Associations Between Physical Activity and Posttraumatic Stress Disorder: A Systematic Review and Daily Diary Study

by

Raquel B. Graham
B.A., University of British Columbia, 2012
M.Sc., University of Victoria, 2016

A Dissertation Submitted in Partial Fulfillment
of the Requirements for the Degree of

DOCTOR OF PHILOSOPHY

in the Department of Psychology

Supervisory Committee

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Abstract

There is growing evidence to suggest an inverse association between physical activity and symptoms of posttraumatic stress disorder (PTSD). However, the mechanisms are not well understood and much of the research in this area stems from cross-sectional studies, thereby limiting what is known about these relationships at the intra-individual level. Chapter 1 of this dissertation is a systematic review examining the literature on the association between physical activity and PTSD in a variety of study designs (i.e., cross-sectional, longitudinal, and intervention). Chapters 2 and 3 used data from a 7-day diary study of 15 participants with a diagnosis of PTSD. In this study, participants completed twice daily surveys on mobile phones and wore Fitbit accelerometers measuring physical activity and sleep. Chapter 2 used multilevel modeling to examine the within-person and between-person associations between physical activity and symptoms of PTSD, sleep, positive and negative affect, and coping. Multiple operationalizations of physical activity were used (i.e., self-report and accelerometer-measured) in order to explore and better understand which metrics are most strongly related to psychosocial factors. Results from Chapter 2 add to the literature by providing evidence of within-person associations between physical activity and PTSD symptoms over the course of the day, such that on days when participants are more physically active than usual, they also report fewer symptoms of PTSD that evening. Chapter 3 discusses the utility of using N-of-1 study designs with an emphasis on the benefits of using frequent repeated measurements in clinical practice. Three case examples are presented to illustrate the intra-individual variability that is observed in symptoms of PTSD, affect, and health behaviours. These examples provide rationale for

the use of intensive measurement designs in order to fully capture and understand how and when variables fluctuate over time.

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Acknowledgments

I would like to express sincere gratitude to my supervisor, Dr. Scott Hofer, for the guidance and encouragement he has provided throughout my graduate training. This dissertation would not have been possible without his mentorship and I appreciate his support in my pursuit of bringing together my research and clinical interests. I would like to thank my supervisory committee members, Dr. Eli Puterman and Dr. Brianna Turner for their expertise, support, and time dedicated to this project, from the initial conceptualization of the study design through to the defence. I would also like to express my gratitude to Dr. Tamara Goranson who helped spark my interest in studying PTSD during a practicum placement – thank you for your contributions to this study design and for your assistance with recruitment.

I would like to thank my lab members for their invaluable contributions to this research. This work would not have been possible without the data management and analysis support from Dr. Jonathan Rush. I would also like to thank Rebecca Vendittelli and Tomiko Yoneda who assisted with data collection and the systematic review. I wish to sincerely thank my PhD and residency cohorts for the endless support, encouragement, and laughter – I can't imagine being on this journey alongside anyone else. To my husband, Peter, thank you for supporting me throughout my academic endeavors and for believing in me, especially during times of self-doubt. Thank you to my family for your unwavering encouragement, love, and support.

Finally, I am grateful for the financial assistance received from the Canadian Institutes of Health Research (CIHR), the Integrative Analysis of Longitudinal Studies of Aging research network, and the University of Victoria.

Prologue

This dissertation consists of three separate, but related papers examining the associations between physical activity and symptoms of PTSD. The overall aims of this dissertation were to a) critically evaluate the literature in this area and identify gaps requiring further study, b) address one of these gaps by conducting the first intensive measurement design study examining the intra-individual associations between physical activity and PTSD symptoms, and c) review the literature on N-of-1 studies in the behavioural sciences and illustrate the advantages of using intensive measurement designs in clinical practice through three case examples. Common to all three chapters is an emphasis on the importance of repeated measurement designs, the benefits of incorporating multiple measures of physical activity (i.e., self-report and accelerometer-derived), and considerations for clinical practice. While these common threads exist throughout this dissertation, the chapters are written as distinct papers to be submitted for publication independently. As a result, some redundancies exist throughout the dissertation overall, particularly in the introductory sections.

Chapter 1: Associations between physical activity and posttraumatic stress disorder: A systematic review of the evidence

Abstract

A growing body of research suggests that greater levels of physical activity are associated with fewer symptoms of posttraumatic stress disorder (PTSD). However, this is a relatively new area of exploration and there is a need for a comprehensive review of the evidence to-date. This systematic review aimed to summarize the literature on physical activity in relation to symptoms of PTSD from studies using a variety of designs (e.g., observational, intervention). Eligible studies included original research reporting the associations between physical activity (self-report or measured) and diagnosis and/or symptoms of PTSD in adults with a diagnosis of PTSD or reported trauma history. The search protocol yielded 21 eligible studies (8 cross-sectional, 5 prospective, and 8 interventions). Across designs, the majority of studies provided support for an inverse association between physical activity and PTSD symptoms. The findings from longitudinal and intervention studies suggest that the association may be reciprocal, such that a diagnosis of PTSD predicts reductions in exercise over time, while greater levels of exercise predict reductions in PTSD symptoms. In studies that looked at specific symptom clusters, hyperarousal symptoms were most strongly associated with physical activity. The findings from this systematic review suggest that physical activity interventions may be a useful standalone or adjunctive treatment component for individuals with PTSD, particularly in terms of reducing hyperarousal symptoms.

Background

Posttraumatic Stress Disorder (PTSD) is a common, often chronic, psychiatric condition with a lifetime prevalence of approximately 6.1% and past-year prevalence of 4.7% (Goldstein et al., 2016). PTSD is characterized by the persistence of symptoms for at least one month after experiencing or witnessing a traumatic event. In the current version of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5), PTSD symptoms are divided into four clusters: *re-experiencing, avoidance, negative alterations in cognitions and mood,* and *hyperarousal*. Changes from the previous diagnostic criteria (DSM-IV-TR) included moving from a 3-factor model (*re-experiencing, avoidance/numbing, and hyperarousal*) to a 4-factor model with the addition of *negative alterations in cognitions and mood*.

