EXAMINING THE ASSOCIATION OF PHYSICAL ACTIVITY AND MINDFULNESS WITH ACUTE STRESS AND MENTAL HEALTH

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ABSTRACT

Stress is one of life's greatest health threats and increases susceptibility to mental illness. Physical activity and mindfulness are lifestyle factors that are protective against mental health concerns. Critically, those with high levels of physical activity also tend to have high levels of trait mindfulness—the tendency to be more mindful in everyday life. However, the relationship between physical activity and mindfulness, and their impact on acute stress and mental health, remains unclear. The current study aimed to explore this association between physical activity and mindfulness, and their relative impact on acute stress reactivity and mental health. Specifically, we examined whether trait mindfulness accounted for unique variance after controlling for physical activity. In a sample of young adult participants (N = 50) we first assessed their physical activity, trait mindfulness, and mental health and then exposed them to the Trier Social Stress Test, during which we recorded using heart rate, blood pressure, salivary cortisol samples, and state anxiety. Hierarchical linear regression revealed a distinct pattern, such that physical activity was more strongly associated with acute stress (heart rate and state anxiety reactivity), whereas trait mindfulness was more strongly associated with mental health even after controlling for physical activity. The results suggest that physical activity and trait mindfulness may work via synergistic mechanisms to enhance wellbeing with physical activity reducing stress reactivity and trait mindfulness improving overall mental health.

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LIST OF ABBREVIATIONS

SAM	Sympatho-Medullary-Adrenal
CRH	Corticotropin-releasing hormone
LC	Locus coeruleus
HPA	Hypothalamus-Pituitary-Adrenal
ACTH	Adrenocorticotropic hormone
PFC	Prefrontal cortex
IPAQ	International Physical Activity Questionnaire-Long Form
FFMQ	Five Facets Mindfulness Questionnaire
BDI-II	Beck Depression Inventory-II
STAI-t	State-Trait Anxiety Inventory- Y-2 Form
PSS	Cohen's Perceived Stress Scale
TSST	Trier Social Stress Test
HR	Heart rate
SBP	Systolic blood pressure
DBP	Diastolic blood pressure
STAI-6	State-Trait Anxiety Inventory- Short Form
VIF	Variance inflation factor
MD	Mean difference
Δ	Change in
PA	Physical activity
MF	mindfulness

DECLARATION OF ACADEMIC ACHIEVEMENT

Allison Mizzi's role:

- Wrote and submitted ethics application at McMaster University
- Designed study protocol and selected measures
- Set up lab equipment and materials
- Trained and supervised undergraduate students to assist with data collection
- Led data collection, analysis, and interpretation
- Prepared manuscript

Role of co-authors:

- JH obtained study funding
- JH assisted AM with ethics application
- JH assisted AM with study design
- JH assisted AM with data analysis and interpretation

INTRODUCTION

Stress is one of life's greatest mental and physical health threats. Approximately 30% of Canadians over the age of 15 report that most days they feel "quite a bit" or "extremely" stressed (*Health Promotion and Chronic Disease Prevention in Canada*, 2019). Stress can be acute, as the result of a stressor in the environment, or chronic, the result of prolonged stress. Critically, individuals who experience high levels of acute and chronic stress are more susceptible to mental illness, such as depression and anxiety. Mental illness severely impacts one's ability to function in daily life, perform at school and work, maintain relationships and social functioning, and can threaten one's life. Considering the growing burden of mental illness on health-care resources (*Health Promotion and Chronic Disease Prevention in Canada*, 2019), cost-effective and accessible interventions are needed to help manage—and prevent—the negative effects of stress. The current study focused on two modifiable lifestyle factors, physical activity and mindfulness, and examined the association and interaction of these two factors with the acute stress response and mental health. The following sections review: 1) the acute response to a psychological stressor and its impact on mental health, 2) the influence of physical activity on the acute response to a psychological stressor and mental health, and 3) the relationship between physical activity and trait mindfulness, and how each contribute to wellbeing.

Stress and Mental Health

The human body continually monitors the functioning of its organ systems to maintain a state of homeostasis. Stress is defined as an actual or perceived disruption to homeostasis (Selye, 1950). In presence of an acute stressor, the stress response is activated to deal with the threat, with the ultimate goal of returning the body back to homeostasis. From an evolutionary standpoint, the stress response enables humans to react quickly to potentially life-threatening situations, such as encountering predators or other environmental hazards. However, in modern day, where such *physical* threats are not as readily encountered, the stress response is often activated in response to *psychological* threats.

The stress response is initiated when a threat is detected by the locus coeruleus (LC), a key brainstem region involved in arousing, alerting, and activating the hypothalamus. The activation of the hypothalamus initiates two parallel axes: the SAM axis and the HPA axis. The SAM axis, or Sympatho-Adreno-Medullary axis, initiates a rapid “fight or flight” response that is mediated by the sympathetic nervous system which activates the adrenal medulla to release epinephrine into the bloodstream (Charmandari, Tsigos, & Chrousos, 2005). Epinephrine has widespread effects that increase heart rate and blood pressure, enhance alertness, and increase the conversion of glycogen into glucose (Charmandari et al., 2005; Wortsman, 2002). Collectively, these changes stimulate the brain and body to be prepared to fight against the ensuing threat or flee the dangerous situation.

The HPA axis, or Hypothalamus-Pituitary-Adrenal (HPA) axis, is mediated by a cascade of hormones and produces a slower, more sustained response that mobilizes the energy needed to deal with the stressor. Specifically, the hypothalamus releases corticotropin-releasing hormone (CRH) that activates the pituitary gland to secrete adrenocorticotropic hormone (ACTH). This in turn activates the adrenal glands to produce cortisol—a glucocorticoid hormone that prompts a slow and steady release of glucose into the bloodstream (Charmandari et al., 2005; Lai & Herman, 2009). Importantly, the HPA axis contains a negative feedback mechanism that terminates the stress response when the stressor has been eliminated. This involves cortisol binding to glucocorticoid receptors located in the hippocampus, which then inhibits the production of hormones from the hypothalamus to shut off the HPA axis (Pariante & Lightman, 2008; Rosenblat, Cha, Mansur, & Mcintyre, 2014). Depending on the level of HPA activation, cortisol and epinephrine will return to baseline levels within minutes to hours following elimination of the stressor (Dhabhar, 2014). Together, the SAM and HPA axes allow the body to deal with threats quickly and thoroughly.

