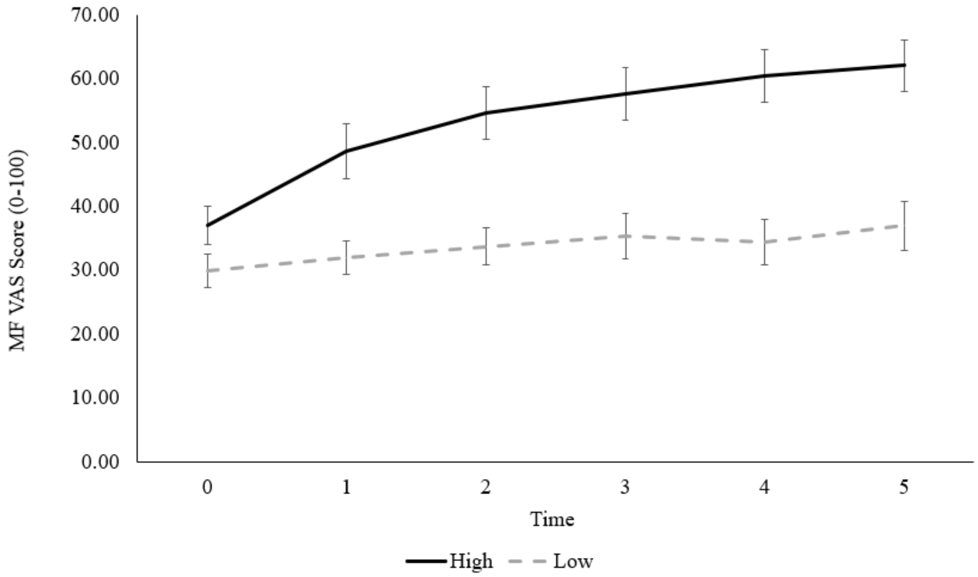
Manipulation Checks

Results of the 2 (group) X 6 (time) ANOVA showed a significant main effect of mental fatigue $F(1,68) = 14.838$, $p < .001$, $d = .873$, such that the HMF group reported higher levels of mental fatigue than the LMF group (Figure 4). These results indicate a successful manipulation of mental fatigue.

For the attentional focus manipulation, results of the 2 (group) X 5 (iso-time) ANOVA indicate a significant main effect of group on attentional focus scores $F\ (1,72) = 31.501$, $p < .001$, $d = .883$. Adjusting for individual's baseline attentional focus scores, the internal group reported a more internal focus and the external group reported a change towards a more external focus while performing the second wall sit trial (Figure 5). These results indicate a successful manipulation of attentional focus.

Figure 5

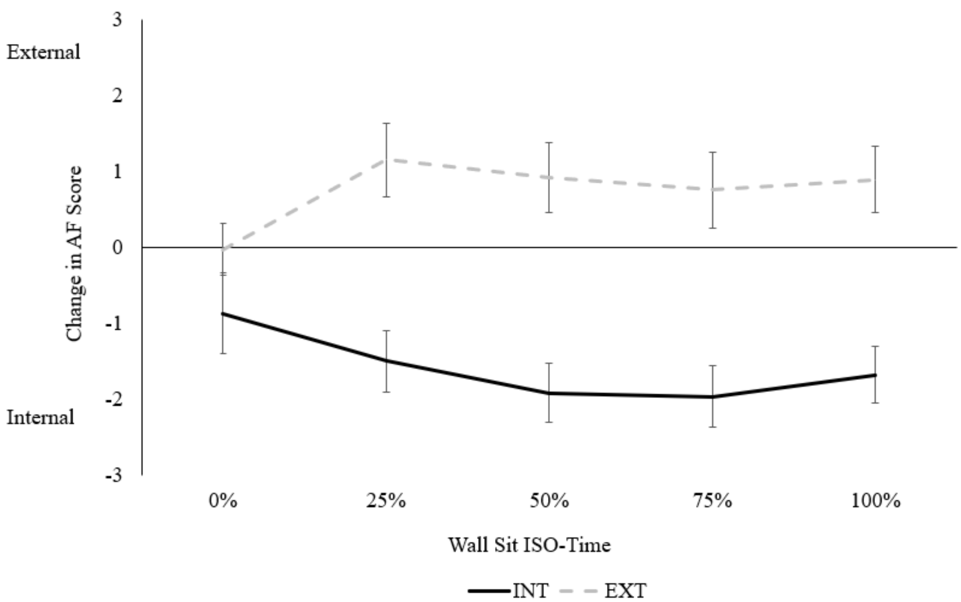
Change in Mental Fatigue during Cognitive Task by Group



Note. Bars indicate standard error (SE).

Figure 6

Change in Attentional Focus during First Wall sit by Condition



Note. Bars indicate standard error (SE).

