

An Examination of Short-Term Mental Conditioning or Mindfulness Training on Physiological, Psychological, and Performance Outcomes during a Cycling Task

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Abstract Mental strength training (MS) and mindfulness (MD) training can increase performance. This study tested the hypothesis that one week of MS or MD would increase performance as well as begin to elucidate the physiological underpinnings that allow for increased performance. In a randomized between groups pre-test – post-test design, 42 participants visited the lab on 4 separate days. A $\dot{V}O_{2peak}$ with ventilatory threshold (VT) was performed on day 1. The subsequent visits consisted of time trials to exhaustion (TTE) performed at 10% above VT. Between visit 3 and 4, MS (n=16) and MD (n=13) groups watched a video or listened to an audio recording for 10-15 minutes each day for one week while the control group (CON) (n=13) did no training. Heart rate (HR), rate of perceived exertion (RPE), VAS scores for pain and fatigue, and EMG were recorded during the time trials. Peripheral fatigue was assessed via changes in pre- vs. post-exercise quadriceps force in response to supramaximal magnetic femoral nerve stimulation ($\Delta Q_{tw,pot}$). CD-Risc, GRIT-S, and the 5-factor mindfulness surveys were also completed before study day 3 and 4. TTE increased significantly in the MS ($8.7 \pm 13.6\%$) and MD ($4.6 \pm 5.5\%$) groups while CON did not significantly change ($-4.9 \pm 11.6\%$). There were no changes in peak HR or RPE. Peak fatigue was increased following MS and peak fatigue and pain were increased following MD. EMG was significantly decreased following MS. One week of mental training, whether MS which included grit and resilience training or for MD, has the ability to improve TTE performance. However, current psychological surveys are not sensitive enough to detect changes in mental performance, perhaps because they are not sport/exercise specific. Further, MS may improve performance by reducing EMG input and shifting to a more external focus, allowing a decreased activation of muscle and subsequent reduced fatigue rate.

Keywords Mental strength, Mindfulness, Fatigue, Behavioral Strategies, Performance

1. Introduction

Endurance performance relies heavily on the ability to sustain aerobic exercise over time to the point of exhaustion, which is traditionally thought to represent the culmination of progressive muscle fatigue [1-4]. However, the psychobiological model for exercise tolerance has recently been suggested as a framework for endurance exercise which relies on the cessation of exercise at a pre-disposed rating of perceived exertion [5,6]. The advantage of the psychobiological model is that it gives attention to perceptual and motivational factors affecting exercise

outcomes in addition to the physiological factors affecting exercise [6,7].

Psychological, or mental, training, whether using psychological skills training [8,9], resilience training [10,11], motivational arousal training [12], self-talk training [13,14] or mental toughness [15] and grit training [16,17] have been suggested to improve performance. However, there has been little focus on the underlying physiological underpinnings that may occur concurrently with, or due, to psychological training.

Three outcome variables appear to exist within systematic mental training: mental toughness, grit, and resilience. Mental toughness is defined as having the ability to believe in oneself while having an insatiable desire to succeed, while also bouncing back from performance setbacks with increased determination to succeed [18,19]. Grit, coined by Duckworth and colleagues [20], is largely a measure of how much passion and perseverance one has to achieve a goal or objective. Finally, resilience can be

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Published online at <http://journal.sapub.org/sports>

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defined as the use of mental processes to protect against a potential negative effect of a stressor during a performance [21,22]. While mental toughness, grit, and resilience are unique constructs, these constructs share characteristics that individuals will generally term as “mental toughness,” “mental strength,” or “mental fortitude.” Indeed, the ability to sustain self-belief, remain passionate and goal oriented, and the ability to withstand stressors and adversity are all aspects of “tough” behavior. Increased mental toughness has been associated with faster running times from adolescent cross country runners [23] and better performance in soldiers [24]. Training grit, along with resilience, has been predictive of increased consistency and performance in sport [17], possibly through coactivation of both the sympathetic and parasympathetic nervous systems [16], potentially conveying a more efficient cardiovascular profile during exercise [25].

Mindfulness, unlike traditional sport psychology interventions such as the cognitive behavioral frameworks of mental toughness which aim to control internal mental factors through minimizing negative internal states [26], is a framework that emphasizes letting go of control and developing skills to be non-judgmentally, present-moment focused [10,27-29]. By being present-moment focused, individuals ensure distractions from past or future events are briefly suspended, potentially enhancing concentration on the task at hand leading to increased performance [11]. Mindfulness has been associated with cognitive inhibition to reactive modes of mind that may heighten stress or emotional distress [30]. Training mindfulness has been associated with increased golf performance and improvements in mile times in runners though outside variables such as training status or competition environment were not controlled [31].

While both mental strength and mindfulness trainings appear to increase performance, the physiological underpinnings that underlie the improved performance following either mental strength or mindfulness training have not been studied. One way to explore the physiological changes related to improved performance related to mental strength or mindfulness training is to examine a common task, such as a time trial to exhaustion (TTE), in a controlled laboratory study. In order for performance to increase, there should be reciprocal changes in a physiological variable such as peripheral fatigue as measured through a potentiated twitch ($Q_{tw,pot}$), heart rate during the trial, or central command as measured by rectus femoris EMG. Therefore, the purpose of this study was to examine whether short term (one week) mental strength (MS) or mindfulness (MIND) training would increase performance during a TTE more than a control group with no mental training. Further, the purpose of this study was to begin to elucidate some of the physiological mechanisms by which MS or MIND training may improve performance. It was hypothesized that both MS and MIND training would improve TTE more than CON and that RPE would be decreased during the TTE while peripheral leg fatigue

and/or pain would be increased following one week of MS or MIND training.