Current treatments for PTSD include psychotherapy and pharmacological intervention (Cipriani et al., 2018; Tran & Gregor, 2016). The most recent American Psychological Association (APA) treatment practice guideline for the treatment of PTSD strongly recommends cognitive behavioral therapy (CBT), cognitive processing therapy (CPT), cognitive therapy (CT), and prolonged exposure therapy (PE) as front-line therapies for PTSD (American Psychological Association, 2017). The guideline also suggests the use of fluoxetine, paroxetine, sertraline, or venlafaxine for pharmacological intervention. However, many individuals with PTSD experience barriers to seeking and/or maintaining treatment (e.g., cost, stigma, drop-out, side-effects). Findings from a nationally representative study indicate that among those who report lifetime PTSD, approximately 59% report seeking some form of treatment (Goldstein et al., 2016). In this study, treatment most commonly consisted of talking with a healthcare provider, counsellor, or therapist (54%), taking prescribed medications (33%), or self-help/support groups (17%). On average, individuals reported a delay of 4.5 years between onset of PTSD and treatment seeking.

Reasons for this time lag may include concerns regarding stigma, financial burden or insurance concerns, and complexities related to comorbid conditions such as alcohol use disorder and major depressive disorder (Goldstein et al., 2016). Stecker and colleagues (Stecker, Shiner, Watts, Jones, & Conner, 2013) examined barriers associated with the decision to not seek treatment in a sample of 143 military veterans who screened positive for PTSD. They identified four main categories of beliefs associated with treatment barriers: stigma, emotional readiness, concerns about treatment, and logistical issues. Some of the predominant treatment concerns included not feeling emotionally ready (35%) and concern that treatment would require taking prescription medication (26%). Interestingly, many participants in this study expressed resistance to taking medication for psychological symptoms. Taken together, the relatively low rates of treatment seeking, the lagged treatment trend, and the aforementioned barriers put individuals with PTSD at risk for a variety of psychological and physical health problems. There is a clear need to better support individuals with PTSD who may not be receiving formal treatments.

A lifestyle intervention such as physical activity may be one such opportunity to support individuals with PTSD who experience some of the previously described treatment barriers. Physical activity has been shown to be an effective stand-alone or adjunctive treatment for depression and anxiety (Asmundson et al., 2013; Josefsson, Lindwall, & Archer, 2014). However, research investigating the potential therapeutic effects of physical activity on symptoms of PTSD is a relatively recent development. Findings from observational research generally support an inverse relationship between physical activity and PTSD, such that individuals with a diagnosis of PTSD are less likely to exercise compared to individuals without PTSD (Zen, Whooley, Zhao, & Cohen, 2012), and higher levels of exercise are associated with less severe PTSD symptoms in trauma-exposed adults (Vujanovic, Farris, Harte, Smits, &

Zvolensky, 2013). Randomized controlled trials have provided initial evidence that physical activity may be an effective intervention for the treatment of PTSD symptoms (Goldstein et al., 2018; Rosenbaum et al., 2015).

To date, four review papers have been published the topic of exercise and PTSD (Caddick & Smith, 2014; Hall, Hoerster, & Yancy, 2015; Rosenbaum et al., 2015; Whitworth & Ciccolo, 2016). Most of these reviews feature a limited scope with respect to study design or population. For example, Rosenbaum and colleagues (2015) published a systematic review and meta-analysis on randomized controlled trial (RCT) intervention designs. In this review, four unique RCTs were eligible and the results provided support for physical activity as an efficacious intervention in reducing PTSD symptoms. Two of the eligible studies were aerobic and/or resistance exercise and two were yoga interventions. The yoga studies were stand-alone interventions, whereas the aerobic exercise interventions were adjunctive to either prolonged exposure therapy or usual care. A more recent systematic review by Whitworth and Ciccolo (2016) examined the association between physical activity and PTSD specifically in studies of military veterans. Thirteen studies with varied designs (observational, experimental, qualitative) were included. Overall, greater levels of physical activity were associated with lower PTSD symptoms in military veterans. However, some conclusions were limited by the heterogeneity of study designs and outcome measures. For instance, not all studies measured PTSD or physical activity, such as a qualitative study reporting on the effects of recreational surfing and the natural environment on veterans' overall well-being (Caddick, Smith, & Phoenix, 2015). Additionally, it is not clear whether these findings extend to non-military trauma populations.

A third systematic review focused on the impact of physical activity and sport on combat veterans' well-being (Caddick & Smith, 2014). Six of the 11 studies included in this review were

qualitative designs and only four studies included samples with a PTSD diagnosis. Although Caddick & Smith's review represents an important contribution to the literature by demonstrating that participation in sport and physical activity are associated with enhanced well-being in military veterans, the focus was not on PTSD specifically and few studies reported on PTSD symptomology at all. To date, the most comprehensive review of PTSD and physical activity was published by Hall and colleagues in 2015 (Hall et al., 2015). The paper included studies on eating behaviors as well, but only the findings related to physical activity will be summarized here. The review identified 10 observational studies reporting associations between PTSD and physical activity, two prospective studies, and two pilot intervention studies. Overall, there were mixed findings with respect to the cross-sectional associations between physical activity and PTSD status or PTSD symptom severity. Findings from the prospective studies and pilot interventions support the notion that changes in physical activity are associated with reductions in PTSD symptoms.

There was limited overlap among these four reviews. Out of a total of 43 papers, only four papers were included in more than one review, and no papers were included in more than two of the four reviews. This minimal overlap likely reflects the degree to which selection criteria were quite specific (e.g., only RCTs) or quite broad (e.g., military veterans with or without PTSD). While these reviews are valuable contributions to literature, there remains a need for a more comprehensive review on the current evidence examining the relationship between physical activity and PTSD from multiple study designs and populations (e.g., civilian and military).