Test of Hypotheses

Changes in wall sit performance (raw scores in seconds) from Trial 1 to Trial 2 are presented in Figure 6 and residualized change scores are presented in Figure 7. Visual examination of both figures shows similar magnitudes of change in three experimental groups (HMF/EXT, LMF/INT, and LMF/EXT) and a relatively larger amount of change in the hypothesized direction for the HMF/INT group.

Mental Fatigue Effects on Performance

Results of the analyses revealed no significant main effects of mental fatigue for either the raw change score $t(1,70) = .469$, $p = .640$, $b = 10.723$, SE = 22.838, or the residualized change score data $t(1,70) = 1.251$, $p = .215$, $b = 21.182$, SE = 16.930.

Attentional Focus Effects on Performance

The main effect of attentional focus was also non-significant for the residualized change scores $t(1,70) = 1.219$, $p = .227$, $b = 20.827$, SE = 17.085 and raw change scores $t(1,70) = 1.135$, $p = .260$, $b = 26.153$, SE = 23.047.

Combined Effects of Mental Fatigue and Attentional Focus

The test of the moderating effect of attentional focus on the hypothesized mental fatigue – performance relationship revealed a non-significant interaction effect for the raw change scores $t(1,70) = -.553$, $p = .581$, $b = -8.052$, SE = 14.563, and residualized change scores $t(1,70) = -.888$, $p = .377$, $b = -9.592$, SE = 10.796.

Although the moderation analyses did not detect a significant interaction, given the sample was underpowered due to premature cessation of data collection attributable to COVID-19, post hoc tests were completed to more comprehensively assess differences in performance

(TTF) between individual groups. Specifically, as a primary focus of the study was on the potential for mental fatigue to combine with internal attentional focus to create the greatest detrimental effect on performance, independent *t*-tests were computed to compare scores between the HMF/INT group and each of the other three groups. Results of those analyses with the residualized change scores showed a significant difference in the expected direction with the LMF/EXT group $t(37) = -1.905$, $p = .032$, $d = .610$ as well as trends in the expected direction with the HMF/EXT group $t(35) = -1.669$, $p = .052$, $d = .553$ and LMF/INT group $t(36) = -1.404$, $p = .084$, $d = .452$, with medium effect sizes. Conversely, with the raw change scores, a significant difference with a large effect size was found in the expected direction with the HMF/EXT group $t(35) = -1.955$, $p = .030$, $d = .645$. The remainder of the comparisons were not significant, with small effect sizes; LMF/INT $t(36) = -.233$, $p = .408$, $d = .076$ and LMF/EXT $t(37) = -1.247$, $p = .110$, $d = .400$. Together these results provide some support for hypothesis 1a.

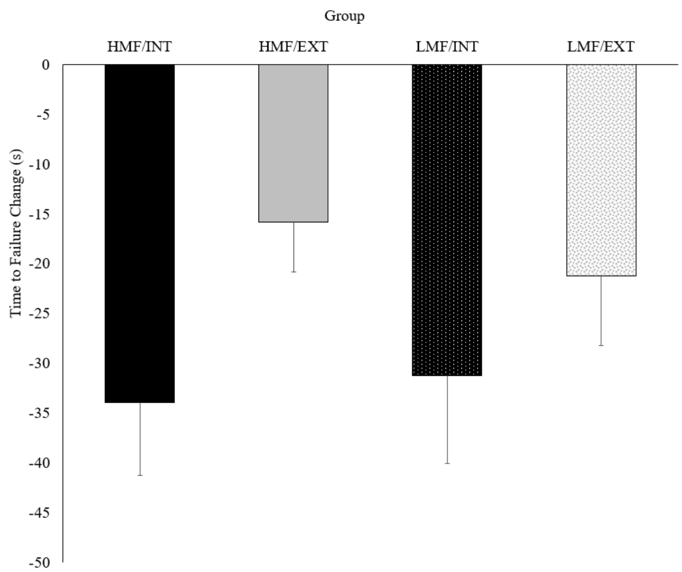
To assess the hypothesis that the LMF/EXT group would perform better than the other three groups, independent *t*-tests were used to compare the residualized change scores for performance for the LMF/EXT group with those from the HMF/EXT $t(34) = .291$, $p = .386$, $d = .098$ and LMF/INT groups $t(35) = .195$, $p = .424$, $d = .064$, with no significant effects. Comparisons computed using the raw change scores also revealed no effects for the HMF/EXT $t(34) = -.610$, $p = .273$, $d = .204$ or the LMF/INT groups $t(35) = .895$, $p = .188$, $d = -.294$. While there was a significant difference between the HMF/INT and LMF/EXT groups ($p = .032$, $d = .610$) with the residualized scores, as reported above, in concert this evidence does not support hypothesis 2a.