2. Methods

2.1. Participant Characteristics

All experimental procedures in this investigation were reviewed and approved by the Westmont College Institutional Review Board (IRB) prior to the beginning of this study. The protocols and procedures were explained, and all participants provided written informed consent prior to testing. Participants ($N = 42$) consisted of recreationally trained individuals recruited from Westmont College by word of mouth (males = 31, females = 11; mean \pm SD; age 20.7 ± 1.8 years, body weight 75.8 ± 11.3 kg, height 179.3 ± 6.3 cm, peak oxygen consumption (VO_{2peak}) 49.8 ± 11.0 mL/kg/min). Eighteen additional participants began the study, but withdrew before completion and were excluded from the analysis. Participants were excluded if any of the following applied: current acute musculoskeletal injury; medications known to interfere with the sympathetic nervous system; unwillingness to comply with training interruptions mandated by the protocol; any uncontrolled chronic health condition.

2.2. Protocol Overview and Exercise Protocols

The study consisted of a controlled, pre-test – post-test design in which participants visited the laboratory on four separate occasions and were randomized into three independent groups using a random number generator (Mental strength $n = 16$; 11 males, mindfulness $n = 13$; 8 males, control $n = 13$; 12 males) during the third visit. All exercise tests were conducted in the same location on the same electromagnetically braked cycle ergometer (Excalibur Sport, Lode, Groningen, the Netherlands), with the saddle adjusted to suit the preference of each participant and maintained for each visit. Each time trial was performed at the same time of day to avoid circadian rhythm differences between trials. Participants were asked to avoid caffeine before each exercise trial and all participants refrained from exercise for 24 hours before each trial. None of the participants were trained cyclists to account for any variance cycling experience would add to time to exhaustion.

2.2.1. GXT Protocol

During visit one, each participant completed an incremental cycling test beginning at 100W (50W for females) with resistance increasing 5W every 15 seconds until volitional exhaustion to establish VO_{2peak} and to determine ventilatory threshold. Participants pedaled at their preferred pedaling rate, and the test was terminated when the cadence dropped below 70rpm for more than five seconds despite strong verbal encouragement. Metabolic data was collected using open circuit calorimetry (Vista MX, Vacumed, Ventura, CA) Peak oxygen consumption (VO_{2peak}) was recorded as the highest VO_2 recorded in a 15 second

period. Subsequently, the ventilatory equivalent method, or power output corresponding to a systematic increase in the ventilatory equivalent of oxygen (VE/VO_2) without a concomitant increase in the ventilatory equivalent of carbon dioxide (VE/VCO_2), was used to determine the power output at ventilatory threshold [32].

2.2.2. Time to Exhaustion (TTE) Protocol

The subsequent three visits consisted of a time to exhaustion test at a wattage of 10% above the determined ventilatory threshold. The time to exhaustion test began with a 5-minute warm-up at 100W (75W for women). Following the warm-up, participants were asked to cease pedaling while the power was set on the ergometer. Participants were encouraged to stand for the first 3-5 seconds to the TTE to start the flywheel spinning but were required to stay seated for the remainder of the trial. Time to exhaustion was defined as the time from the onset of pedaling until the point at which cadence had fallen below 70rpm for more than five seconds. If cadence fell below 70rpm, researchers tapped on the cycle ergometer's tachometer to alert the participant to increase cadence. No verbal encouragement was provided at any point during the time to exhaustion test so as to eliminate any external encouragement. Heart rate was recorded every minute throughout the time to exhaustion test using a wireless chest strap (Polar Electro Inc., Bethpage, New York, USA).

Visits two, three, and four were separated by a minimum of 48 hours with visit two being a familiarization session. Visit three and four were separated by seven days during which the mental strength (MS) and mindfulness (MIND) interventions took place. MS and MIND interventions consisted of watching an initial training video immediately following the exercise test on visit 3. During the subsequent week, participants in the MS group were asked to watch one of three videos each day for the following week (ending with watch all three videos twice during the week) while the MIND group was asked to listen to one of two guided mindfulness audio files each night for the subsequent six nights. Prior to visit 3 and visit 4, participants in each group were instructed to complete the CD-RISC 10, GRIT-S, and the 5-Factor Mindfulness questionnaires.

2.2.3. Mental Training Interventions

Two mental training interventions were designed to examine the primary research question regarding the physiological underpinnings of traditional mental skills training and mindfulness training. For each intervention, a Certified Mental Performance Consultant © (CMPC) who had expertise in mental skills and mindfulness interventions, designed the mental strength and mindfulness protocols. The mental strength protocol consisted of three videos with exercises for participants to use to enhance their performances and the mindfulness intervention consisted of an introductory video on mindfulness with two audio recordings for participants to practice. Both the mental

strength and mindfulness protocols were video recorded to ensure consistent delivery to participants and to ensure that the time of the interventions were similar in length. Details on specifics aspects of the interventions are in the following subsections.

The mental strength intervention consisted of four videos: an introduction to mental skills training and breathing techniques to reduce stress and anxiety (video time 9 minutes and 43 seconds), a "controlling the controllables" lesson to focus more on controllable aspects of performance to reduce stress (video time 8 minutes), self-talk and confidence intervention to combat negative thinking and doubt (video time 11 minutes and 25 seconds), and finally an imagery intervention to mentally prepare for performances and challenging moments (video time 4 minutes and 40 seconds). The goal of the mental strength intervention was to equip participants with breathing techniques, thinking strategies, and preparation strategies to endure fatigue and enhance endurance. Each of the videos, other than the introduction, were watched two times during the week. Total time of the mental strength intervention was 57 minutes and 53 seconds.