The purpose of this systematic review is to summarize the published literature on the association between physical activity and PTSD symptoms, with particular emphasis on

considering study design and identifying areas requiring further investigation. Unlike previously published reviews in this area, this paper aims to encompass evidence from a variety of study designs and populations who are affected by PTSD (e.g., military veterans, civilians), and therefore provide a more comprehensive summary of the current evidence.

Method

Literature Search, Eligibility Criteria, and Data Extraction

Studies were identified through electronic searches of PsycINFO, PsycARTICLES, and PubMed (Title/abstract/key words) using the following search terms: "physical activity *or* exercise *or* physical exercise *or* exercising", and "posttraumatic stress disorder *or* post traumatic stress disorder *or* post-traumatic stress disorder *or* PTSD". Studies were included if they examined the association between physical activity/exercise (self-reported or objectively measured) and diagnosis of and/ or symptoms of PTSD in adults with a PTSD diagnosis and/or trauma history. Studies not meeting these criteria were excluded, as were studies that featured yoga or tai chi as the type of activity, animal studies, studies in which the outcome and/or predictor variable(s) was assessed in childhood. Review papers and non-published reports were also excluded. Studies featuring yoga or tai chi were excluded based on previous research demonstrating significant heterogeneity compared to aerobic or resistance exercise and associations with mental health (i.e., depression; Bridle, Spanjers, Patel, Atherton, & Lamb, 2012). The initial search was completed in July 2018. It was updated in April 2019 and again in March 2020 to identify new articles published within this time frame. Two reviewers (PhD students) separately evaluated eligibility of each article and extracted relevant study characteristics to inform these decisions. Any discrepancies were reconciled through discussion. Reference lists were scanned for additional titles not identified in the electronic search. The initial search yielded 341 unique articles. After screening the titles and abstracts, 81 were reviewed in full-text, with 21 meeting eligibility for inclusion in this review. Eligible studies were further classified into the following categories based on study design: cross-sectional studies (i.e., studies reporting data from a single measurement occasion), prospective studies

(i.e., studies reporting data from at least two time points for at least one of the primary variables), and intervention studies (i.e., studies featuring a form of exercise intervention, either aerobic or resistance exercise, implemented using either a pre-post or randomized controlled design).

Results

Cross-Sectional Studies

Eight cross-sectional studies met criteria for this review. Details of the study characteristics and main findings are presented in Table 1.

Table 1. *Cross-Sectional Study Characteristics and Findings.*

Study	Population	Sample Size	Mean Age (SD)	% Male	Exercise Measure	PTSD Measure	Main Findings
Bourn et al., 2016	Veterans seeking PTSD treatment	239	50 (15.3)	91.1	GLTEQ	CAPS	Physical activity moderated association between pain and PTSD symptoms; individuals reporting high levels of pain had fewer PTSD symptoms if they were physically active.
Godfrey et al., 2013	Veterans & civilians	80	39.9 (13.5)	55	IPAQ-SF	CIDI	Participants with PTSD reported significantly fewer minutes of vigorous exercise than non-PTSD controls.
Harte et al., 2015	Trauma-exposed adults, not meeting full PTSD criteria	108	23.9 (10.22)	45	EHQ-R	PDS	Vigorous exercise was significantly associated with fewer hyperarousal symptoms. No associations between light- or moderate-intensity exercise and symptom severity.
Mason et al., 2019	Trauma-exposed adults	246	48.03 (12.45)	48	IPAQ-SF	PCL-5	PTSD symptoms were not associated with physical activity, but were associated with sedentary behaviour.
Rosenbaum et al., 2016	Inpatients with PTSD	76	47.6 (11.9)	83	IPAQ-SF	PCL-C	Significant negative association between PTSD symptoms and walking time; no significant relationship with moderate-to-vigorous activity.
Vujanovic et al., 2013	Trauma-exposed adults, not meeting full PTSD criteria	86	24.3 (10.54)	41.90	EHQ-R	PDS	Greater levels of exercise were significantly associated with fewer hyperarousal symptoms only.
Whitworth et al., 2017	National Sample with PTSD	165	33.7 (11.3)	26.70	GLTQ	PCL-C	Exercise was significantly associated with lower PTSD symptoms, particularly for men; strenuously active men reported significantly lower hyperarousal symptoms compared to strenuously active women.
Zen et al., 2012	Men and women with cardiovascular disease	1,024 (95 with PTSD)	61 (11)	76	Self-reported frequency in past month	CDIS for DSM-IV	Individuals with PTSD reported significantly higher rates of physical inactivity compared to non-PTSD controls.

Note: CIDI = The Composite International Diagnostic Interview; EHQ-R= Exercise Habits Questionnaire-Revised ; GLTEQ = Godin Leisure-Time Exercise Questionnaire; IPAQ-SF = International Physical Activity Questionnaire–Short Form; PCL-C = Posttraumatic Stress Disorder Checklist–Civilian version; PCL-5 = Posttraumatic Stress Disorder Checklist for DSM-5; PDS = Posttraumatic Diagnostic Scale.

The findings from these eight cross-sectional studies provide emerging evidence for an inverse relationship between physical activity and PTSD symptoms. Three of the studies demonstrated that greater levels of physical activity are specifically associated with fewer hyperarousal symptoms (Harte et al., 2015; Vujanovic et al., 2013; Whitworth, Craft, Dunsiger,

& Ciccolo, 2017). Two of the seven studies were conducted with military veterans (Bourn et al., 2016; Godfrey et al., 2013), and two studies included participants reporting trauma exposure without meeting full PTSD criteria (Harte et al., 2015; Vujanovic et al., 2013). Sample sizes ranged from 76 (Rosenbaum et al., 2016) to 1024 (Zen et al., 2012) and the average age of participants ranged from 23.9 (Harte et al., 2015) to 61 (Zen et al., 2012). All studies utilized a validated measure of PTSD symptoms, whereas measures of physical activity ranged from commonly used validated scales (e.g., the Godin Leisure-Time Exercise Questionnaire; GLTEQ) to single-item self-reported indicators of exercise frequency (e.g., Zen et al., 2012).