The previously presented data were also used to assess the hypothesis that the HMF/EXT and LMF/INT groups would have moderate performance. The independent *t*-tests comparing the

HMF/EXT and LMF/INT groups with the HMF/INT group, as well as with the LMF/EXT group were used. No effects were found for LMF/EXT compared with HMF/EXT (residualized p=.386, d=.098; raw p=.273, d=.204) or LMF/INT (residualized p=.424, d=.064; raw p=.188, d=-.294). While no effect was found for the HMF/INT compared with LMF/INT (residualized p=.084, d=.452; raw p=.408, d=.076), an effect was partially found when compared to HMF/EXT as the raw scores were significant while the residualized scores were not (residualized p=.052, d=.553; raw p=.030, d=.645). This potential effect, along with the significant difference between the HMF/INT and LMF/EXT groups residualized scores (p = .032, d = .610; raw p =.110, d =.400), as reported above, provides partial support to hypothesis 3a.

Figure 7

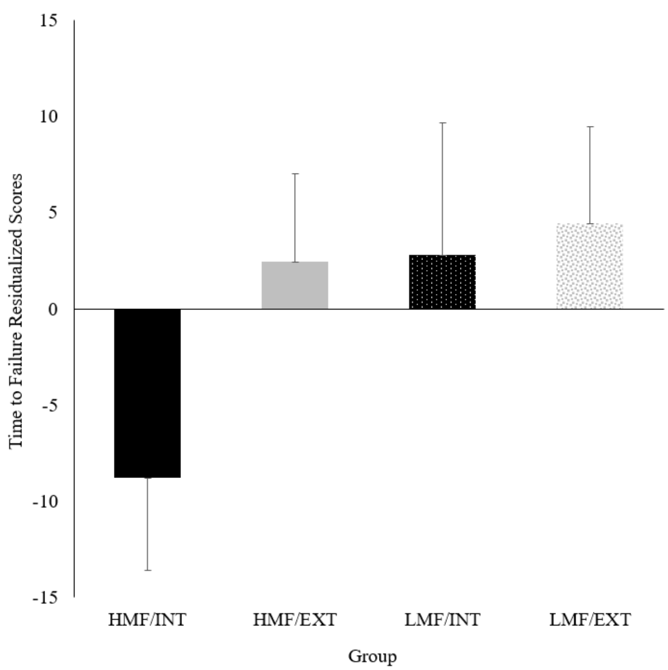
Raw Time to Failure Change Scores by Experimental Group



Note. Bars indicate standard error (SE).

Figure 8

Residualized Time to Failure Change Scores by Experimental Group



Note. Bars indicate standard error (SE).

RPE Analyses

Results of the 2 (AF) X 2 (MF) X 2 (Trial) X 5 (iso-time) mixed ANOVA found a main effect of Trial, $F(1,59) = 10.706$, $p = .002$, $d = .233$, and a main effect of iso-time, $F(1.74, 102.53) = 250.670$, $p < .001$ $\eta^2_p = .809$. There was also a significant Trial X MF interaction, $F(1,59) = 4.244$, $p = .044$, $\eta^2_p = .067$, no other main effects or interaction effects were found to be significant (see Table 2 for full statistical summary). With this analysis the assumption of sphericity was not met for iso-time as determined by Mauchly's test of sphericity (ps < .001), thus the main effect of iso-time is presented using corrected (Greenhouse-Geisser) values.

The significant Trial X MF interaction effect in the omnibus analyses indicated the mental fatigue groups did not experience RPE in both trials similarly. With this finding in mind and, given the sample size was smaller than planned, post-hoc analyses were computed to further probe this effect as well as potential Trial X Iso-time effects for each of the four groups independently. Results of the four, 2 (Trial) x 5 (Iso-time) ANOVAs showed significant main effects of iso-time for all four groups (HMF/INT: $F(2.103, 33.65) = 126.528$, $p < .001$, $\eta^2_p = .888$; HMF/EXT: $F(1.195,15.538) = 21.509$, $p < .001$, $\eta^2_p = .623$; LMF/INT: $F(1.923,30.775) = 116.145$, $p < .001$, $\eta^2_p = .879$; LMF/EXT: $F(1.5,20.993) = 94.775$, $p < .001$, $\eta^2_p = .871$), indicating RPE increased throughout the trial for all groups. There was also a main effect of Trial for the HMF/INT group, $F(1,16) = 8.70$, $p = .009$, $d = .592$, such that the RPE scores were higher during the second trial compared to the first trial in that group (Figure 8); however the Trial X Iso-time interaction was not significant $F(2.077,33.238) = .627$, $p = .546$, $\eta^2_p = .038$. The main effects for Trial and the Trial X Iso-time interactions were not significant in the other three groups. The Mauchly's test of sphericity was also not met for the main effects of Iso-time and the Trial X Iso-time data reported here (*p*s <.001), thus these data are also presented as Greenhouse-Geisser corrected values.