The mindfulness intervention consisted of an introductory video defining mindfulness, how to use it, why it is useful, and introduced the participants to the two audio files they would listen to throughout the intervention (video time 5 minutes). The two specific mindfulness practices given to the participants were a basic mindful sitting with breath awareness and a basic mindful body scan, two foundational and beginning mindfulness practices from Jon Kabat-Zinn's Mindfulness Based Stress Reduction (MBSR) protocol [27]. These practices were chosen because they are foundational to mindfulness practice and easy to follow and use. Additionally, when performing to fatigue, having an awareness of your breath and body are important if one is trying to enhance their ability to endure fatigue. Each mindfulness practice was 15 minutes in length and recorded as an MP3 file by the CMPC, which is a suggested minimum amount of time to practice mindfulness [33]. Each of the two mindfulness practices were listened to a total of three times. Total time of the mindfulness intervention was approximately 95 minutes.

2.2.4. Psychological Measures

The 10-item Connor Davidson Resilience Scale (CD-RISC; [34,35]) was employed to measure resilient characteristics in the participants. The 10-item CD-RISC was used in place of the original 25-item scale because the 10-item scale has stronger psychometric properties in sport and performance contexts [36,37]. Participants were directed to indicate how much they agreed with statements as they apply to their lives. Each item was responded to on a five-point Likert-Type Scale (0- *not at all true* to 4- *true nearly all the time*). Example items included "I can deal with whatever comes my way," "Having to cope with stress can make me stronger," and "I tend to bounce back after illness, injury, or other hardships." Scores were summed and ranged

from 0-40 with higher totals indicating more resilient characteristics. Cronbach's alpha for the CD-RISC in this study was 0.833 at pre-test and 0.864 at post-test.

Grit was assessed with the Short Grit Scale (Grit-S; [38]). The Grit-S consists of two, four item subscales that measure interest and effort. Each participant was asked to answer the following statements honestly on a five-point Likert-Type scale (1- *not at all like me* to 5- *very much like me*). Examples of items included "I have difficulty maintaining my focus on projects that take more than a few months to take" (interest subscale) and "Setbacks don't discourage me" (effort subscale). Scores were summed for each subscale and ranged from 4-20 with higher totals indicating more interest or effort. Cronbach's alphas for the interest subscale was 0.740 at pre-test and 0.831 at post-test and the effort subscale was 0.682 at pre-test and 0.742 at post-test.

The 5-factor Mindfulness Questionnaire was used to assess mindfulness capabilities in the participants [39]. The five factors of the 5-Factor Mindfulness Scale include: 1) observing, 2) describing, 3) acting with awareness, 4) non-judging of inner experience, and 5) non-reactivity to inner experience. Each participant was asked to rate the provided statements with a five-point Likert-Type Scale (1- *never or very rarely true* to 5- *very often or always true*). Examples of items for each of the subscales include "When I'm walking, I deliberately notice the sensations of my body moving" (observing), "I'm good at finding words to describe my feelings" (describe), "When I do things, my mind wanders off and I'm easily distracted" (acting with awareness), "I tell myself I shouldn't be feeling the way I'm feeling" (non-judging of inner experience), and "When I have distressing thoughts or images, I "step back" and am aware of the thought or image without getting taken over by it" (non-reactivity to inner experience). Scores were summed for each subscale from 8-40 with higher scores indicating higher abilities on the five factors, Cronbach's alphas for the scales ranged from 0.745 to 0.906 pre-test and 0.704 to 0.928 post-test.

2.2.5. Neuromuscular Testing

Central and peripheral contributions to muscle fatigue, 5-10 minutes before and one minute after each exercise test (GXT and TT) were examined by superimposing a supramaximal magnetic stimulation of the femoral nerve during and five seconds after a series of maximal voluntary contractions (MVCs) of the quadriceps. Participants sat in a semi-reclined position on a table, with the upper body and lower back supported at a hip angle of 45°, and the knee joint angle set at 90° of flexion and the arms folded across the chest. A magnetic stimulator (Magstim 200²; Wales, UK) connected to a 70mm double coil was used to stimulate the femoral nerve. The evoked quadriceps twitch force was obtained from a calibrated load cell (MLP-300; Transducer Techniques, Rio Nedo Temecula, CA) connected to a noncompliant strap which was placed around the participant's right leg, just superior to the malleoli.

Maximal femoral nerve stimulation was verified in each participant by assessing unpotentiated quadriceps single twitch forces (Q_{tw}) obtained at 70, 80, 85, 90, 95, and 100% of maximal stimulator output. A plateau in baseline Q_{tw} with increasing stimulus intensities was observed in every participant and a plateau in M-wave amplitudes was observed in the sub-set of participants in which EMG was recorded. The stimulator was set at 100% for all participants and trials.

We measured a superimposed twitch force during and a potentiated Q_{tw} ($Q_{tw,pot}$) force five seconds after a 5-second maximal isometric voluntary contraction of the quadriceps and performed this procedure six times. Like others, [40], we found the degree of potentiation was slightly smaller after the first and second MVC, therefore we discarded the first two measurements. Peak force, maximal rate of force development (MRFD), contraction time (CT), and reaction time ($RT_{0.5}$) were analyzed for all $Q_{tw,pot}$. Voluntary activation of the quadriceps during the MVCs was calculated using the following equation: $1 - (\text{superimposed twitch force} / Q_{tw,pot \text{ force}}) * 100$.

2.2.6. Electromyography

Quadriceps electromyogram (EMG) was recorded from a subset of participants ($n = 24$; MS=8, MIND=7, CON=9) from the right rectus femoris (RF) using monitoring electrodes with full-surface solid adhesive hydrogel (Delsys Trigno Wireless EMG, Natick, MA, USA) with on-site amplification. Electrodes were placed in a bipolar electrode configuration on the midpoint of the RF with an inter-electrode distance of 100mm. The EMG electrode was placed in the same location during all visits. The surface EMG electrodes were used to assess the maximal EMG of the RF during a maximal voluntary contraction and RF EMG was continuously measured during the subsequent time trial to estimate changes in central neural command.