The efficiency of the SAM and HPA axes are integral to maintaining homeostasis, but their prolonged activation can have detrimental consequences on the health of the mind and the body. Allostatic load refers to chronic activation of the stress system, and is defined as activation of the stress response that lasts several hours per day across weeks or months (Dhabhar, 2014; McEwen, 1998). Chronically high levels of cortisol can desensitize the hippocampal glucocorticoid receptors; this interferes with cortisol binding to the receptors and prevents effective shut off of the stress response. Consequently, even in the absence of a stressor, one can have high levels of cortisol and a hyperactive HPA axis, which creates dysfunction within brain and body that can negatively impact mental health (Pariente & Miller, 2001; Raison & Miller, 2003). In animal models, chronic stress paradigms elicit symptoms of anxiety that last long after the original stressor has been removed (Eiland & Mcewen, 2012; Vyas, Pillai, & Chattarji, 2004). Similarly, humans with major depressive disorder have higher levels of cortisol compared to healthy individuals (Nemeroff & Vale, 2004; O' Brien, Scully, Fitzgerald, Scott, & Dinan, 2007; Pariante & Lightman, 2008). Depressed individuals can also exhibit elevated CRH, blunted ACTH response to CRH, and hippocampal damage (Holsboer, 2000; Varghese & Brown, 2001), all indicative of a hyperactive HPA axis. Critically, damage to the hippocampus can lead to widespread deficits due to its extensive connectivity with brain regions involved in emotion regulation, anxiety, and inhibition, including the amygdala and prefrontal cortex (PFC) (Drevets, 2001; Wager, Davidson, Hughes, Lindquist, & Ochsner, 2008; Warner-Schmidt &

Duman, 2006). Therefore, it is critical to identify ways to help individuals manage stress to prevent chronic activation and dysfunction.

Physical Activity and Stress

Engaging in regular physical activity reduces perceived psychological stress and improves mental health. Physical activity serves as a controllable and customizable acute physiological stressor that activates and deactivates the stress system in a non-threatening way (Dhabhar, 2014; Sothmann et al., 1989). An acute bout of moderate-to-high intensity aerobic exercise (60-80% of VO_2 max) activates the SAM and HPA axes to increase circulating epinephrine and cortisol (Hill, Battaglini, Viru, Viru, 2008; Shojaei, Jafari, & Farajov, 2011). When repeated over time, aerobic exercise training at moderate and high intensities reduces heart rate (Almeida & Araújo, 2003; Cornelissen, Verheyden, Aubert, & Fagard, 2010) and systolic blood pressure (Kelley, Kelley, & Tran, 2001; Steffen et al., 2001) at rest and immediately following exercise. Furthermore, during exercise, aerobically trained individuals produce less epinephrine and cortisol than their sedentary counterparts (Sothmann et al., 1989). Taken together, the evidence points to less stress reactivity for physically activity individuals.

According to the cross-stressor hypothesis, the repeated activation and deactivation of the stress response with regular physical activity induces physiological, neuroendocrine, and psychological adaptations to improve the efficiency of the allostatic stress response (Sothmann et al., 1989). These adaptations minimize the disruption of homeostasis by stressors of all kinds. Indeed, when faced with an acute psychosocial stressor, individuals of higher aerobic fitness have an attenuated stress response compared to lower fit individuals, including lower heart rate and cortisol response (Klaperski, von Dawans, Heinrichs, & Fuchs, 2013; Rimmele et al., 2007; Traustadottir, Bosch, & Matt, 2005) as well as lower systolic and diastolic blood pressure reactivity (Forcier et al., 2006). High fit individuals also experience less decline in mood following acute stress than lower fit individuals (Childs & de Wit, 2014) and highly active individuals report lower state anxiety during and after an acute psychosocial stressor (Rimmele et al., 2009, 2007). Following a 6-week aerobic exercise program, previously untrained young adults experienced reduced heart rate reactivity and faster heart rate recovery in response to a mental arithmetic stressor task relative to the non-active control group (Spalding, Lyon, Steel, & Bradley, 2004), providing support for a causal effect of physical activity reducing psychological stress reactivity.

The observation that physical activity can reduce physiological and psychological stress reactivity has important implications for longer-term mental health care interventions. Higher levels of physical activity are associated with lower depressive symptoms and less incidence of anxiety in young adult, middle-aged, and older adult populations (Ströhle, 2009). Lower cardiovascular reactivity to acute psychosocial stressors is associated with reduced risk of stress-related illness, such as anxiety, depression, and cardiovascular conditions (Chida & Steptoe 2010; Ellenbogen, Hodgins, Walker, Couture & Adam, 2006). For the general population, meta-analyses demonstrate that moderate-intensity aerobic exercise training reduces anxiety with a small-to-moderate effect size of 0.22 (Conn, 2010; Norris & Carroll, 1992; Petruzzello, Landers, Hatfield, Kubitz, & Salazar, 1991; Wipfli, Rethorst, & Landers, 2008). One study demonstrated that as little as 10 weeks of moderate-intensity aerobic training for 21 minutes, three times per week was effective at decreasing trait anxiety— i.e., the tendency for an individual to experience anxiety (Spielberger & Vagg, 1984), in the general population (Norris & Carroll, 1992; Petruzzello et al., 1991). For individuals with high levels of anxiety, moderate-intensity aerobic exercise reduces anxious mood (Steptoe, Edwards, Moses, & Mathews, 1989) and lowers post-exercise state anxiety (Lucibello, Parker, & Heisz, 2019)— i.e., the anxiety that an individual is feeling in the current moment (Spielberger & Vagg, 1984). Similar effects are seen in depression; numerous meta-analysis support the notion that moderate- and high-intensity aerobic training reduce depression and improve mood (Blumenthal & Madden, 1988; Byrne & Byrne, 1993; Josefsson, Knapen et al., 2015; Lindwall, & Archer, 2013; Moses, Steptoe, Mathews, & Edwards, 1989; Mota-Pereira et al., 2011). Thus, engaging in physical activity represents an effective and powerful mode of lowering the acute stress response as well as decreasing the risk of developing more serious mental illness.

Mindfulness and Mental Health

Another lifestyle factor that reduces stress and improves mental health is mindfulness, defined as a "non-judgemental, present-oriented focused attention" (Kabat-Zinn, 2003). Importantly, the emphasis is put on becoming more aware of one's thoughts, feelings, and sensations, both positive and negative, and accepting them regardless of their positive or negative nature (Kabat-Zinn, 2003). Mindfulness has a long history, with roots in Buddhism and Hinduism meditation (Kabat-Zinn, 1992). While meditation consists of a set of specific techniques that are used for practicing mindfulness, mindfulness is broader concept that can be practiced in any context, and thus can be more easily incorporated into activities of daily life, including physical activity (Kabat-Zinn, 2003). The tendency to engage in this mindful way of thinking in one's daily life, termed trait mindfulness, is associated with a wide range of positive cognitive and psychological outcomes. For example, individuals with higher levels of trait mindfulness report better perceived health and less symptoms of depression and anxiety (Bränström, Duncan, & Moskowitz, 2011).

More recently, standardized programs, such as Mindfulness-Based Stress Reduction (MBSR) (Kabat-Zinn, 1992), have been developed to specifically target mindfulness skills, reduce stress, and positively influence mental health. MBSR is an 8-week, evidence-based program that uses mindfulness practice to train attention, cultivate mind and body awareness, and practice non-judgemental acceptance of thoughts, feelings, and sensations.
MBSR reduces depressive and trait anxiety symptoms in both healthy (Khoury, Sharma, Rush, & Fournier, 2015; Sharma & Rush, 2014) and clinical populations (Hofmann, Sawyer, Witt, & Oh, 2010; Strauss, Cavanagh, Oliver, & Pettman, 2014). Furthermore, in healthy young adults, MBSR increased cortical thickness in the right insula, a brain region implicated in emotional regulation (Santarnecchi et al., 2014). It also enhances attention (van der Oord, Bögels, & Peijnenburg, 2012), led to greater ability to inhibit the processing of distracting information (Moore, 2009, Tang, 2007, Chan 2007), and increased PFC activity and attentional control (Gotink, Meijboom, Vernooij, Smits, & Hunink, 2016; Kilpatrick et al., 2011). In adults with social anxiety, MBSR reduced negative emotions during an emotional attention task, as well as reduced amygdala activity, a brain region highly involved in fear and anxiety responding and emotional regulation (Goldin & Gross, 2010).