Table 2

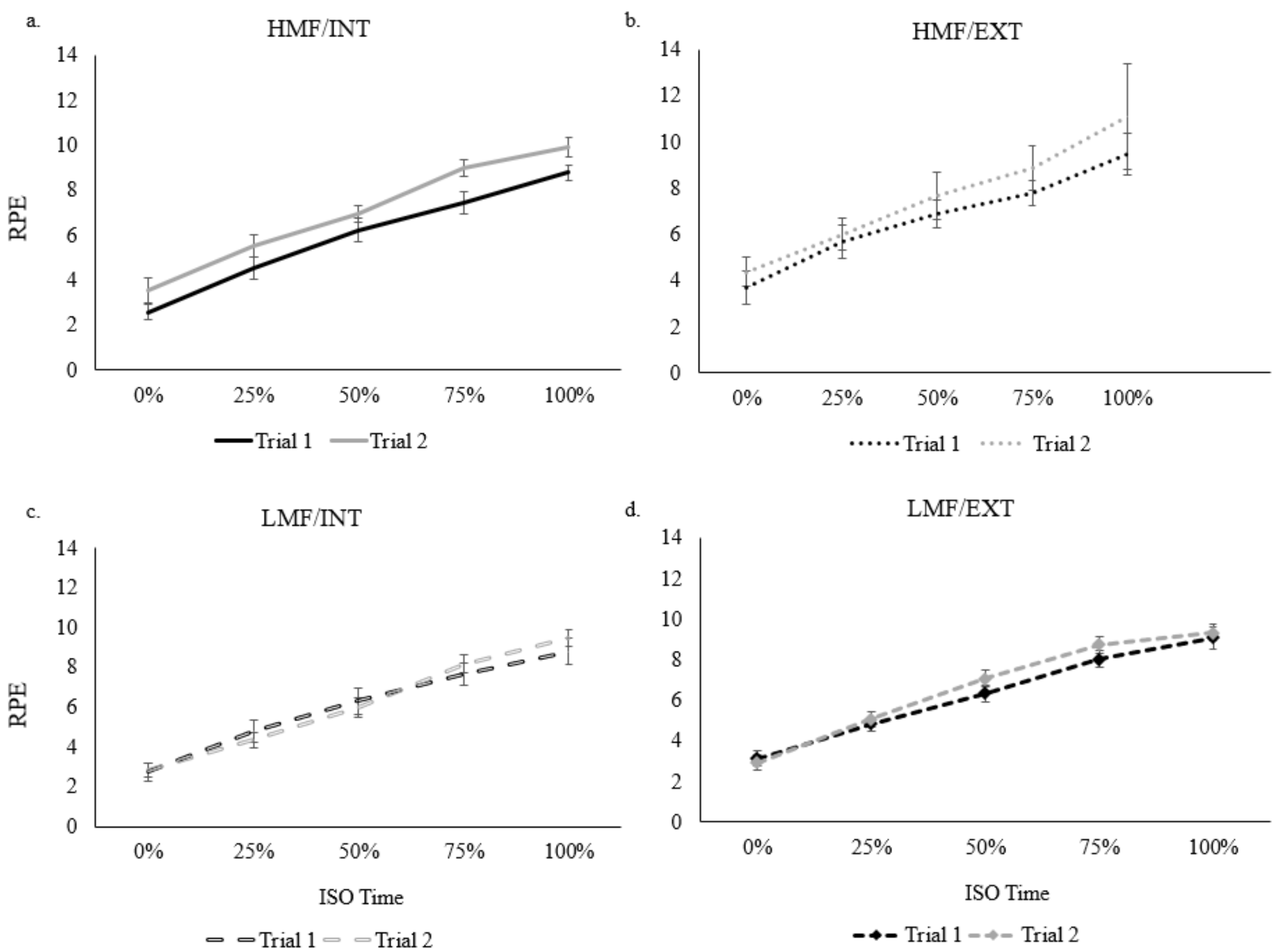
Statisical summary of 2 x 2 x 2 x 5 ANOVA on RPE

	DF	*Error DF*	*F*	*p*	η^2_p
Trial	1	59	10.706	.002*	.154
Iso-time	1.738	102.529	250.67	<.001*	.809
MF	1	59	1.161	.285	.019
AF	1	59	1.152	.288	.019
Trial * MF	1	59	4.244	.044*	.067
Trial * Iso-time	1.792	105.718	3.155	.126	.035
Trial * AF	1	59	.006	.939	.000
Iso-time * MF	1.738	102.529	.529	.514	.009
Iso-time * AF	1.738	102.529	.182	.803	.003
MF * AF	1	59	.126	.724	.002
Iso-time * AF * MF	1.738	102.529	.629	.514	.011
Trial * Iso-time * MF	1.792	105.718	.117	.869	.002
Trial * Iso-time * AF	1.792	105.718	.600	.533	.010
Trial * MF * AF	1	59	.329	.568	.006
Trial * Iso-time * MF * AF	1.792	105.718	1.132	.322	.019

Note. η^2_p = partial eta squared (effect size), MF = mental fatigue, AF = attentional focus, * = significant effect at >.05.