All EMG recordings were high-pass filtered using 4th order zero-lag Butterworth filters and subsequently smoothed using a root-mean-square (RMS) filter (30-ms symmetrical moving window with successive 1-ms steps). EMG-signal amplitudes from the TTE was normalized to the maximum RMS EMG amplitude recorded during MVC testing of the quadriceps. The EMG amplitudes during the TTE was measured over one second at baseline and then measured as an average of 0-20%, 20-40%, 40-60%, 60-80%, and 80-100% of each trial.

2.2.7. Perceptual Measures

Perceptual responses during each time to exhaustion were recorded every minute. Numerical ratings of leg fatigue and pain, from 0 to 100 were used to assess the severity of preexisting and exercise-related leg fatigue and pain symptoms, comparable to "perceived discomfort" scales described by [41]. Fatigue and pain ratings were anchored with 0 being described as no pain or fatigue, 25 being described as mild pain or fatigue, 50 being described as

moderate pain or fatigue, 75 as severe pain or fatigue, and 100 as the worst possible fatigue or pain imaginable. Participants provided ratings of perceived exertion (RPE) using the Borg 6-20 scale [42], explained as the answer to the question “how hard do you feel like you are working?” representing the combination of effort and peripheral sensations.

2.3. Statistical Analysis

Time to exhaustion, end-exercise heart rate, RPE, leg fatigue, leg pain, and neuromuscular data were analyzed using 3 (treatment) x 2 (trial) RM ANOVAs using SPSS. Significant treatment effects and time by treatment interactions were followed up with post hoc paired t tests.

To evaluate treatment and time effects for EMG data, a 3 (treatment) x 2 (trial) x 6 (time) RM ANOVA using SPSS was performed. In instances where Mauchly's test for sphericity was significant, Huynh Feldt correction was used to adjust for degrees of freedom. If time effects were significant, planned contrasts were used to determine which points differed from baseline. Significant treatment effects and treatment by time interactions were followed up with post hoc paired t tests. Psychological data were analyzed using a RM ANOVA. All data were presented as means and standard deviations, with significance set at $\alpha < 0.05$.

3. Results

3.1. Group Characteristics

Age, VO₂peak, PPO (peak power output), TTE workload, and TTE workload as a percentage of PPO were not statistically different ($p > 0.05$) between treatments (see Table 1).

Table 1. Baseline data for MS, MIND, and CON groups

	Age (years)	VO ₂ max (ml/kg/min)	PPO (W)	TTE Workload (W)	TTE % of PPO
MS (n=16)	20.7 ± 1.8	49.0 ± 12.2	278.8 ± 53.3	239.4 ± 47.8	86.2 ± 9.9
MIND (n=13)	20.2 ± 1.0	52.1 ± 13.2	281.9 ± 50.5	253.2 ± 47.3	89.8 ± 5.5
CON (n=13)	21.2 ± 1.9	48.4 ± 7.1	295.8 ± 35.4	264.1 ± 32.5	89.5 ± 6.7

3.2. Effect of Mental Training on Time to Exhaustion

As predicted, both mental and mindfulness training had a significant effect on time to exhaustion, (Trial x treatment interaction, $F(2,39) = 4.327$, $p = 0.02$). A post-hoc test revealed that time to exhaustion significantly increased following MS from 6.38 ± 4.35 to 7.11 ± 4.68 minutes ($p < 0.05$) and following the MIND from 4.32 ± 1.51 to 4.50 ± 1.55 minutes ($p < 0.05$) while the CON did not change (pre – 5.29 ± 3.62 to post – 5.06 ± 3.69 minutes, $p > 0.05$) (see Figure 1). When TTE was controlled by examining change as a percentage of initial TTE, the effects of MS ($8.7 \pm 13.6\%$) and MIND ($4.6 \pm 5.5\%$) remained significantly different from CON ($-4.9 \pm 11.6\%$) (MS, $p < 0.01$, MIND, $p < 0.05$).

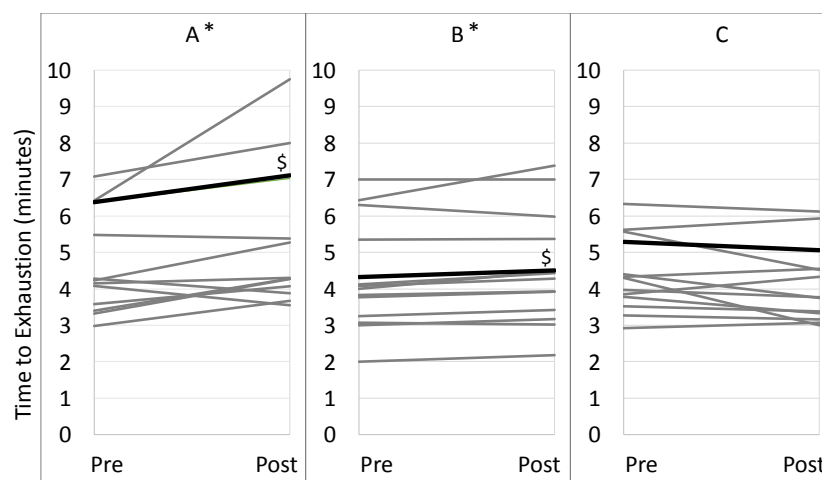


Figure 1. Mean pre-training to post-training changes in time to exhaustion for (A) mental strength, (B) mindfulness and (C) control groups (black lines) and individual values for pre-training to post-training. \$ indicates significant difference ($p < 0.05$) between pre-training and post-training. * indicates a significant group difference ($p < 0.05$) from CON following the training