Given that the impact of an acute psychosocial stressor is amplified by negative thoughts and worry (Gianferante et al., 2014), it follows that individuals high in trait mindfulness may also have reduced reactivity to an acute stressor. Indeed, two recent studies support this notion. One study found that those high in trait mindfulness had significantly lower cortisol and state anxiety response to an acute psychosocial stressor (Brown, Weinstein, & Creswell 2012). The other study found that those who engaged in a 3-day mindfulness program had reduced state anxiety to an acute stressor compared to control participants who did not receive the mindfulness program (Creswell, Pacilio, Lindsay, & Brown, 2014). However, more research is required to fully understand how mindfulness impacts the acute stress response both physiologically and psychologically.

Physical Activity and Mindfulness Relationship

As noted earlier, mindfulness can be cultivated through everyday activities including physical activity and two recent reviews report a positive relationship between trait mindfulness and physical activity, with a small-to-medium effect size (Schneider, Malinowski, Watson, & Lattimore, 2019; Yang & Conroy, 2019). In general, individuals who are more physically active have higher trait mindfulness (Kangasniemi, Lappalainen, Kankaanpää, & Tammelin, 2014; Tsafou, Lacroix, van Ee, Vinkers, & De Ridder, 2016) and the relationship appears to be bi-directional. On one hand, individuals who consistently engaged in physical activity (over a one year period) have higher trait mindfulness than those who were less consistent (Ulmer, Stetson, & Salmon, 2010). On the other hand, individuals with higher trait mindfulness engage in more physical activity (Gilbert & Waltz, 2010).

It is postulated that physical activity may lead to increased trait mindfulness by fostering moment-to-moment attention via focused awareness of breathing and movement through space (Asztalos et al., 2012; Salmon, Hanneman, & Harwood, 2010). Endurance activities such as running, cycling, or swimming in particular may foster a state of sustained concentrated attention on breathing and repetitive body movements that promotes attention to thoughts and feelings, and acceptance of both the negative and the positive. One study demonstrated that a 12-week aerobic exercise intervention increased levels of trait mindfulness in healthy adult males. The intervention also improved emotional and social functioning as well as perceived wellbeing (Mothes, Klaperski, Seelig, Schmidt, & Fuchs, 2014). This begs the question: if we control for one's physical activity level, do we still see an association between trait mindfulness and mental health? All prior studies demonstrating a link between trait mindfulness and mental health did not control for physical activity. Therefore, a primarily aim of the present study was to determine the association between trait mindfulness and mental health while controlling for physical activity.

Purpose

The current study aimed to:

(1) Examine the relationships between physical activity, trait mindfulness, and mental health.

(2) Determine whether physical activity and trait mindfulness are associated with acute responses to a psychological stressor.

(3) Evaluate whether trait mindfulness accounts for unique variance associated with mental health and the acute response to a psychological stressor over and above that attributed to physical activity.

Hypotheses

It was hypothesized that:

(1) Physical activity and trait mindfulness would be negatively associated with mental health (depression, trait anxiety, and chronic stress).

(2) Physical activity and trait mindfulness would be negatively associated with change in acute stress with respect to an acute psychosocial stress task.

(3) Adding trait mindfulness to the model of the relationship between physical activity and mental health/acute stress will account for more variance in mental health and acute stress than physical activity alone.

METHODS

Participants

McMaster University students were recruited using poster and online advertisements to participate in a study examining the relationship between physical activity, mindfulness, and mental health. Eligibility criteria required participants to be between the ages of 18-30 years old and currently enrolled in undergraduate or graduate studies at McMaster University. A priori power calculations (G*Power version 3.1.9.3; Faul, Erdfelder, Buchner, & Lang, 2009) based on an effect size of d = 0.49 from the heart rate response to an acute stressor indicated that a sample size of 24 was required (Rimmele et al., 2007). Rimmele and colleagues recruited distinct high and low fit individuals and although we originally planned to analyze the data by high and low physically active groups our sample was relatively low active, and thus separating into high and low active groups was not valid. Thus, regression analysis was chosen and the sample size calculation was doubled to account for this change. All participants provided written informed consent and received either $20 or course credit for participation. All study procedures were approved by the McMaster Research Ethics Board, #2017-205. All experimental sessions were conducted between 1:00 pm and 4:30 pm to control for the diurnal variation of cortisol. Participants were requested to refrain from vigorous exercise for 12 hours, eating for two hours, and caffeine for six hours prior to the onset of their experimental session. Fulfillment of these criteria was assessed through verbal confirmation during the informed consent process.

Materials

Baseline questionnaires

Participants completed a battery of questionnaires to assess their demographic information, physical activity, trait mindfulness, and mental health. All questionnaires were administered on a desktop computer using the LimeSurvey platform.

Demographic Information. Demographic characteristics of participants were reported using a demographic information questionnaire, including age, gender, year/level of university, and faculty.

Physical Activity. Physical activity was measured using the International Physical Activity Questionnaire-Long Form (IPAQ; Craig et al., 2003), which measures several types of physical activity, including: Job-related Physical Activity, Transportation Physical Activity, Housework, House Maintenance, and Caring for Family, and Recreation, Sport, and Leisure Physical Activity. Activity intensity is factored into the MET minutes calculation: the number of minutes the activity was carried out is multiplied by the MET value (walking/low intensity activities = 3.3; moderate intensity activities = 4; vigorous activity = 8). This number is then multiplied by the number of days the activity was undertaken that week, and we used this number in our analyses. The validity and reliability of the IPAQ has been demonstrated in young adult populations (Craig et al., 2003).

Trait Mindfulness. Trait mindfulness was measured using the Five Facets Mindfulness Questionnaire (FFMQ; Baer, Smith, Hopkins, & Toney, 2006). The FFMQ uses 39 items to assess participants on five factors of mindfulness in everyday life: observing, describing, acting with awareness, nonjudging of inner experience, and nonreactivity to inner experience. Given that all five factors may influence mental health and stress reactivity, we analyzed the total score (Baer, Smith, Lykins, Button, Sauer, et al., 2008; Carmody & Baer, 2008). The FFMQ has established validity in measuring trait mindfulness in both experienced meditators and non-meditators (Baer, Smith, Lykins, Button, Krietemeyer, et al., 2008).

Depression. Depressive symptoms were measured using the Beck Depression Inventory-II (BDI-II; Beck, Steer, & Brown, 1996). The BDI-II consists of 21 items that assess severity of depressive symptoms over the past two weeks, rated on a scale of increasing severity (least severe = 0; most severe = 3). We analyzed the total score, which was calculated as sum of each item (max = 63), where higher scores indicate more depressive symptoms. The BDI-II is has been demonstrated to be valid to assess depressive symptoms in both clinically depressed patients and healthy populations (Beck, Steer, & Garbin, 1988).