In a community sample of 86 trauma-exposed adults, Vujanovic and colleagues (2013) examined the association between self-reported physical activity and PTSD symptoms. Participants were selected from a pooled database of three studies examining emotional vulnerability. On average, PTSD symptom severity was in the mild range for this sample. Results indicated that greater average levels of weekly physical activity were significantly associated lower levels of hyperarousal symptoms, but not re-experiencing, avoidance, or total PTSD symptoms. The study also examined the influence of cigarette smoking and found an interaction to suggest that regular smokers who report low physical activity levels reported the highest levels of PTSD symptoms. In a follow-up analysis of these data (without restrictions on smoking status), Harte and colleagues (Harte, Vujanovic, & Potter, 2015) examined whether exercise intensity was related to PTSD symptom severity (N = 108). In these analyses, only vigorous exercise was significantly, negatively associated with hyperarousal symptoms, while no significant relationships were found between light or moderate-intensity exercise and PTSD symptom severity.

Godfrey and colleagues reported findings from a cross-sectional case-control study examining health and health behaviors in the context of PTSD (Godfrey, Lindamer, Mostoufi, & Afari, 2013). They compared 25 participants with PTSD and 55 non-PTSD controls in a sample of both community dwelling adults and military veterans. Physical activity was measured using the International Physical Activity Questionnaire-Short Form (IPAQ-SF). Results indicated that participants with PTSD reported engaging in significantly fewer minutes of vigorous exercise than those without PTSD. No significant differences were observed for moderate activity and walking.

Zen and colleagues examined physical activity in 1022 individuals with cardiovascular disease, 95 of whom met criteria for PTSD (Zen et al., 2012). PTSD was associated with significantly lower rates of overall physical activity, light activity, and self-rated level of exercise compared to others their same age and sex. No significant between group differences were observed regarding engagement in moderate and heavy levels of physical activity.

In another study, Whitworth and colleagues (2017) examined gender differences in self-reported exercise behavior and symptoms of PTSD (Whitworth, Craft, Dunsiger, & Ciccolo, 2017). A sample of 165 participants was recruited using online-classified listings and social media. To be eligible, participants had to report a traumatic life event and screen positive for PTSD. Through an online survey, participants reported the frequency with which they participated in minimal, moderate, and strenuous effort exercise. Individuals were considered insufficiently active if they scored less than 24 on the Godin Leisure-Time Exercise Questionnaire (GLTEQ; Godin, 2011), which corresponds to less than 150 minutes of moderate-vigorous weekly exercise. Analysis of the entire sample indicated that individuals who were more physically active reported significantly fewer PTSD symptoms than those who were

considered insufficiently active. When considering different exercise intensities, strenuously active men and women had significantly fewer hyperarousal symptoms and total PTSD symptoms, whereas no significant differences were observed for moderate or minimal intensity exercise and PTSD symptoms. With respect to gender differences, physically active men had significantly lower total PTSD symptoms than physically active women. When PTSD symptoms were divided into symptom clusters, this association remained true only for hyperarousal symptoms.

Bourn and colleagues (2016) investigated the role of physical activity as a moderator of PTSD symptom severity in a sample of veterans with chronic pain (Bourn, Sexton, Porter, & Rauch, 2016). There was no association between physical activity and PTSD symptom severity in this study. However, physical activity did moderate the association between pain and PTSD symptoms, such that individuals who reported higher levels of pain had fewer PTSD symptoms if they were more physically active.

Rosenbaum and colleagues (2016) used backward step-wise regression to investigate the extent to which PTSD severity and other clinical variables (i.e., depression, anxiety) predicted time spent walking and time spent in moderate to vigorous physical activity in inpatients receiving treatment for PTSD (Rosenbaum et al., 2016). Physical activity participation was measured using the IPAQ-SF, which assesses activity over the past seven days. While no significant associations were observed between the predictor variables and time spent in moderate to vigorous activity, only PTSD symptom severity independently predicted walking time in a joint regression analysis including depression, anxiety, stress and sleep quality. Specifically, greater PTSD symptoms were associated with less time spent walking.

Mason and colleagues examined the association between PTSD and health behaviors after accounting for comorbid depression and generalized anxiety disorder (GAD) in a sample of 246 adults with a history of trauma exposure. Using multivariate multilevel modeling, results suggested that PTSD, depression, and GAD were differentially associated with health constructs. PTSD symptoms were found to be associated with greater levels of sedentary behavior, but not physical activity, which was associated with depression. The authors emphasized previous research demonstrating that sedentary behavior is a distinct from physical activity and not simply the opposite end of the same spectrum (Owen, Healy, Matthews, & Dunstan, 2010).

Prospective Studies

Five studies reported on the prospective associations between physical activity and PTSD, measuring individuals on at least two occasions (see Table 2 for study details). Three of these studies looked at physical activity predicting subsequent PTSD symptoms, while two studies reported on PTSD symptoms predicting future physical activity levels.