3.3. Effect of Mental Training on Physiological and Perceptual Variables

No significant treatment x test interaction or main effect of test were present for peak heart rate at exhaustion (Trial x treatment interaction, $F(2,38) = 2.115$, $p = .135$) (See Figure 2). Nor were there any differences between peak RPE (Trial x treatment interaction, $F(2,39) = .665$, $p = .520$). However, for peak fatigue, there was a significant increase in fatigue

from pre to post treatment ($F(1,39) = 6.554$, $p < 0.05$). Post-hoc paired t-test analysis revealed that peak fatigue increased significantly for MS ($p < 0.05$) and MIND ($p < 0.05$), but not for CON ($p > 0.05$). For peak pain, there was a significant treatment by trial interaction ($F(2,39) = 4.174$, $p < 0.05$). Post-hoc analysis revealed that MIND was able to reach a significantly higher level of leg pain during the post-treatment time trial ($p < 0.05$).

RPE was examined during the pre- and post-treatment time trial for the first three minutes of each TTE to determine if MS or MIND had an effect on RPE. Only the first three minutes of each trial were chosen as all participants completed these time points. Analysis revealed that there were no differences between pre- and post-treatment for MS, MIND, or CON ($F(2,37) = .405$, $p > 0.05$), nor were there any Trial \times Time \times Treatment differences ($F(4,74) = 1.93$, $p > 0.05$) (Figure 3). However, RPE did increase over the course of both TTE ($F(2,36) = 182.5$, $p < 0.001$).

3.4. Effect of Mental Training on Electromyography

Initial analysis of EMG revealed a significant trial \times treatment interaction ($F(2,20) = 5.71$, $p < 0.05$). Post-hoc

analysis revealed that there was a significant reduction in time trial EMG from pre- to post-treatment for MS ($-28.2 \pm 35.9\%$) as compared to MIND ($18.6 \pm 35.9\%$, $p < 0.05$) or CON ($13.8 \pm 35.9\%$, $p < 0.05$), but there were no treatment differences between MIND and CON ($p > 0.05$). Post-hoc analysis revealed significant decreases in EMG for MS from MIND and CON at the initial EMG ($F(1) = 4.54$, $p < 0.05$ MIND, $p < 0.05$ CON) and at 40% ($F(1) = 4.97$, $p < 0.05$ MIND, $p < 0.05$ CON), 60% ($F(1) = 5.15$, $p < 0.05$ MIND, $p < 0.05$ CON), and at 80% ($F(1) = 4.42$, $p < 0.05$ MIND, $p < 0.05$ CON) of the trial as shown in Figure 4. There were no differences at the end of the TTE.

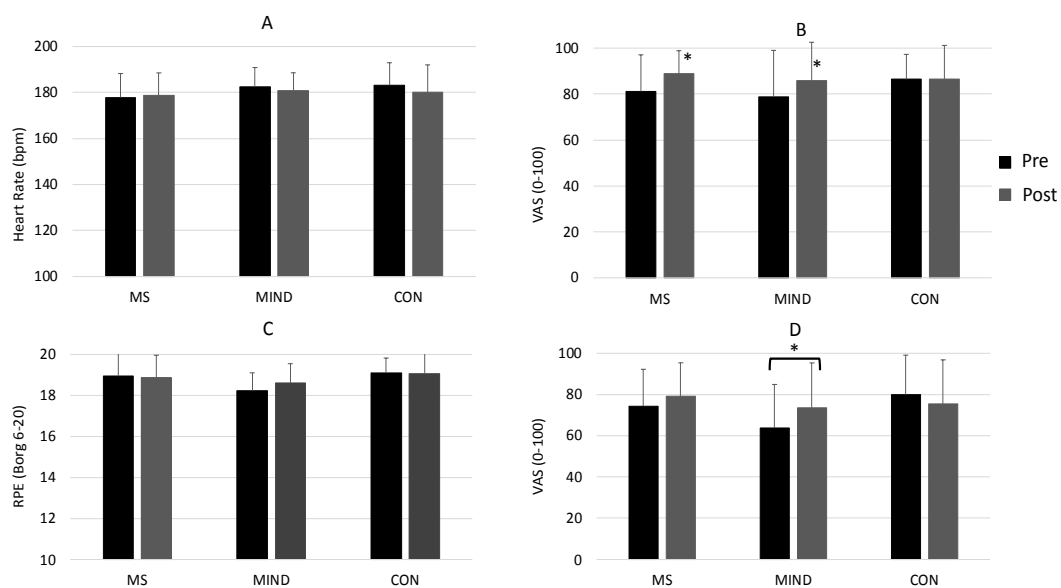


Figure 2. Pre- and Post-training values for (A) peak heart rate, (B) peak rating of perceived exertion (RPE), (C) peak leg fatigue, and (D) peak leg pain for Pre- and Post-training. * indicates a significant difference ($p < 0.05$) between trials