Trait Anxiety. Trait Anxiety was assessed using the State-Trait Anxiety Inventory-Form Y-2 (STAI-t; Spielberger, 1989). The STAI-t specifically assesses *trait* anxiety, the more general, personality-level of anxiety that the individual exhibits. The STAI-t consists of 20 items that ask the participant to reflect on how they generally feel along a scale from "almost never" to "almost always" (max = 80). We analyzed the total score, which was calculated by reverse scoring select items and then summing all items. The STAI-t is an established, valid, and reliable measure of trait anxiety in adult populations (Barnes, 2002).

Chronic stress. Chronic stress was measured using Cohen's Perceived Stress Scale (PSS; Cohen, Kamarck, & Mermelstein, 1983). The PSS consists of 10 items that assess severity of perceived stress over the past month. Each item describes a potentially stressful experience, which the participant rates on a scale from 0 (never) to 4 (very often) in terms of frequency of experience. We analyzed the total score, which was calculated as the sum of each item (max = 40), where higher scores indicate higher perceived stress. The PSS is a validated measure of perceived chronic stress in adult populations (Roberti, Harrington, & Storch, 2006).

Acute stress reactivity

Acute stress was induced using the Trier Social Stress Test (TSST; (Clemens Kirschbaum & Hellhammer, 1993). Stress reactivity was tracked using physiological and psychological measures, including heart rate, blood pressure, salivary cortisol, and state anxiety questionnaires, all taken at pre-, mid-, post-, and recovery time points.

Heart Rate. Heart rate was measured throughout the TSST using a chest strap-based Polar FT1 Heart Rate Monitor and Polar T31 sensor to obtain beats per minute.

Blood pressure. Blood pressure (BP) was measured using the BIOS Precision Series 8.0 Blood Pressure Monitor-Model BD215 blood pressure cuff (BIOS Medical, Newmarket, Ontario, Canada). After a five-minute seated rest, systolic blood pressure (SBP) and diastolic blood pressure (DBP) were assessed on the left arm from a seated position.

Cortisol. Four saliva samples were collected from each participant using Salivettes (Sarstedt, Germany). Participants were instructed to gently chew on the cotton swab provided for one minute, after which the swabs were replaced into the plastic tube of the Salivette. Samples were stored in -20°C until analysis (mean storage time = 5 months). Samples were analyzed by Dr. Cameron Muir's research team at Brock University (St. Catharines, Canada).

State Anxiety. State anxiety was assessed using the State-Trait Anxiety Inventory (Short Form: STAI-6; Marteau & Bekker, 1992). The STAI-6 was adapted directly from the full-length State-Trait Anxiety Inventory. It uses 6 items to assess how the individual is feeling in the *current moment*. We analyzed the total score, which is calculated by reverse-scoring select items and adding the scores from each item together. The STAI-6 was selected for its minimal length, making it optimal for quick and frequent administration. The STAI-6 has scores comparable to the full-length State-Trait Anxiety Inventory and is sensitive to acute anxiety fluctuations (Marteau and Bekker, 1992).

Procedure

Overview

An overview of the study design is presented in Figure 1. Participants provided written informed consent and completed baseline questionnaires. Ten minutes before the TSST, pre-TSST stress reactivity measurements were taken, including heart rate, SBP, DBP, salivary cortisol, and state anxiety. Following completion of pre-TSST measurements, the TSST panel confederate judges entered the room and were seated across from the participant. The judges explained the speech task, provided the participant with a paper and pen, and began the TSST protocol (Clemens Kirschbaum & Hellhammer, 1993). Mid-TSST stress reactivity measurements were taken between the speech and mental arithmetic tasks. Post-TSST measurements were taken after the mental arithmetic task. Recovery-TSST measurements were taken 15-minutes after the end of the TSST. The participant was then debriefed, informed of the true nature of the study, and compensated.

The Trier Social Stress Test (TSST)

The Trier Social Stress Test (TSST) (Kirschbaum & Hellhammer, 1993) was administered to induce psychological stress. The TSST consists of a five-minute speech task followed by a five-minute mental arithmetic task, performed in front of a panel of judges. After completing baseline questionnaires and pre-TSST measures, participants received an explanation of the upcoming task, were provided with a piece of paper and a pen, and the TSST was initiated. The TSST is a reliable inducer of the stress response, with consistent two- to three-fold increases in HPA axis and cardiovascular response from its administration (Dickerson & Kemeny, 2004;

Clemens Kirschbaum & Hellhammer, 1993). The TSST was carried out as indicated, with one 2-minute break between the speech and mental arithmetic tasks at the mid-time point to collect heart rate, SBP, DBP, saliva, and state anxiety.

The Speech Task. Participants were instructed that they were going to be delivering a five-minute speech to a panel of judges trained in public speaking, on the topic of "Why you are the ideal candidate for your dream job". Participants were provided with a paper and pen to use during a ten-minute preparation period before the task. A stopwatch was started, and the participant prepared their speech. After the preparation period, the paper was taken from the participant, and they were requested to stand. The participant was reminded of the task and instructed to use the full five minutes for their speech. The participant's consent was obtained to set up a prop video camera, to further increase psychological stress. The participant was instructed to begin the speech, and a timer was set for five minutes. The judges made eye contact with the participant, took notes, and remained emotionally neutral, giving no positive feedback or encouragement throughout the task. If the participant fell silent for more than 20 seconds, a judge prompted the participant with the time remaining. Immediately after the five-minute speech, the participant was asked to be seated, and the mid-TSST measurements were taken.

The Mental Arithmetic Task. The participant was instructed to stand opposite the judges. The judges explained that the participant would be given a four-digit number, and they were to sequentially subtract the number thirteen from that four-digit number, as quickly and accurately as possible, for five minutes. A timer was set for five minutes, and the participant performed the mental arithmetic task. Again, judges made eye contact with the participant, tracked accuracy using an answer sheet, and remained emotionally neutral, giving no positive feedback or encouragement. Judges informed the participant when an incorrect answer was given and requested that they start over from the initial number. Immediately after the mental arithmetic task, the post-TSST measurements were taken. Fifteen minutes later, the recovery-TSST measurements were taken.

Statistical Analysis

Data was analyzed using IBM SPSS Statistics Software 23. Descriptive statistics were computed for all study variables. Data were screened for outliers within each measure; values beyond quartiles 1 (Q1) and 3 (Q3) with a step of 1.5 times the interquartile range (IQR; i.e., values <Q1-1.5*IQR or >Q3+1.5*IQR) were considered outliers and removed from analysis (Tukey, 1977). Normality was assessed using visual inspection of histograms, and skewness and kurtosis based on current recommendations (Kim, 2013). Multicollinearity was assessed using tolerance and variance inflation factor (VIF). For all statistical analyses, a *p* value (two-tailed) of <.05 was considered significant. Missing values were analyzed for pattern of missing data using Little's MCAR test.

For all acute stress measures, with the exception of cortisol, a change score was calculated by subtracting the score at the mid-TSST time point from the score at the pre-TSST time point. This provides a value indicating the magnitude of change in stress in response to the TSST. Change scores were also calculated by subtracting the score at the post-TSST time point from the score at the pre-TSST time point, and used in subsequent analyses. This has been used in the literature previously because the mid-point is the peak point of activation of the stress response, compared to the other possible time points within the protocol (Hellhammer & Schubert, 2012). Use of the post-pre-TSST change scores produced a similar pattern of results to that of the mid-pre-TSST change scores, and thus only the mid-TSST minus pre-TSST change score analyses are presented in the results section.