Table 2. *Prospective Study Characteristics and Findings.*

Study	Population	Sample Size	Mean Age (SD)	% Male	Exercise Measure	PTSD Measure	Main Findings
Bosch et al., 2017	Veterans with PTSD symptoms	76	36 .4 (9.9)	82	Self-reported vigorous and moderate/light exercise	PCL-M, Sleep Quality	Baseline exercise engagement was associated with better sleep quality, but not PTSD symptoms, at 1-year follow-up.
LeardMann et al., 2011	U.S service members	38, 883 (1,401 with PTSD)	--	77.70	Self-reported frequency and duration of strength training, vigorous activity, and moderate/light activity	PCL-C	Vigorous physical activity was associated with reduced risk of persistent PTSD symptoms and new-onset PTSD at 1-year follow-up.
Talbot et al., 2014	Military Veterans	736	58 (10.0)	89	Self-reported physical activity in past month (frequency and intensity)	CAPS	The relationship between PTSD status at baseline and physical activity at 1-year follow-up was mediated by sleep quality. PTSD was associated with poor sleep quality which in turn predicted lower engagement in physical activity.
Whitworth et al., 2017	Adults with PTSD	182	34.6 (13.34)	27.50	GLTEQ	PCL-C	Strenuous intensity exercise was associated with reduced hyperarousal and avoidance/numbing symptoms at 3-month follow-up.
Winning et al., 2017	Females from the Nurses' Health Study II	15, 353	35.1 (4.4)	0	Self-reported average weekly engagement in variety of activities	Brief Trauma Questionnaire; Short Screening Scale for DSM-IV PTSD	PTSD symptom severity was associated with significantly steeper declines in physical activity over 20 years. Trauma exposure without PTSD was not related to changes in physical activity.

These five studies shed light on the temporal associations between physical activity and PTSD symptoms. The majority of the prospective longitudinal evidence comes from studies with only two measurement occasions, with most follow-up assessments occurring one year or less after baseline. Only one study (Winning et al., 2017) examined trajectories of change in physical activity over a longer time period (i.e., 20 years). Three studies included PTSD status/severity as the outcome variable (Bosch et al., , 2017; LeardMann et al., 2011; Whitworth et al., 2017), whereas two studies focused on physical activity engagement as the primary outcome (Talbot et al., 2014; Winning et al., 2017). While most of the prospective longitudinal studies revealed significant negative associations between PTSD symptoms and exercise engagement, Bosch and colleagues (2017) did not find evidence to support this association. In terms of specific PTSD

symptom clusters, one prospective study found evidence to suggest lower levels of hyperarousal specifically following strenuous intensity exercise (Whitworth et al., 2017). Two studies (Bosch et al., 2017; Talbot et al., 2014) included sleep quality in their models, with both finding support that sleep quality is associated with PTSD symptoms and one suggesting that it mediates the relationship between PTSD severity and participation in physical activity. Among the prospective studies included in this review, sample sizes ranged from 76 to 38,883 with mean ages ranging from 34.6 to 58. In line with the cross-sectional results, all of the studies utilized validated measures of PTSD, while measures of physical activity were more varied and tended to include single-item self-reported frequency of physical activity.

Whitworth and colleagues (2017) examined the association between physical activity and PTSD symptoms in a community sample of 182 individuals at baseline and three months later (James W. Whitworth et al., 2017). Participants were recruited through online-classified ads and completed the baseline and follow-up surveys over the internet. Eligible participants endorsed a traumatic event and screened positive for PTSD based on their baseline score on the Posttraumatic Stress Disorder Checklist–Civilian version (PCL-C). Overall, individuals who reported higher baseline levels of physical activity reported fewer PTSD symptoms at follow-up than those who were considered insufficiently active. This association was even stronger for strenuous exercise. Exercise intensity also differentially impacted PTSD symptoms, such that individuals who reported both moderate and strenuous intensity activities reported significantly fewer avoidance/numbing symptoms. Those who reported engaging in only strenuous activities had significantly fewer hyperarousal and avoidance/numbing symptoms. No associations between exercise and re-experiencing symptoms were observed.

In a sample of 76 military veterans, Bosch and colleagues (2017) examined the associations between exercise, sleep and PTSD symptoms at baseline and 1-year follow-up (Bosch, Weaver, Neylan, Herbst, & McCaslin, 2017). In this study, physical activity was significantly negatively associated with PTSD symptoms at baseline, but baseline activity was not associated with PTSD symptoms at 1-year follow-up. However, there were significant associations between greater levels of baseline physical activity and better sleep quality at 1-year follow-up. The authors did not report physical activity data from the follow-up assessments and therefore no information was available regarding change in physical activity levels over the course of the study.

In a large prospective study of 38,883 U.S. service members, participation in regular vigorous physical activity (i.e., $\geq$ twice weekly) was associated with a reduced risk of persistent PTSD symptoms and the development of new-onset PTSD at 1-year follow-up (LeardMann et al., 2011). In this study, physical activity was only measured at follow-up (i.e., retrospectively reporting average exercise engagement), thereby limiting interpretations regarding the temporal association between activity levels and PTSD symptoms.

Two studies reported associations between baseline PTSD symptoms and prospective physical activity. Talbot and colleagues (2014) used baseline PTSD status to predict exercise engagement 1-year later in a sample of 736 military veterans (Talbot, Neylan, Metzler, & Cohen, 2014). They found that individuals with PTSD at baseline (N=258) reported poorer sleep quality at baseline, which, in turn, predicted lower engagement in physical activity at follow-up. However, PTSD status did not independently predict future physical activity. To date, only one longitudinal study has examined the association between PTSD onset and subsequent *changes* in physical activity (Winning et al., 2017). Data were from the Nurses Health Study II (Bao et al.,

2016), an ongoing cohort study of female registered nurses. Included in the analysis were 15,353 women who reported trauma exposure and/or trauma exposure and PTSD symptom onset over the course of the study. Physical activity was assessed on six occasions over 20 years. Higher levels of PTSD symptoms were associated with significantly steeper declines in subsequent physical activity, whereas trauma exposure without PTSD was not related to changes in physical activity over time. Importantly, these trajectories were observed after controlling for depression and anxiety. This study represents an important contribution in the literature with respect to demonstrating change over time, providing evidence that physical activity engagement tends to decline more rapidly when trauma exposure results in PTSD, compared to when it does not.