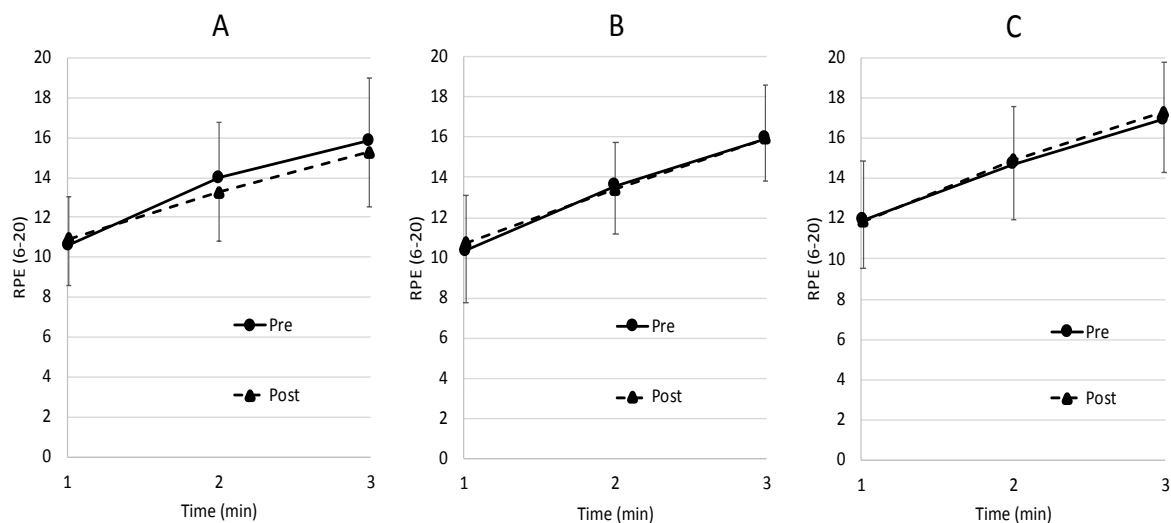


Figure 3. Pre- and Post-training values for RPE at minutes 1-3 for (A) mental strength, (B) mindfulness, and (C) control

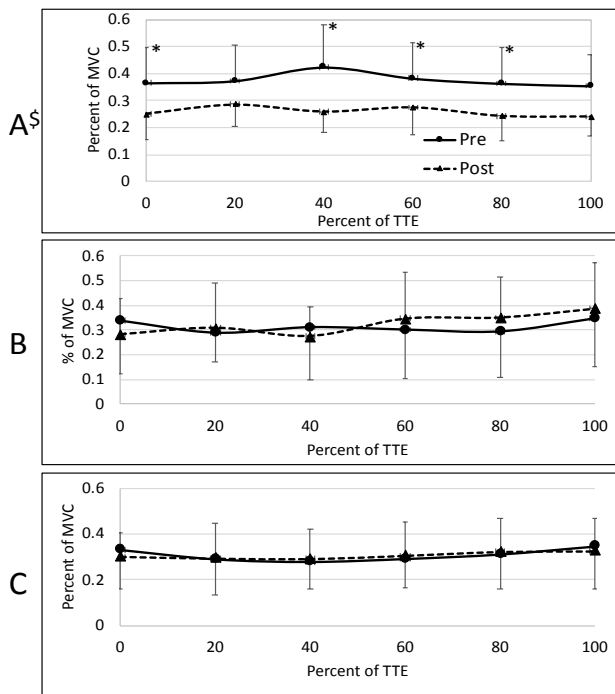


Figure 4. Pre- and Post-training EMG normalized to the pre-exercise maximal voluntary contraction for (A) mental strength, (B) mindfulness, (C) control. * indicates a significant decrease ($p < 0.05$) in EMG as compared to control at each time point. \$ indicates a significant group difference ($p < 0.05$) from CON

3.5. Effect of Mental Training on Neuromuscular Function

Immediately after each time trial, the mean $Q_{tw,pot}$ was reduced from pre-exercise baseline ($p < 0.01$). MVC for and all within-twitch measurements (MRFD, MRR, CT, and $RT_{0.5}$) were significantly reduced following each time trial ($p < 0.01$, Table 2). Exercise-induced changes in quadriceps muscle functions were similar between MS, MIND, and CON nor were there any treatment changes for MS or MIND as compared to CON for $Q_{tw,pot}$ ($F(2,32) = .08$, $p > .05$), MRFD ($F(2,32) = .09$, $p > 0.05$), $RT_{0.5}$ ($F(2,32) = .06$, $p > 0.05$), CT ($F(2,32) = .09$, $p > 0.05$), MVC ($F(2,39) = 0.9$, $p > 0.05$), or VMA ($F(2,32) = .747$, $p > 0.05$) (see Table 2).

3.6. Effect of Mental Training on Psychological Questionnaires

Between pre- and post- time trials, grit had an overall significant trial increase ($F(1,34) = 13.5$, $p < 0.001$), though there was not a trial \times treatment interaction ($F(2,34) = .160$, $p > 0.05$). For the subcategories of grit, only consistency of interest ($F(1,34) = 8.5$, $p < 0.01$) had a significant trial effect while perseverance of effort ($F(1,34) = 2.9$, $p = 0.10$) was not different between trials (Table 3). For resilience, there was no trial or trial \times treatment interaction (Table 3). For mindfulness, there were no overall effect for trial nor was there a trial \times treatment interaction. There were also no trial

or trial \times treatment interactions for any of the subcategories for mindfulness ($p > 0.05$, Table 3).