Figure 9

RPE Scores during Wall Sit Tasks by Trial



Note. Separate graphs for each of the four groups; a. High mental fatigue and internal, b. High mental fatigue and external, c. Low mental fatigue and internal, and d. Low mental fatigue and external. Bars indicating standard error.

DISCUSSION

The purpose of the present study was to investigate the effects of mental fatigue on endurance performance in the context of different attentional focus instructions. Additionally, this study aimed to investigate the effects of mental fatigue and attentional focus on RPE during exhaustive exercise to failure. Overall, the omnibus statistical analyses did not support the hypotheses; however, in supplemental analyses, partial support was found for a moderating effect of attentional focus on the mental fatigue – performance relationship. Specifically, it was found that the group with high mental fatigue and internal focus had significantly worse performance on the endurance wall sit task compared to the other three groups with medium effect sizes. Some evidence was also found for a moderating effect of attentional focus on the mental fatigue – RPE relationship. In particular, the high mental fatigue and internal attention group reported significantly higher exertion during the second trial compared to the first, while all other groups reported no differences in exertion between trials.

Moderating effect of AF on MF – performance relationship

The first hypothesis for the present study was that high mental fatigue and internal attentional focus would lead to the shortest time to failure. While there was no significant interaction in the 2 (mental fatigue group) X 2 (attentional focus group) analyses for the moderating effect of attentional focus on the mental fatigue – performance relationship, the hypothesis was partially support by the independent *t*-test results. Given uncontrollable circumstances halted data collection prior to achieving an optimal sample size to test the a-priori hypotheses, it seemed justified to contrast group scores with one another and to treat those underpowered hypothesis tests as independent contrasts. Under those liberal conditions, and when assessing the residualized scores, the HMF/INT group was found to have experienced a much larger decrease in performance relative to their baseline trial performance, compared to the HMF/EXT, LMF/INT, and LMF/EXT groups. The difference between the HMF/INT and LMF/EXT reached significance (although not for the raw scores) with a medium-to-large effect size, while the difference between HMF/INT and HMF/EXT approached significance with medium effect sizes. The final comparison (HMF/INT versus LMF/INT) did not reach significance, however the effect size was small-to-medium, thus similar to the other three comparisons. This finding suggests the detrimental effects of high mental fatigue combined with the internal focus of attention exacerbate performance decrements.

These findings support previous research on mental fatigue (Brown et al., 2020) and attentional focus (Hill et al., 2017) in terms of performance decrements experienced under both high mental fatigue and internally-focused attention and show, for the first time, that both in combination may be particularly problematic. Although this study did not set out to investigate possible mechanisms that might underlie the negative effects of mental fatigue and internal focus, both literatures point to muscle fatigue as a potential answer. With regards to mental fatigue, research suggesting a mechanism for its effect on endurance performance has been centered around the amount of muscle activation that is present during a physical task. Such research has found increased muscle activation (Bray, Martin Ginis, Hicks, & Woodgate, 2008; Graham, Sonne, & Bray, 2014), through measures of surface electromyography, for mentally fatigued groups in comparison to non-mentally fatigued groups. Similarly, within the attentional focus research it has been suggested that the shift towards an internal focus as duration or intensity of exercise increases may be associated with increasingly salient signals within the body (Ekkekakis, 2003). Indeed, it has been found that internal attentional instructions are accompanied by increased muscle activation compared to external attentional instructions (Lohse & Sherwood, 2012; Marchant et al., 2009).

The second hypothesis was that a combination of low mental fatigue and external attentional focus would lead to the longest time to failure. This hypothesis was not supported by the present results, as the LMF/EXT group was not found to perform significantly better than either the HMF/INT or the LMF/INT groups. Although there was a significant difference between the LMF/EXT group and the HMF/INT group, this effect relates more to the latter group performing worse, rather than the former group performing better. From the standpoint of attentional focus, low mental fatigue in combination with internal focus not differing from low mental fatigue in combination with external focus is in contrast to the literature showing an advantage of external focus instructions as these two conditions equate to a simple comparison of the two attentional foci. A potential explanation for the null results could be confounding effects of the cognitive task, separate from the mental fatigue effects. For example, it has been suggested that boredom may present similar negative effects as mental fatigue (Milyavskaya, Inzlicht, Johson, & Larson, 2019); however, this affective response to the task may not be assessed through the measures used in mental fatigue research. As such, the low mental fatigue condition may have induced unexpected cognitive responses that confounded the well-established advantage of external over internal attentional focus.