Intervention Studies

Eight intervention studies met inclusion criteria. In this area of research, some studies evaluated physical activity as a stand-alone intervention, while others included physical activity as an adjunctive element to existing treatment, such as psychotherapy. These eight intervention studies were diverse in terms of duration, frequency, and type of exercise. Five studies were randomized controlled trials and three studies featured pre-post design with only one group (Babson et al., 2015; Manger & Motta, 2005; Shivakumar et al., 2017). The majority were aerobic exercise interventions, while two were exclusively resistance exercise programs (Rosenbaum et al., 2015 & Whitworth et al., 2019), and one combined aerobic and resistance exercises (Goldstein et al., 2018). Two of the studies specifically examined the effect of exercise *over and above* existing treatment protocols (Powers et al., 2015; Rosenbaum et al., 2015). Sample sizes ranged from nine participants (Powers et al., 2015) to 217 (Babson et al., 2015).

Table 3. *Intervention Study Characteristics and Findings*

Study	Study Design	Study Duration	Population	Sample Size	Mean Age (SD)	% Male	Exercise Measure	Exercise Intervention	PTSD Measure	Main Findings
Babson et al., 2015	Pre-post	60-90 days	Military veterans in residential treatment	217	52.1 (7.06)	100	Distance cycled	Group-based cycling program	PCL-M	Exercise was associated with greater reductions in hyperarousal symptoms, but only in veterans with poor sleep quality at baseline.
Fetzner et al., 2015	RCT	2 weeks	Civilians with full or partial PTSD	33	36.9 (11.2)	24	--	2 weeks stationary biking (6 sessions) with 3 conditions of attentional focus.	PCL-C; Traumatic Life Events Checklist	Significant improvements in PTSD symptoms post-intervention, but not maintained at 1-week and 1-month follow-up.
Goldstein et al., 2018	RCT	12 weeks	Veterans with full or partial PTSD	47	46.8 (14.93)	81	GLTEQ	Group-based program combining aerobic, resistance, and mindfulness exercises 3x/week for 12 weeks	CAPS	Significantly greater reductions in PTSD symptoms in the Integrative Exercise group compared to controls, particularly on hyperarousal symptoms
Manger & Motta, 2005	Pre-post	10 weeks	Adults meeting clinical cut-off for PTSD symptoms	26	48.1	26.9	--	2-3 sessions of aerobic exercise per week for 10 weeks	PDS, CAPS-DX	Significant reductions in PTSD symptoms after intervention and at 1-month follow-up.
Powers et al., 2015	RCT	12 weeks	Individuals with PTSD	9	34 (11.82)	12	BDNF	30 mins of moderate-intensity exercise right before prolonged exposure (PE) session	PTSD Symptom Scale-Interview; PSSI	Exercise group showed greater improvements in PTSD symptoms and elevated BDNF levels compared to PE alone.
Rosenbaum et al., 2015	RCT	12 weeks	Inpatients with PTSD	81	47.8 (12.1)	84	IPAQ-SF	3x 30-minute resistance training sessions a week for 12 weeks in addition to usual care	PCL-C	Compared to usual care, the exercise group showed significant reductions in PTSD symptoms.
Shivakumar et al., 2017	Pre-post	12 weeks	Female veterans with PTSD	22	34	0	--	30-40 minutes brisk walking 4 days/week for 12 weeks	CAPS; PCL	Significant improvements in overall PTSD symptoms in those who completed the intervention.
Whitworth et al., 2019	RCT	3 weeks	Non-treatment seeking adults with PTSD and anxiety	30	29.1 (7.38)	26.9	--	3x 30-minute resistance exercise a week for 3 weeks	PDS5	Resistance exercise had beneficial effects on hyperarousal and avoidance symptoms compared to control group.

Note: BDNF = Brain derived neurotrophic factor; CAPS = Clinician Administered PTSD scale; GLTEQ = Godin Leisure Time Exercise Questionnaire; IPAQ-SF = International Physical Activity Questionnaire-Short Form; PCL-M = PTSD Checklist- Military Version; PCL-C= PTSD Checklist-Civilian Version; PDS5= Posttraumatic Stress Diagnostic Scale for DSM-5; SCID-5 = Structured Clinical Interview for DSM-5.

One of the first intervention studies to examine the association of physical activity and PTSD symptoms was conducted by Manger and Motta (2005). In this study, 26 individuals who screened positive for PTSD and were relatively inactive at baseline, were recruited to take part in a 10-week aerobic exercise program. The intervention consisted of two to three weekly sessions of moderate intensity aerobic exercise (i.e., 30 minutes of walking or jogging on a treadmill with 10 minutes spent on warm up and cool down). Only nine participants were considered fully compliant in this study (i.e., completing at least 12 total sessions over 10 weeks) and therefore results were primarily based on this group. Importantly, the decision to exclude non-compliant participants from the analysis limits conclusions that can be drawn from the data in this study. Participants completed two series of baseline measures, post-intervention measures, and measures at 1-month follow-up. During the follow-up period, participants were not permitted to continue exercising. Analyses indicated significant reductions in overall PTSD symptoms between baseline and post-intervention. At baseline, six participants met full criteria for PTSD, while only two participants did at the end of the intervention. After 1-month of inactivity, an increase was seen with four participants meeting full criteria for PTSD. The differences between post-intervention to one-month follow-up were not statistically significant.

Shivakumar and colleagues (2017) reported on the results of a 12-week moderate intensity aerobic exercise intervention for female veterans of childbearing age (Shivakumar, Anderson, Suris, & North, 2017). In this study, 22 participants enrolled in a brisk walking intervention featuring four weekly sessions of 30-40 minutes each. Among the 16 participants who completed the intervention, significant reductions in symptoms of PTSD and depression were observed and no adverse effects were reported. In addition to pre-post measures,

participants completed weekly surveys and weekly scores on the PCL declined over the course of the study.