Manipulation Check

To test whether the TSST was effective at inducing the stress response, repeated measures ANOVAs were performed to assess differences in acute stress (heart rate, SBP, DBP, cortisol, and state anxiety) across the TSST. Post-hoc analyses using the Bonferroni correction were used to determine where any significant differences occurred.

Correlational Analyses

Partial correlations were used to test the first hypothesis that physical activity and trait mindfulness would be negatively associated with trait anxiety, chronic stress, and depression. Gender was entered as a covariate, as there are reported gender differences in the symptoms of trait anxiety (Lewinsohn, Gotlib, Lewinsohn, Seeley, & Allen, 1998; McLean, Asnaani, Litz, & Hofmann, 2011), perceived stress (Matud, 2004), and depression (Findlay, 2017; Salk, Hyde, & Abramson, 2017),

Partial correlations were used to test the second hypothesis that physical activity and trait mindfulness would be negatively associated with change in acute stress with respect to the TSST. Gender was entered as a covariate, as there are known gender differences in mental health outcomes (Kelly, Tyrka, Anderson, Price, & Carpenter, 2008) and the acute stress response (Clemens Kirschbaum & Hellhammer, 1993).

Hierarchical Regression Analyses

Hierarchical regression analyses were used to determine the relative association of physical activity and mindfulness on mental health measures (trait anxiety, depression, and chronic stress) and change in acute stress with respect to the TSST (Δ heart rate, Δ SBP, Δ DBP, mid-TSST cortisol, and Δ state anxiety). Gender was entered as a covariate in step 1 of all regression analyses, with gender coded as 1=female, 2=male. In Model A, gender was entered in step 1, followed by physical activity in step 2, and trait mindfulness in step 3, to determine whether adding trait mindfulness to the models explains additional variance over and above that of than physical activity alone.

RESULTS

Demographic information is presented in Table 1. Of all the data, 1.2% were outliers (SBP = 4, DBP = 4, Cortisol = 8, STAI-6 = 2) and were removed from subsequent analyses and 1.5% of the data were missing due to technological issues (Rec-TSST HR = 5, Rec-TSST SBP = 5, Rec-TSST DBP = 5, Rec-STAI-6 = 4). Little's MCAR test was non-significant ($p = .17$), indicating that the data were missing completely at random. Thus, given the few cases that were identified as outliers or missing no replacement strategy was used, and all analyses used pairwise deletion of missing value cases (Schafer, 1999). All variables were normally distributed and had skewness and kurtosis within the acceptable normal range (±2 and < ±4, respectively). Physical activity and trait mindfulness were correlated ($r(47) = .34$, $p = .02$); multicollinearity poses a problem when the VIF is greater than 10, and the tolerance statistic is less than .1 (Field, 2013). In all analyses, the VIF was 1.13 and tolerance was .88, indicating low collinearity and no issues with performing hierarchical regression analyses.

Mean physical activity, trait mindfulness, and mental health scores are presented in Table 2. The mean physical activity level was 5183 MET mins/week. Without factoring in intensity of activity, this translates to an average of 113 minutes of total physical activity per week, with an average of 42 minutes of moderate-to-vigorous physical activity per week. This is below the CSEP Canadian Physical Activity Guidelines of 150 moderate-to-vigorous physical activity minutes per week (Canadian Society for Exercise Physiology, 2017). The mean trait anxiety score was 44.5, which is in the average to elevated range for young adults (scores of 40+ are considered mild for trait anxiety) (Julian, 2011). The mean chronic stress was 18.7, indicative of moderate chronic stress (under 14 = low stress; 14-26 = moderate, 27-40 = high stress) (Cohen, 1994). Participants were on average non-depressed, with a mean BDI-II score of 11, which is indicative of a healthy, non-depressed sample (>13 indicates mild depression, >19 indicates moderate to severe depression) (Whisman & Richardson, 2015). Finally, the mean trait mindfulness score was 50.3, which indicates a meditation-naïve sample that has not participated in extensive mindfulness-based training or meditation (Baer, Smith, Lykins, Button, Krietemeyer, et al., 2008).

Manipulation Check

Acute stress measures were tracked across the TSST and are presented in Tables 3 and 4. Repeated measures ANOVAs conducted on the acute stress measures revealed a main effect of time for heart rate ($F(3,42) = 53.89$, $p < .001$), SBP ($F(3,40) = 3.43$, $p = .019$), DBP ($F(3,40) = 6.48$, $p = .002$), and state anxiety $F(3,43) = 31.12$, $p < .001$. As reported in Table 3, all measures significantly increased from pre to mid, remained elevated from mid to post, and significantly decreased from post to recovery, returning back to statistically non-significantly different from baseline. However, cortisol did not follow this same trajectory. Pre-TSST cortisol levels were elevated at baseline, and fell gradually at the beginning of the TSST before stabilizing. This unexpected pattern suggests that a true baseline measure of cortisol may not have been captured, and therefore cortisol was analyzed at the mid-TSST time point, rather than calculating a change score.

Correlational Analyses

Mental Health

Partial correlations between physical activity, trait mindfulness, and mental health measures, controlling for gender, are presented in Table 5. Physical activity and trait mindfulness were positively correlated ($r(47) = .34$, $p = .02$). Physical activity was negatively correlated with trait anxiety ($r(47) = -.29$, $p = .04$) and chronic stress ($r(47) = -.27$, $p = .04$) and displayed a trending negative correlation with depression ($r(47) = -.25$, $p = .09$). Similarly, trait mindfulness was negatively correlated with trait anxiety ($r(47) = -.64$, $p < .01$), chronic stress ($r(47) = -.67$, $p < .01$), and depression ($r(47) = -.63$, $p < .01$).

Changes in Acute Stress

Partial correlations between physical activity, trait mindfulness, and change in acute stress measures, controlling for gender, are presented in Table 6. Physical activity was negatively correlated with change in HR ($r(47) = -.37$, $p = .01$), mid-TSST cortisol ($r(43) = -.38$, $p = .03$), and change in state anxiety ($r(47) = -.36$, $p = .01$). Trait mindfulness displayed a trending negative correlation with change in HR (pre-TSST to mid-TSST) ($r(47) = -.27$, $p = .06$) but was not associated with mid-TSST cortisol ($r(43) = -.11$, $p = .49$) or change in state anxiety (pre-TSST to mid-TSST) ($r(47) = -.03$, $p = .81$). Neither physical activity nor trait mindfulness were associated with SBP or DBP (see Table 6).

Hierarchical Regression Analyses

Mental Health

Overall, the hierarchical regression analyses for mental health measures revealed that trait mindfulness accounted for additional variance over and above that accounted for by physical activity alone.

Trait Anxiety

The hierarchical regression revealed that at step 1, gender significantly contributed to the regression model, $F(1, 48) = 4.91$, $p = .03$) and accounted for 9.3% of the variability in trait anxiety with females reporting higher trait anxiety than males. Introducing the physical activity in step 2 explained an additional 7.3% of variance (16.9% overall) of variance in trait anxiety and this change in R^2 was significant, $\Delta F(1, 48) = 4.30$, $p = .04$. Adding trait mindfulness into the regression model in step 3 explained an additional 29.3% of the variance (46.6% overall) of the variance in trait anxiety and this change in R^2 was significant, $\Delta F(1, 46) = 25.64$, $p < .001$.