Table 2. Peripheral fatigue was assessed via supramaximal magnetic stimulation of the femoral nerve before and one minute after exercise. Changes in fatigue variables are expressed as a percentage change from pre-exercise baseline to one minute after the completion of TTE. Values are expressed as mean \pm SD. Abbreviations: $Q_{tw,pot}$, potentiated single twitch; MRFD, maximal rate of force development; CT, contraction time; $RT_{0.5}$, one-half relaxation time; MVC, maximal voluntary contraction. All variables changed significantly ($p < 0.05$) compared with baseline one minute after exercise ($p < 0.05$). $n = 42$ participants

	Percentage change from pre- to 2 min post-exercise					
	MS		MIND		CON	
	Pre-	Post-	Pre-	Post-	Pre-	Post-
$Q_{tw,pot}$ (N)	-45.9 \pm 8.7	-44.7 \pm 12.5	-41.5 \pm 14.1	-46.7 \pm 12.5	-44.5 \pm 11.4	-44.3 \pm 14.7
MRFD (N/s)	-37.3 \pm 23.8	-38.9 \pm 21.0	-36.3 \pm 53.4	-41.8 \pm 18.8	-37.2 \pm 20.0	-44.5 \pm 20.5
CT (s)	-6.4 \pm 11.5	-9.1 \pm 17.0	-5.9 \pm 16.6	-6.1 \pm 25.7	-11.1 \pm 13.7	-9.5 \pm 21.3
$RT_{0.5}$ (s)	-10.4 \pm 18.0	-14.6 \pm 25.0	-13.6 \pm 13.6	-17.2 \pm 19.1	-18.4 \pm 25.5	-15.0 \pm 29.4
MVC Peak Force (N)	-10.2 \pm 12.3	-13.6 \pm 13.7	-8.3 \pm 12.7	-13.7 \pm 12.6	-13.8 \pm 16.5	-14.9 \pm 15.1
Percentage Voluntary Muscle Activation	-8.9 \pm 14.1	-8.8 \pm 19.8	-8.8 \pm 11.8	-7.2 \pm 6.9	-6.2 \pm 10.4	-4.4 \pm 18.2

4. Discussion

This study investigated the effects of either short term mental strength training or mindfulness training on time trial to exhaustion performance as well as attempting to elucidate the physiological or perceptual mechanisms by which MS or MIND may alter performance. As hypothesized, performance during a TTE increased following both MS and MIND training more than in the CON group. Specifically, perception of leg fatigue at exhaustion was increased post-training for MS and MIND; perception of leg pain was increased following only MIND training; and rectus femoris EMG was reduced following MS training. The present study is unique as it is the first to experimentally demonstrate that both MS and MIND training can improve performance in as little as one week, similar to that of self-talk [13] or psychological skills training [43], and the first to attempt to determine the physiological adaptations that occur with psychological training.

The present findings of an 8.5% improvement in TTE with MS training and a 4.6% improvement with MIND training are supported by other endurance based psychological interventions. When motivational self-talk was used during a TTE, an 18% improvement was found, though the exercise intensity was 6-10% lower than the current intervention [13]. Similarly, during a timed distance running test following psychological skills training with focuses on goal setting, arousal regulation, mental imagery, and positive-self talk, an 8% improvement in performance was found [43].

Table 3. Total GRIT-S questionnaire scores as well as the subcategories for grit which include consistency of interest and perseverance of effort. Scores for the CD-Risc resilience scale and 5-factor mindfulness survey with subcategories are also shown. * indicates a significant difference ($p < 0.05$) between Pre- and Post-training

	Grit						Resilience	
	Consistency of Interest *		Perseverance of Effort		Total *		Total	
	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
MS	11.4 ± 3.1	12.2 ± 3.0	16.5 ± 2.5	16.9 ± 2.3	27.9 ± 4.2	29.2 ± 4.9	31.0 ± 5.1	30.9 ± 5.0
MIND	12.8 ± 3.1	13.5 ± 2.8	15.7 ± 2.3	16.2 ± 2.3	28.5 ± 4.8	29.6 ± 4.6	31.0 ± 4.7	29.7 ± 5.9
CON	12.0 ± 3.3	13.1 ± 3.1	15.9 ± 2.52	16.5 ± 1.9	28.0 ± 5.1	29.5 ± 4.3	31.5 ± 4.1	31.1 ± 4.5

	Mindfulness											
	Observe		Labeling		Nonjudgmental		Non-react		Awareness		Total	
	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
MS	24.8 ± 6.4	26.2 ± 5.6	26.3 ± 4.2	25.6 ± 5.6	20.6 ± 6.4	22.6 ± 7.8	22.4 ± 3.7	22.9 ± 4.2	20.0 ± 4.8	21.4 ± 4.0	114.2 ± 13.5	118.7 ± 10.1
MIND	26.8 ± 3.9	27.0 ± 4.8	26.8 ± 26.3	28.5 ± 2.8	25.8 ± 4.6	20.5 ± 5.4	24.3 ± 4.2	22.2 ± 3.9	20.7 ± 3.7	20.2 ± 5.2	117.3 ± 8.7	118.4 ± 12.0
CON	26.3 ± 4.6	25.2 ± 5.7	26.3 ± 4.6	26 ± 2.4	26.2 ± 4.7	20.4 ± 4.2	22.4 ± 3.7	24.3 ± 3.0	22.1 ± 6.2	19.9 ± 5.3	120.1 ± 7.6	115.7 ± 11.1

The changes in performance following MS or MIND occurred without corresponding changes in the psychological surveys which suggests three points. One, that there was no change in self-reported mental strength or mindfulness due to the intervention; two, that the self-report measures did not adequately detect subtle changes in the mindset for athletic performance; or three, the mental training was not long enough to cause a change in the psychological survey. Originally, the three surveys employed to assess mental strength and mindfulness were designed to detect a more stable personality trait or characteristic, leaving little sensitivity to detect training induced changes [20,36]. While these psychological surveys have been deemed as valid and reliable instruments in sport for baseline measurements [36,37], it may be beneficial to develop sport-specific questionnaires that are more sensitive and able to detect changes in mental strength or mindfulness that accompany mental training. However, a 12 week imagery training study did demonstrate an increase in grit in professional soccer players [44].