Babson and colleagues (2015) examined the interactive role of sleep and physical activity in a sample of male military veterans in a residential PTSD treatment program (Babson et al., 2015). Individuals receiving treatment for PTSD were provided with the opportunity to participate in a group cycling program as an adjunctive treatment to the standard cognitive behavioural therapy program. Physical activity was measured by distance cycled over the course of the 60-90 day residential program. At the end of the study, physical activity was associated with significant reductions in hyperarousal symptoms, but only in individuals who reported poor sleep quality at baseline. The authors suggest that this interaction could be due to the fact that hyperarousal is a key mechanism in insomnia, noting that improvements in sleep quality may be one of the pathways through which physical activity yields benefits in individuals with PTSD. Exercise participation was not associated with reductions in symptoms of re-experiencing or avoidance/numbing. Compared to those who did not cycle, those who participated in the cycling program reported lower levels of depression at baseline and discharge.

Goldstein and colleagues (2018) evaluated the impact of an integrative exercise program on PTSD symptom severity and overall quality of life in a sample of military veterans. Participants were randomized to either an integrative exercise program or waitlist control. The group-based exercise program incorporated elements of aerobic exercise, resistance exercise, and mindfulness-based practices. Participants attended 1-hour exercise sessions three times a week for a total of 12 weeks. Participants in the exercise group showed significant reductions in PTSD severity compared to the control group. Specifically, there was an average reduction of 31 points on the *Clinician Administered PTSD Scale* (CAPS; Blake, Weathers, Nagy, Gusman, & Charney,

1995), which is considered a clinically significant change in symptom severity. Consistent with other studies, hyperarousal symptoms showed the greatest improvement. Re-experiencing and avoidance/numbing showed moderate improvements but these changes were not statistically significant.

In a small randomized controlled trial, Fetzner and Asmundson (2015) examined the impact of manipulating attentional focus during exercise. Thirty-three individuals with PTSD were randomly assigned to one of three exercise groups: 1) cognitive distraction from somatic arousal, 2) attention to somatic arousal via interoceptive prompts, and 3) exercise only. Each group participated in stationary cycling for six 20-minute sessions over two weeks. At the completion of the study, 89% of participants across all groups reported clinically significant reductions in PTSD severity. However, at 1-week follow-up and 1-month follow-up, only 14% and 6.7% of participants maintained significant reductions in symptoms, respectively. This suggests that the maintenance of benefits may require maintenance of activity. With respect to between-group differences, the group that received prompts to attend to somatic arousal experienced significantly less symptom reductions in hyperarousal and anxiety sensitivity compared to both other groups.

Powers and colleagues (2015) conducted a very small pilot study to evaluate the potential benefit of engaging in exercise immediately before prolonged exposure (PE) therapy sessions (Powers et al., 2015). A community sample of nine individuals (8 females) with PTSD was randomly assigned to receive 12 sessions of PE therapy alone, or 12 sessions of PE therapy plus exercise. Those in the exercise condition engaged in 30 minutes of moderate-intensity exercise immediately before their therapy sessions. Although the sample size was not large enough to compute statistical significance tests, the authors computed between-group effect sizes of

changes in the outcome variables. While both groups showed clinically significant reductions in PTSD symptoms, the PE + exercise group had greater symptom reduction, and this difference was associated with a large effect size (Cohen's *d* = 2.65). Building on prior research, the authors of this paper also investigated the role of brain-derived neurotrophic factor (BDNF) as a potential mechanism underlying the association between physical activity and mental health outcomes. In particular, the authors emphasized the role of BDNF in extinguishing conditioned fear. Plasma BDNF increased to a greater extent in the exercise group, yielding a large between- group effect size (Cohen's *d*= 1.08).

To date, the largest RCT evaluating the impact of exercise on PTSD symptoms was conducted by Rosenbaum and colleagues (2015). In this study, 81 participants were recruited from an inpatient PTSD program and randomized to a usual care condition or usual care plus exercise. In this 12-week study, usual care consisted of a combination of psychotherapy, pharmacological intervention, and group therapy. The exercise component consisted of three 30-minute resistance-training sessions each week. Participants also were provided with a pedometer and were advised to achieve 10,000 steps per day. Follow-up assessments were completed an average of 13.9 weeks after the baseline assessment. At follow-up, the intervention group showed significantly larger reductions in PTSD symptoms, depression, anxiety, and stress compared to the usual care group. Effect sizes ranged from moderate (PTSD symptoms) to large (depression, anxiety, and stress). With respect to physical health, the intervention group showed significant reductions in body fat and waist circumference, and spent significantly less time sitting than the control group. However, there were no significant between-group differences in blood pressure, grip strength, resting heart rate, or cardiorespiratory fitness. Taken together, the

findings from this study underscore the potential widespread impact that exercise can have on both mental and physical health in individuals with PTSD.

More recently, Whitworth and colleagues (2019) conducted the first study to evaluate a stand-alone resistance exercise intervention in individuals with PTSD (J. W. Whitworth, Nosrat, SantaBarbara, & Ciccolo, 2019). They sought to investigate the feasibility of a 3-week resistance exercise intervention in individuals who screened positive for PTSD and anxiety. In this brief RCT, participants in the intervention group completed three, one-on-one, 30-minute sessions of resistance exercise per week. Specifically, each session featured a 5-minute warm up and cool down on a stationary bicycle and 20-minutes of exercises such as squats, bench press, pulldown, overhead press, and bicep curls. The control group received matched non-intervention interactions such as interactions from research staff and informative videos about exercise and mental health. Following the intervention, the exercise group reported significantly larger reductions in avoidance-related posttraumatic stress symptoms and improved global sleep quality. Differences were also observed in total posttraumatic stress symptoms, hyperarousal symptoms, and alcohol use, but these did not reach statistical significance. In terms of feasibility, 80% of participants completed the intervention with three out of 15 dropping out before completion. The authors noted that attendance for total sessions was also 80%, which was considered excellent for this population.