Chronic Stress

The hierarchical regression revealed that at step 1, gender significantly contributed to the regression model, $F(1, 48) = 5.94$, $p = .02$) and accounted for 11% of the variability in chronic stress with females reporting higher chronic stress than males. Introducing the physical activity in step 2 explained an additional 6.3% of variance (17.3% overall) in chronic stress and this change in R^2 was trending in significance, $\Delta F(1, 47) = 3.60$, $p = .06$. Adding trait mindfulness to the regression model in step 3 explained an additional 33.4% of variance (50.7% overall) in trait anxiety and this change in R^2 was significant, $\Delta F(1, 46) = 31.17$, $p < .001$.

Depression

The hierarchical regression revealed that at step 1, gender did not significantly contribute to the regression model, $F(1, 48) = 2.51$, $p = .12$) and accounted for 5% of the variability in depression with females reporting higher depression than males. Introducing the physical activity in step 2 explained an additional 5.8% of variance (10.8% overall) in depression and this change in R^2 was not significant, $\Delta F(1, 47) = 3.07$, $p = .09$. Adding trait mindfulness into the regression model in step 3 explained an additional 31.8% of variance (42.6% overall) in depression and this change in R^2 was significant, $\Delta F(1, 46) = 25.50$, $p < .001$.

Acute Stress

Overall, the hierarchical regression analyses for acute stress measures revealed that trait mindfulness *did not* account~~ed~~ for additional variance over and above that accounted for by physical activity alone.

Heart Rate

The hierarchical regression revealed that at step 1, gender did not significantly contribute to the regression model, $F(1, 48) = .01$, $p = .93$) and accounted for 0% of the variability in change in heart rate. Introducing the physical activity in step 2 explained an additional 13.5% of variance (13.5% overall) in change in heart rate, and this change in R^2 was significant, $\Delta F(1, 47) = 7.34$, $p = .01$. Adding trait mindfulness into the regression model in step 3 explained an additional 2.2% of the variance (15.7% overall) in change in heart rate, and this change in R^2 was not significant, $\Delta F(1, 46) = 1.20$, $p = .28$.

Systolic Blood Pressure

The hierarchical regression revealed that at step 1, gender did not significantly contribute to the regression model, $F(1, 46) = .72$, $p = .40$) and accounted for 1.5% of the variability in change in SBP. Introducing the physical activity in step 2 explained an additional 0.1% of variance (1.6% overall) in change in SBP, and this change in R^2 was not significant, $F(1, 45) = .00$, $p = .96$. Adding trait mindfulness into the regression model in step 3 explained no additional variance (1.6% overall) in change in SBP, and this change in R^2 was not significant, $F(1, 44) = .01$, $p = .94$.

Diastolic Blood Pressure

The hierarchical regression revealed that at step 1, gender did not significantly contribute to the regression model, $F(1, 46) = .18$, $p = .68$) and accounted for 0.4% of the variability in change in DBP. Introducing the physical activity in step 2 explained and additional 0.9% of variance (1.3% overall) in change in DBP, and this change in R^2 was not significant, $\Delta F(1, 45) =$

.40, $p = .53$. Adding trait mindfulness into the regression model in step 3 explained and additional 1.9% of variance (3.2% overall) in change in DBP, and this change in R^2 was not significant, $\Delta F(1, 44) = .88$, $p = .35$.

Cortisol

The hierarchical regression revealed that at step 1, gender significantly contributed to the regression model, $F(1, 44) = 4.59$, $p = .03$) and accounted for 9.5% of the variability in mid-TSST cortisol with higher cortisol in males than females. Introducing the physical activity in step 2 explained an additional 5.1% of variance (14.6% overall) in mid-TSST cortisol, and this change in R^2 was not significant, $\Delta F(1, 43) = 2.59$, $p = .12$. Adding trait mindfulness into the regression model in step 3 explained an additional 0.1% of variance (14.7% overall) in mid-TSST cortisol, and this change in R^2 was not significant, $\Delta F(1, 42) = .03$, $p = .86$.

State Anxiety

The hierarchical regression revealed that at step 1, gender did not significantly contribute to the regression model, $F(1, 48) = 2.831$, $p = .09$) and accounted for 5.6% of the variability in change in state anxiety. Introducing the physical activity in step 2 explained and additional 12.4% of variance (18% overall) in change in state anxiety, and this change in R^2 was significant, $\Delta F(1, 47) = 7.13$, $p = .01$. Adding trait mindfulness into the regression model in step 3 explained an additional 0.9% of variance (18.9% overall) in change in state anxiety, and this change in R^2 was not significant, $\Delta F(1, 46) = .49$, $p = .49$.

DISCUSSION

Prior research has suggested that physical activity increases trait mindfulness. We sought to determine whether trait mindfulness accounted for unique variance over and above that of physical activity when predicting indicators of mental health and acute responses to a psychological stressor. With respect to mental health, both physical activity and trait mindfulness were negatively correlated with mental health; however, trait mindfulness accounted for unique variance over and above that of physical activity. In contrast, reactivity to an acute psychosocial stressor was negatively correlated with only physical activity and trait mindfulness was not associated.

The observation that an individual's trait mindfulness can predict their mental health status is in line with prior research reporting a strong association between trait mindfulness and mental health (Bränström et al., 2011; Brisbon & Lowery, 2011; Carmody & Baer, 2008; Grossman et al., 2004; Khoury et al., 2015; Sharma & Rush, 2014), which is largely attributed to the development of non-judgemental and non-reactive acceptance of one's thoughts (Kabat-Zinn, 1982). This way of thinking minimizes negative reactivity and rumination (Kabat-Zinn, 1982; Segal, Teasdale, Williams, & Gemar, 2002) while also enhancing emotional and cognitive flexibility when faced with negative situations (Gu, Strauss, Bond, & Cavanagh, 2015), and thus, is believed to aid in enhancing mood and reducing stress and anxiety. Indeed, we observed that symptoms of stress, anxiety and depression were associated with trait mindfulness over and above that of physical activity, suggesting that trait mindfulness may be an important characteristic to foster to support mental health.

Yet, when considering the response to an acute psychological stressor, trait mindfulness did not explain unique variance in participants' responses beyond that accounted for by physical activity. These results point to a dissociation between general mental health versus acute stress reactivity, such that trait mindfulness may be more important for promoting mental health rather than mitigating stress reactivity. This finding is somewhat surprising given that practicing mindfulness helps develop specific cognitive, emotional, and behavioural strategies for maintaining a calm state of mind that increases mood and reduces anxiety and stress. However, it is not specifically designed to evoke any advantageous *physiological* adaptations that minimize stress reactivity, such as increased heart rate, in the face of an immediate threat (Kabat-Zinn, 1982).

In contrast, physical activity was associated with stress reactivity such that individuals who were more physically active had lower heart rate and less state anxiety when dealing with an acute psychological stressor. Unlike mindfulness practice, physical activity induces a controlled and temporary activation of the stress response to elicit physiological and psychological adaptations (Sothmann et al., 1989). Our results lend support for the cross-stressor adaptation hypothesis, which purports that physical activity-related adaptations would minimize one's reactivity to all types of stressors, even psychological ones as demonstrated here.