While there were no changes in the psychological measures, there were improvements in the underlying TTE. The 4.6% improvement following MIND may be due to increasing the amount of voluntary cognitive control while anchoring attention in the present moment [27]. In addition, an increase in mindfulness may explain the increase in the sensation of leg fatigue and pain felt at the end of exercise as there may be an increased sensitivity or awareness of the inner state [45]. Increasing mindfulness may also help sway the ongoing internal negotiation between continuing and quitting toward an acceptance of the necessary effort that needs to be sustained for the duration of the exercise [46]. Mindfulness may also increase recruitment of prefrontal

regions of the brain while reducing the reactivity of central stress processing regions, leading to a reduction in sympathetic nervous system activation and an increase in performance [47].

The goal of MS training was to use techniques to reduce stress and anxiety, reduce negative thinking and doubt, and prepare for challenging moments [8,19,24]. The 8.5% improvement following MS may have been due to reduced stress and subsequent reductions in sympathetic activation at baseline [48], though there was no decrease in peak HR at the end of the TTE. Imagery, a subset of our MS training, may decrease anxiety [49] while also increasing motivation [50], better preparing participants from the discomfort of the TTE. However, there was not a manipulation check to detail the psychological components that participants actually used to increase performance during the second TTE unlike a previous study on self-talk [13].

Even though there were no changes in the psychological measures, the present study was designed to begin elucidating how mental strength training and mindfulness training may affect the underlying physiology that contributes to the increases in endurance performance. While peak heart rates were unchanged with mental training, EMG, or central motor drive, during the TTE decreased following MS training but was unchanged following MIND or control, even with keeping power output constant. This decrease may be due to a shift from internal to external locus of control following MS training due to participants shifting their focus from pushing on the pedals to their breathing or thoughts [51-54]. By decreasing EMG, there may be an increased efficiency of muscle recruitment, allowing intramuscular glycogen to be spared [55,56], reducing the rate of fatigue accumulation, and increasing TTE during high intensity

exercise [51]. Alternatively, intrinsic factors such as recruitment or decruitment of motor units [57], amplitude cancellation [58], or motor-unit synchronization [59] may have also had a role in attenuating EMG with MS training.

Contrary to previous studies [13], there was no reduction in RPE associated with increased TTE, either when comparing absolute time (minute 1-3) or peak RPE. When considering that minutes 1-3 following mental training occurred at a lower overall percentage of the TTE, it should be expected that RPE would be lower if perception of effort is the ultimate determinant of endurance performance [6,60,61]. However, neither the peak nor rate of increase in RPE was changed. Even though it is beyond the scope of this study, mental training may enable participants to be more willing to “lean into” suffering, spending more time at or near a maximal RPE before giving in to exhaustion. Mental training may also increase focus during the cycling trial, blocking out, or non-judgmentally accepting, negative thoughts.

During a fixed resistance TTE above critical power, metabolites accumulate until cessation of exercise occurs [62-65]. This cessation occurs at an “individual critical threshold” of peripheral locomotor muscle fatigue (quantified from pre- to post-exercise changes in quadriceps twitch force, $Q_{tw,poi}$) and is associated with a certain sensory perception of fatigue and/or pain and a fixed level of metabolites [66-68]. Following MS or MIND training, even with an increase in TTE across both conditions, peripheral locomotor muscle fatigue was unchanged. [2,69]. This indicates either a change in metabolite level to cause the same “individual critical threshold” or a decrease in the rate of accumulation of metabolites if there is an invariable intramuscular level of metabolites at exhaustion [1].

Finally, this study demonstrated an increased perception of leg fatigue following both MS and MIND, suggesting an increased metabolic activation of the Group III/IV muscle afferents [68] or a greater decrease in intramuscular glycogen [70], both of which would be consistent with an increase in TTE. However, the decrease in EMG following MS may also lead to decreases in corollary discharge and a subsequent reduction in the activation of sensory areas within the cortex that may influence effort perception [71]. Taken together, this increase in peripheral leg fatigue coupled with a decrease in EMG following MS, supports the concept of the more global negative feedback loop entailed within the concept of a “sensory tolerance limit” [69].

4.1. Limitations

In order to contextualize our findings, potentially limiting aspects of the study should also be acknowledged. First, a time trial to exhaustion was used during this study rather than a fixed distance time trial. While a fixed distance time trial allows for pacing, it would also increase variance in many of the physiological and perceptual variables, limiting the ability to discern how mental training may function to improve performance.

Second, the control group did not watch a video or listen to an audio, making this not a true placebo control group. In addition, participants were able to watch the video or listen to the audio on their own, rather in the lab, making it difficult to verify if the participant actually performed and was focused during the intervention phase. However, participants were asked what aspects of the MS videos or MIND audio were most interesting in order to verify if they listened. If they were not able to answer, they were removed from the study ($n=2$).

Third, this study used EMG on the rectus femoris, rather than the vastus lateralis, as a proxy for the whole leg during cycling. While the vastus lateralis is typically used during cycling if only one electrode is used, the rectus femoris mirrors that of the vastus lateralis during constant-load intense cycling [72].

In light of our findings, it is important that research further examines the effects of mental strength and mindfulness training on performance and physiological variables. In particular, it may be beneficial to examine if oxygen consumption or ventilation were affected by mental training, especially as one aspect of MS focused on breathing techniques to reduce anxiety. It may also be beneficial to examine whether mental training for more than one week has a greater effect on increasing performance. Finally, this study should be extended to explore whether mental training works to improve performance on the spectrum of exercisers, from relatively untrained to elite individuals.

5. Conclusions

In summary, our study is the first to attempt to elucidate how one week of mental training affects performance. Even one week of mental strength training significantly improves performance, partly through decreasing rectus femoris EMG and through increasing the amount of perceptual leg fatigue and pain that participants were willing to endure. However, even with an increase in performance, the end-exercise peripheral leg fatigue did not change, suggesting a fixed end-point of peripheral fatigue beyond which participants are not able to supersede.

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