The third hypothesis proposing external focus would offset the negative effects of mental fatigue and internal focus would combine with low mental fatigue for moderate performance outcomes, was partially supported. While the HMF/EXT and LMF/INT groups did perform better than the HMF/INT group, as discussed previously, they did not perform significantly worse than the LMF/EXT group. As such, the lack of significant findings may be predominantly driven by the lack of effect between internal and external attentional focus. That being said, there is some previous research that has also failed to find a significant difference between internal and external attentional instructions. For example, in a study conducted by McNevin et al. (2003), no significant differences in condition were found throughout the first study visit while completing the physical task (during skill acquisition/practice; $p > .05$). Some investigators also suggest that novices for a task may not experience the same benefit of external instructions due to the task not being automated for them yet (Neumann, Walsh, Moffit & Hannan, 2020).

In contrast, from the mental fatigue perspective, the fact that the HMF/EXT group outperformed the HMF/INT group is theoretically and practically relevant as it illustrates how maintaining a focus on what one is doing vs. how one is feeling may be an effective way to combat feelings of fatigue that might otherwise interfere with performance. Other such moderators have been investigated in previous research, also looking at potential means to overcome the negative effects of mental fatigue on performance. For example, Brown and Bray (2017) investigated the effect of a monetary incentive on the mental fatigue – physical endurance performance relationship. Results indicated an effect of the incentive on performance outcomes, as those in the high mental fatigue group with incentive performed significantly better than those in the high mental fatigue group without incentive (p =.01, $\eta^2_p = .17$) but not significantly different form the low mental fatigue and no incentive group (p =.52, $\eta^2_p = .01$). This research suggests that providing a monetary incentive in conditions of mental fatigue may mitigate the negative effects of mental fatigue on performance. A similar pattern of results is also found when considering social motivation (drive to be accepted and get along with others) as a moderator for the mental fatigue – performance relationship. Indeed, Seeley and Gardner (2003) had participants complete a hand-grip task to volitional failure either after an ego-depleting task or after a control task. It was found that those with high social motivation performed equally well on the hand-grip task regardless of their condition. However, those with low social motivation performed significantly worse when mentally fatigue compared to when not mentally fatigued ($p < .05$). A third example of a potential moderator is self – monitoring, such as using a heart rate monitor during aerobic exercise as investigated by Brown and Bray (2019). In this study participants completed self-paced cycling exercise following each of the four conditions; mental fatigue with monitoring, mental fatigue without monitoring, no mental fatigue with monitoring, and no mental fatigue without monitoring. It was found that the mental fatigue with no monitoring condition performed significantly less total work than each of the other three conditions (ps $< .004$). However, the mental fatigue group with monitoring did not significantly differ from the low mental fatigue conditions (ps $> .99$), suggesting the performance can be returned to non – mental fatigued levels with the inclusion of monitoring.

Together these data suggest there are a variety of potential moderating factors to help mitigate the negative effect of mental fatigue on physical performance. The prospect of having means to overcome mental fatigue has some important implications in the fields of sport and therapy. With mental fatigue being such a salient barrier to engaging in physical activity and being able to perform optimally, strategies to overcome feelings of fatigue are in high demand. Such strategies may allow for improved outcomes following an injury as patients can adhere to their exercises or provide a competitive edge to athletes who may be able to train and compete more effectively.

RPE

Similar to the hypothesized performance outcomes, it was hypothesized that RPE would be greatest in the HMF/INT group, lowest in the LMF/EXT group and moderate in the

HMF/EXT and LMF/INT groups. The first of these hypotheses was supported as the HMF/INT group had significantly higher RPE during the second trial compared to the first trial. As seen in Figure 7, for the HMF/INT group, RPE ratings start out higher during the second trial and remain higher at each time point throughout the endurance wall sit. This is the hypothesized trend for the exertion experienced in the context of high, relative to low, mental fatigue. Indeed, the same trend was seen by Marcora et al. (2009) where RPE was higher during the mental fatigue condition at every time point of the physical task compared to the control condition. These findings align with Brehm's Motivational Intensity Theory (Brehm & Self, 1989), suggesting that potential and actual motivation for the given task underlie the effort one exerts for the task. As such, reduced motivation for a physical task due to mental fatigue would require greater amounts of effort in an attempt to perform as long as possible, but ultimately leads to earlier task disengagement as the investment of greater effort is not deemed worthwhile to the performer.