Higher levels of physical activity were also associated with better mental health, which is consistent with prior research (Blumenthal, Babyak, Moore, Craighead, Herman, Khatri, Waugh, Napolitano, Forman, Appelbaum, Doriaswamy, & Krishnan, 1999; Byrne & Byrne, 1993; Josefsson et al., 2013; Norris & Carroll, 1992; Petruzzello et al., 1991; Steptoe et al., 1989) and points to two distinct benefits of physical activity for psychological wellbeing: one that reduces stress reactivity and one that promotes trait mindfulness to improve mental health. The novel finding here was that mindfulness accounted for unique variance related to mental health over and above that of physical activity alone. Given the propensity of some physical activities to foster trait mindfulness (Asztalos et al., 2012; Salmon et al., 2010), the results have important implications for physical activity intervention strategies designed to improve mental health that need to be tested. For example, a future physical activity intervention designed to improve mental health and reduce stress reactivity may need to be sufficient in intensity and frequency to induce physiological and psychological adaptations of the stress system, yet also include elements that promote the development of trait mindfulness over time, such as aerobic exercise with a rhythmic element (e.g., swimming, biking, running) or physical activities with an explicit mindfulness component (e.g., yoga, tai chi).

Although the primary focus of the study was on the predictive relationships between physical activity and trait mindfulness and mental health and acute responses to stress, gender was also associated with mental health measures. Females reported significantly higher trait anxiety and chronic stress, and tended (though not significantly so) to have higher depression. This is consistent with prior research (Lewinsohn et al., 1998; McLean et al., 2011; Matud, 2004; Findlay, 2017; Salk et al., 2017), and suggests that females may be more susceptible to mental health issues than males. We also observed as association between gender and cortisol during the acute psychological stressor; however, in this case, males had higher cortisol than females indicating greater reactivity. The observation that males have greater cortisol reactivity to psychosocial stress than females is well documented in the literature (Liu et al., 2017; Taylor et al., 2000), and includes higher CRH, ATCH, and cortisol reactivity to the TSST (Uhart, Chong, Oswald, Lin, & Wand, 2006). It is unclear exactly what causes this gender difference but it may be related to the HPA axis and its release of cortisol in response to a threat as a way to prepare the body to fight, flee, and survive (Boyce & Ellis, 2005; Charmandari et al., 2005). Evolutionarily, when faced with an acute threat such as a predator, males and females differed in their roles: while males confronted the threat, females tended to their offspring and united social groups to maximize their cases of survival (Taylor et al., 2000; Wang et al., 2007). This is termed the “Tend-and-Befriend Theory” (Taylor et al., 2000), and suggests that males may have a higher hormonal response to acute stress, specifically greater cortisol reactivity, that enables them to quickly confront a predator or overcome environmental threat. In contrast, females are thought to exhibit the same fight-or-flight response, coincident with a "tend-and-befriend" response that initiates caregiving processes which may slightly buffer cortisol reactivity to an immediate threat in comparison (Wang et al., 2007). Although this gender difference makes females less stress reactive, it may make them more susceptible to mental illness when under with chronic stress. Starting in adolescence, females are more likely than males to respond to stress with rumination and an inward focus on distress and personal feelings, rather than taking outward action to determine a cause or solution to this distress (Hoeksema, 2001). Longitudinal studies suggest that rumination is a risk factor for the development of many types of psychopathology, including depression and anxiety (Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008) because it causes chronic activation of the HPA leading to dysfunction. While intriguing, more empirical research is needed to fully test this evolutionary theory.

An unexpected observation was that cortisol was elevated at baseline and decreased during the experimental session despite administration of the acute psychological stressor. At the same time, we observed increased heart rate and state anxiety, which confirms that our administration of the TSST was sufficient to evoke a stress response. Although stress-related increases in heart rate and state anxiety are typically accompanied by increases in cortisol (Gerra et al., 2001; Kirschbaum, Pirke, & Hellhammer, 1993; Puterman et al., 2011; Rimmele et al., 2009, 2007), there are important differences in the temporal dynamics of their responses to a stressor that may be attributing to the observed differences. Relative to the onset of a stressor, heart rate peaks within approximately one to five minutes, whereas cortisol may not reach peak levels until after ten to 30 minutes (Brown, Weinstein, & Creswell, 2012; Rimmele et al., 2007). Following the cessation of the stressor, heart rate also recovers faster than cortisol, which can remain elevated for minutes to hours (Dhabhar, 2014). Given that the acute stressor was administered for ten minutes and our final measurement of the stress responses was taken 15 minutes post, this would have provided a sufficient time widow to capture the peak and recovery of heart rate but not cortisol.

Our other measure of the cardiovascular response to stress, namely SBP and DBP, showed a similar peak and recovery as heart rate, though the relative changes were not significant and neither SBP nor DBP were associated with either physical activity or trait mindfulness. There are differences in exercise-training adaption rates of heart rate and blood pressure that may suggest these cardiovascular measures may respond differently to an acute stress. It is also possible that SBP and DBP may not have been as robust as heart rate on account of measurement error. Ideally, automated blood pressure measurements are taken twice, one to two minutes apart after five minutes of quiet rest, and the average of the two measurements are taken (Myers, Valdivieso, & Kiss, 2008); but because of the time-sensitive nature of the TSST we were only able to take blood pressure once after one minute of quiet rest, and this may have created additional variance.

Limitations and Future Directions

The current study is not without limitations. Although the stress system was clearly activated by the TSST, we were unable to capture a predicted acute cortisol response. Cortisol was elevated at baseline and this is likely the consequence of testing undergraduate student participants. Prior to our experimental session, engaging in strenuous schoolwork or testing may have activated the HPA axis and resulting in elevated baseline cortisol. Thus, we are unable to make definitive conclusions regarding cortisol reactivity and its association with physical activity or trait mindfulness. Given the gradual rise and fall of cortisol to an acute stressor, a more accurate reading of cortisol may have been achieved by extending the sampling period to include more quiet rest time before and after the TSST. We only measured the participants' physical activity rather than their physical fitness. Although our results are consistent with the cross-stressor hypothesis, a central tenet of this theory is that the development of physical fitness is an important driver of the physiological adaptations to repeated exercise stress (Sothmann et al., 1989). It follows that fitness may play an important role in the establishing stress reactivity. Future studies should include a measure of aerobic fitness, such as VO_2 max, in concert with a physical activity questionnaire (as used here) to gain a more well-rounded picture of the relationship between physical activity, physical fitness, stress reactivity, and mental health

Conclusion

We examined the association between physical activity and mindfulness, and their relative associations with acute stress reactivity and mental health. Specifically, we examined whether trait mindfulness accounted for unique variance after controlling for physical activity. Hierarchical linear regression revealed a distinct pattern, such that physical activity was more strongly associated with acute stress (heart rate and state anxiety reactivity), whereas trait mindfulness was more strongly associated with mental health even after controlling for physical activity. The results suggest that physical activity and trait mindfulness may work via synergistic mechanisms to enhance wellbeing with physical activity reducing stress reactivity and trait mindfulness improving overall mental health. The results may help to inform the implementation of physical activity for mental health promotion, such that activities with a natural mindfulness component may be more effective at enhancing mental health and mitigating stress reactivity.

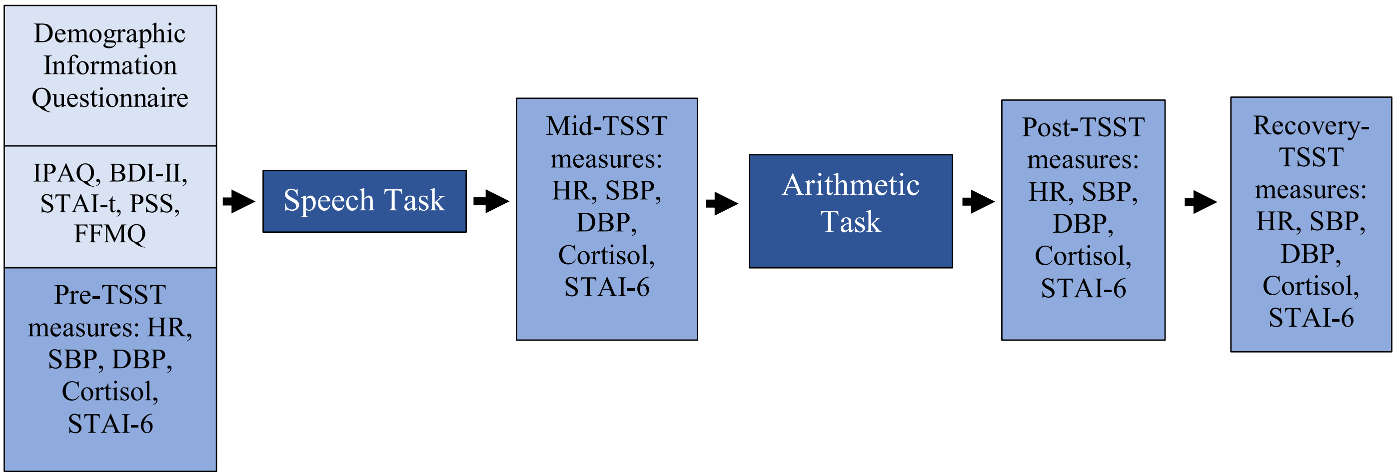

Figure 1. Study design. Questionnaires on demographic information, physical activity, trait mindfulness, and mental health were administered, followed by the pre-TSST acute stress measures. The TSST speech task and arithmetic tasks were presented, with the mid-TSST measures taken in between. Following the arithmetic task, the post-TSST measures were taken, and 15 minutes later, the recovery-TSST measures were taken.

Table 1. Demographic information

Variable	
Mean Age in years (SD)	19 (0.2)
	Count (Frequency %)
Sex	
Female	29 (58%)
Male	21 (42%)
Year of university	
1	33 (66%)
2	9 (18%)
3	5 (10%)
4	2 (4%)
5+	1 (2%)
Faculty	
Science	29 (58%)
Health Science	8 (16%)
Social Science	6 (12%)
Business	3 (6%)
Arts & Science	2 (4%)
Humanities	1(2%)
Engineering	1(2%)

Table 2. Baseline scores for physical activity, trait mindfulness and mental health.

	Mean (SD)	Range
Physical Activity	5183.4 (3998.6)	132-19595
Trait Mindfulness (max=75)	50.3 (8.0)	33-68
Depression (max = 63)	11.0 (7.7)	0-31
Trait Anxiety (max=80)	44.5 (10.3)	25-64
Chronic Stress (max=40)	18.7 (7.2)	6-32

Table 3. Acute stress measures tracked across the TSST

	Pre	Mid	Post	Recovery
Heart rate (bpm)	76.0 (10.1)	89.7 (14.2)	89.5 (12.9)	74.027 (9.708)
SBP (mmHg)	118.4 (14.7)	123.2 (14.0)	121.9 (14.6)	118.5 (13.3)
DBP (mmHg)	73.2 (7.1)	77.0 (7.3)	76.0 (7.4)	75.94 (6.8)
Cortisol (ng/mL)	4.1 (2.3)	3.2 (1.5)	3.5 (2.1)	3.4 (2.2)
State Anxiety (max score=80)	30.5 (8.3)	40.7 (12.1)	39.1 (10.4)	28.1 (7.7)

Note: Raw values are presented as Mean (Standard Deviation), without adjusting for covariates.

Table 4. Partial correlations between physical activity, trait mindfulness, and mental health, controlling for gender

	1.	2.	3.	4.	5.
1. Physical Activity	-				
2. Trait Mindfulness	.34*	-			
3. Depression	-.25†	-.63**	-		
4. Trait Anxiety	-.29*	-.64**	.76**	-	
5. Chronic Stress	-.27*	-.67**	.72**	.82**	-

Note: $^{*}p < .05$, $^{**}p < .01$, † trending correlation (p = .5-.8).

Table 5. Partial correlations between physical activity, trait mindfulness, and change in acute stress, controlling for gender

	1.	2.	3.	4.	5.	6.	7.
1. Physical Activity	-						
2. Trait Mindfulness	.34*	-					
3. Change in HR	-.37*	-.27†	-				
4. Change in SBP	-.01	.01	.05†	-			
5. Change in DBP	-.09	-.16	.12†	.62**	-		
6. Mid-TSST Cortisol	-.38*	-.11	.14	-.13	-.10	-	
7. Change in State Anxiety	-.36*	-.03	.16	-.11	-.12	-.24	-

Note: Changes in HR, SBP, DBP, and state anxiety are from pre-TSST to mid-TSST.
* $p < .05$, ** $p < .01$, † trending correlation (p = .5-.8)

Table 6. Regression: Mental health

		Trait Anxiety		Chronic Stress		Depression	
	Predictor	ΔR^2	β	ΔR^2	β	ΔR^2	β
Step 1:							
	Gender	.093	-.31*	.110	-.33*	.05	-.22
Step 2:							
	Gender		-.28*		-.31*		-.20
	PA	.076*	-.28*	.063†	-.25†	.058	-.24†
Step 3:							
	Gender		-.29**		-.32*		-.22†
	PA		-.08		-.04		-.04
	Trait MF	.298**	-.58**	.334**	-.62**	.318**	-.60**

Note: Gender was coded as 1=female, 2=male.
$^{*} = p < .05$, $^{**} = p < .01$, † = trending (p = .5-.8).

Table 7. Regression: Change in acute stress

		ΔHR		ΔSBP		ΔDBP		Mid-TSST Cortisol		ΔState Anxiety	
	Predictor	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β
Step 1:											
	Gender	.00	-.01	.02	-.124	.00	-.06	.10	.31*	.06	-.24
Step 2:											
	Gender		-.02		-.13		-.05		.33*		-.20
	PA	.14**	.37**	.00	.01	.01	.10	.10	.29	.12**	.35*
Step 3:											
	Gender		.02		-.13		-.06		.33*		-.20
	PA		-.32*		.00		-.04		-.22		-.39**
	Trait MF	.02	-.16	.00	.01	.02	.15	.00	.03	.01	.10

Note: Gender was coded as 1=female, 2=male. * = $p < .05$, ** = $p < .01$, † = trending (p = .5-.8). Changes in HR, SBP, DBP, and state anxiety are from pre-TSST to mid-TSST.

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