In the context of attentional focus, the increased RPE in the HMF/INT group also aligns with previous literature. As discussed previously, several studies have found increased RPE for a physical task during conditions of internal attentional focus compared to external attentional focus (Hill et al., 2017; Lohse & Sherwood, 2011). These findings support the parallel processing model (Leventhal & Everhart, 1979), such that there is a relationship between the intensity of a task and salience of internal bodily cues. As such, when focus is directed toward the body and its sensations, this stimulus becomes the most salient and perceptions of effort increase.

Taken together, high mental fatigue and internal instructions would theoretically contribute independently to increases in RPE. The high mental fatigue condition starts participants off at increased levels of RPE, potentially initiating more internal thoughts from the onset of the exercise. When internal attentional instructions are added, further attention is drawn to the negative sensations in the body further exacerbating RPE.

Strengths and Limitations

There are several strengths and weakness to consider with this study when interpreting the results. Firstly, in addressing the methodological issues discussed by Wolf (2013), the attentional focus instructions were carefully constructed. The instructions used in the study were based on previous research, recommendations from Wulf's review, and direct feedback received from Dr. Wulf via personal correspondence. Therefore, the attentional focus instruction methodology should be seen as a strength insofar as it should not suffer from methodological limitations that have been noted in prior literature.

Secondly, while no previous literature has combined the investigation of mental fatigue and attentional focus manipulations, each of these components were based on previous literature. Methodological considerations for studying both mental fatigue and attentional focus were constructed and closely resemble previous literature (Boat & Taylor, 2017; Harris & Bray, 2019; Lohse & Sherwood, 2011).

Another methodological strength relates to the fact that the primary researcher was blinded to the participants' mental fatigue and attentional focus condition until after data collection was completed. This was seen as a strength as it reduces conscious or unconscious bias in the experimenter's interactions with participants which can compromise the internal validity of experiments where subjective decisions such as determining when a participant has reached failure in a physical task.

Among the limitations to consider with the present study is the bivariate representation of attentional focus for the participants. As previously discussed, there are several ways to categorize attentional focus and there is disagreement in the literature on how best to do this. While the internal – external definitions seem appropriate when providing instructions for a physical task, it does not encompass all attentional thoughts a participant may have. For example, as it relates to improving performance on a task, internal and external instructions must be relevant to the task at hand. However, while completing a task, particularly a physical endurance task, one's mind may wander, and task irrelevant thoughts are common (Stevinson & Biddle, 1998). Indeed, distracting thoughts are commonly used strategies for those that are not elite athletes during endurance tasks to keep one's mind off the physical sensations (Brewer & Buman, 2006). That being said, the specific definitions for internal and external foci will not encompass all the thoughts a participant may need to report. As a result, these distracting thoughts would be categorized under a broader external definition, however instructional manipulations remained within the strict definition of internal and external.

A second limitation to be considered is the potential effect of asking participants to intermittently report both RPE and attentional focus throughout the physical task. As suggested by Hutchinson and Tenenbaum (2007), having participants rate RPE inherently requires they devote attention to their psychophysiological state and, therefore, focus more internally than they might otherwise. This drawing of attention to bodily thoughts may then change the speed at which shifting towards internal attention generally occurs, underestimating the influence of external focus that might have been observed if RPE had not been reported. To address this issue, the order of reporting RPE and attentional focus was counterbalanced between subjects, such that half of the participants reported RPE first and the other half reported attentional focus first to control for order effects. While no order effects were observed, the fact remains that both perceptions were rated in close temporal proximity throughout the endurance task, which may have inflated internal focus of attention and limited the effect of external focus manipulation.

An additional limitation to note is that attentionally focused instructions were only provided to the participants prior to their physical task trial whereas some previous research has provided attentional focus prompts throughout performance of the physical task (Lohse & Sherwood, 2011; Neumann & Brown, 2013). However, because the researcher was blind to participants' condition, only generic: "remember to follow the attentional focus instructions you were given" reminders rather than specific attentional focus reminders could be provided. While this protocol may have limited the saliency of the attentional focus instructions throughout the endurance task, it was viewed as a worthwhile trade-off and manipulation checks still verified the internal and external instruction sets created statistically distinct groups.

Future Directions

Given the aforementioned limitations, future research should look to improve upon the present study and take further steps forward in this area of research. Primarily, collecting data from a larger sample size to provide more power to detect complex interactions is essential. With the present difficulties in conducting meta-analyses for attentional focus research an overall effect size is challenging to determine. Therefore, studying larger samples would be beneficial in terms of more accurately determining effect sizes because a small sample may not be representative of the population and can lead to low statistical power. For a study with low power it can a) be more challenging to observe a significant effect when one is present, or b) when an effect is seen, the magnitude of the effect can be exaggerated (Button et al., 2013).

The first limitation mentioned earlier is one direct avenue for further research, as little research has included assessing participants' experience of external and internal foci. Even those that have assessed this measure, have done so in various ways; some using a bipolar scale as in the present study, some using thinking out loud strategies (Hutchinson & Tenenbaum, 2007), and others using post study questionnaires (Emanuel et al., 2008; Hill et al., 2017). Thus, further research on a comprehensive and reliable measure for assessing attentional focus strategies would be beneficial.

Thirdly, to increase generalizability, this study could be extended to other well investigate endurance tasks and skills. This could include running, cycling, balance tasks, and golf shot accuracy tasks. Diversifying our understanding of the relationships between attentional focus, mental fatigue, perceived exertion, and performance will improve ecological validity and eventually aid in the development of interventions that may help optimize performance.

Practical Applications

As alluded to earlier, there may be important practical applications of this line of research for practitioners such as therapists, sport coaches, and strength and conditioning coaches. Primarily, the importance of how professionals communicate with clients and athletes, as the words used may influence how effortful a task feels and the performance outcome. Thus, understanding the circumstances surrounding an individual, such as feelings of mental fatigue, and being able to mitigate the impact on their performance outcome is an important job for a coach or therapist. While understanding individual differences is necessary, critically assessing the best way to instruct an athlete can lead to superior training and performance outcomes. Similarly, while practitioners need to be aware of the risks to training under stress or mental fatigue, this research helps us understand that mental fatigue is a barrier to overcome, not one to be avoided.

With the extensive applications the present area of research has in clinical and sport performance settings, further investigating the implementation of attentional focus instructions and similar coping strategies is warranted. While the areas of mental fatigue and attentional strategies for performance continue to grow, their effective application in practical settings remains unclear. As is evident from the methodological issues outlined by Wulf (2013), the manner in which instructions are framed and communicated by practitioners working with patients or performers is of utmost importance. Thus, an appropriate understanding and training in these intervention methods is required for practitioners to effectively use attentional focus manipulations as performance enhancing strategies.

Conclusion

This study is the first to our knowledge to investigate moderating effects of attentional focus instructions on mental fatigue, performance, and RPE. It was found that a combination of high mental fatigue and an internal focus of attention may exacerbate performance decrements, particularly in comparison to low mental fatigue and external focus. While the present study was under-powered to test the hypotheses as originally planned, it provides preliminary evidence of a potential interaction between mental fatigue and attentional focus strategies on muscular endurance performance and perceived exertion.

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Appendix A. Demographics and footedness

Participant ID:

Age: ____ years

Sex: Male Female Other:_________ Prefer not to answer

Dominant Leg	
Height	
Weight	

Appendix B. International Physical Activity Questionnaire (Booth et al., 2003).

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

Appendix C. Ratings of Perceived Exertion (Borg, 1998).

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

Appendix D. Ratings of Perceived Mental Exertion (Borg, 1998).

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

Appendix E. Subjective Mental Fatigue Visual Analogue Scale (Wewers & Lowre, 1990).

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

Appendix F. Attentional Focus Scale

0	100% internal, 0% external
1	
2	
3	
4	
5	50% internal, 50% external
6	
7	
8	
9	
10	0% internal, 100% external

Appendix G. Study script explaining attentional focus and the difference between internal and external foci.

Next, we will look at attentional focus and the scale you will be using to measure it.

Internal thoughts are thoughts about your body and how your body reacts to exhaustion. For instance, on which body parts you focus your attention, thoughts about your bodily sensations like your heartbeat, sweating, heavy breathing, aching muscles, pain etc. This may also include thoughts about how your body moves for example focusing on your arm swing while running.

Can you provide me with an example of an internal thought you have had recently?

External thoughts are all the thoughts not related to your bodily sensations. This can include thoughts about how you are performing the task like how long you have been doing the task or thoughts that distract your attention away from your body symptoms. This may also include thoughts about objects around you like noticing other people in a gym when you are doing an exercise.

Can you provide me with an example of an external thought you have had recently?

Throughout the session you will be asked to indicate the relationship between your internal and external thoughts, using this 0-10 scale. Where a rating of 0 would indicate completely internal, so all of your thoughts were strongly internal and a rating of 10 would be completely external, so all of your thoughts were strongly external.

Now I am going to read you a few statements and have you indicate where these statements are on the scale for you.

1. Imagine you are walking home carrying a heavy back pack, the thought that goes through your mind is “Wow my backpack is heavy, it is starting hurt my back”
2. Now imagine you are going for a bike ride on the road, the thought that goes through your mind is “I need to bike in a straight line to the stop light ahead”

During the wall sit task you will be asked to give a rating several times and that rating should only be for the period of time since the last rating you gave. It could change, or it could stay the same, simply rate how your thoughts were during that time. (*Show the scale to the participant*). Please note, that you do not have to be fully aware of all your thoughts, an approximation is totally fine. Do you understand these instructions?