Discussion

This systematic review evaluated the association between physical activity and PTSD across multiple study designs. To-date, the evidence from cross-sectional, prospective, and experimental trials largely supports an inverse relationship between physical activity and PTSD. However, this area of research is still relatively new and many questions remain regarding optimal duration, intensity, and type of physical activity (e.g., aerobic vs. resistance exercise) to reduce PTSD symptoms. Further investigation into the differential impact of exercise on specific PTSD symptom clusters is also warranted (Vujanovic et al., 2013; Whitworth et al., 2017), given several studies that suggest that exercise may be helpful in reducing hyperarousal but not avoidance, negative mood/cognitions, or re-experiencing symptoms. Compared to previous reviews in this area, this review paper was broader in terms of types of study design. However, unlike some previous reviews (e.g., Caddick & Smith, Rosenbaum et al., 2015), the current review did not include qualitative studies or studies featuring yoga as the sole form of physical activity. In terms of overlap, ten of the 22 studies that met eligibility for this review were also included in previous reviews (Babson et al., 2015; Fetzner et al., 2014; Godfrey et al., 2013; Leardmann et al., 2011; Manger & Motta, 2005; Powers et al., 2015; Rosenbaum et al., 2015; Talbot et al., 2014; Vujanovic et al., 2013; Zen et al., 2012).

This review included studies from a variety of research designs, each of which present with strengths and limitations. Cross-sectional designs do not permit conclusions regarding causality or the temporal associations between engagement in physical activity and PTSD. The prospective longitudinal studies represent an improvement in this regard; however, only one of the five studies measured participants on more than two occasions. While two measurement occasions permit the use of one variable to predict another variable at a second time point,

conclusions regarding fluctuation or *change* in the variables of interest are not possible. Physical activity and PTSD symptom severity likely fluctuate over time and by measuring these variables at only two measurement occasions, we may be missing out on potential valuable information pertaining to within-person dynamics in relation to health behaviors. The exception to this trend was the study conducted by Winning and colleagues (2017), which modeled trajectories in physical activity over the course of up to 20 years, demonstrating that greater PTSD symptom severity was associated with steeper declines in physical activity over time. Unfortunately, studies examining trajectories of PTSD symptoms as an outcome in relation to activity engagement have not yet been conducted. Indeed, more longitudinal studies are needed to better understand the temporal and reciprocal associations between these variables.

It would also be worth focusing on the timing and/or duration of PTSD in order to understand when exercise habits begin to change following a diagnosis as well as informing the optimal timing for interventions. Only the prospective longitudinal studies focus on change at the individual level and to date, no studies have utilized an intensive measurement design to clarify the role of physical activity on daily symptoms of PTSD. This represents a significant gap in the literature and such a design could shed light on a number of important associations that cannot be captured through traditional methodologies (e.g., cross-sectional or pre-post designs). For instance, daily diary studies could provide rich information regarding the within-person associations of physical activity and PTSD symptom severity within and across days. Indeed, symptoms of PTSD are known to fluctuate across days and there is evidence to suggest that these fluctuations are related to daily variations in sleep quality and physical pain (Berghoff, McDermott, & Dixon-Gordon, 2018).

Findings from experimental RCTs provide the strongest evidence in support of the benefits of physical activity in reducing PTSD symptoms. The increase in the number of studies using experimental designs in this area in recent years is encouraging. However, the intervention studies to-date are not without limitations. For instance, many studies are limited by small sample sizes, lack of a true control group, lack of long-term follow-up, and have high drop-out rates.

Across study designs, six studies found that higher levels of physical activity are specifically related to or lead to lower levels of hyperarousal symptoms, whereas support for improvements in other symptoms domains is more equivocal. Specific symptoms in the DSM-5 hyperarousal cluster include hypervigilance, exaggerated startle response, sleep problems, concentration problems, and irritability/angry outbursts. It is perhaps not surprising that this cluster of symptoms shows the most improvement from physical activity given that research in other areas has associated higher activity levels with improvements in sleep, cognition, and mood in the general population (Dolezal, Neufeld, Boland, Martin, & Cooper, 2017; Haas, Schmid, Stadler, Reuter, & Gawrilow, 2017; Stillman, Cohen, Lehman, & Erickson, 2016). More research is needed to elucidate the specific mechanisms underlying the differential effects on PTSD symptom clusters.

Conclusions and Future Directions

In summary, the topic of physical activity and PTSD is a growing area of research with encouraging results so far. Findings from longitudinal and intervention research suggest that the associations between physical activity and PTSD may be reciprocal. That is, a PTSD diagnosis and/or severity can predict reductions in exercise levels over time, and greater levels of exercise are associated with lower levels of PTSD symptom severity. Intervention studies support the

notion that increases in physical activity can lead to improvements in symptoms of PTSD and related variables such as sleep quality and pain.

The existing research has several limitations including lack of longitudinal studies with more than two time points , few large-scale RCTs, and lack of objective physical activity measures and reliance on single-item self-report questions for measuring activity levels. Future research should focus on better understanding the underlying mechanisms associated with improvements in PTSD symptoms in order to effectively tailor interventions to individuals with a history of trauma and/or PTSD. Although physical activity interventions seem to reduce symptoms of PTSD, some findings suggest that adherence to the intervention can be challenging for this population. Future research could benefit from exploring ways to identify individuals who are less likely to adhere to this type of intervention or strategies to enhance tolerability of physical activity interventions. Future prospective studies would benefit from using the same standardized measure of physical activity and/or moving towards objective indicators of activity such as accelerometer data. Additionally, these studies would be improved by measuring participants more often, which would permit the analysis of within-person *change* over time in both physical activity and symptoms of PTSD. This is an important avenue for future research because it will help illuminate the extent that these variables change together over time and could inform the optimal timing for interventions. Intervention studies would benefit from specifically examining what type (e.g., intensity) and dose (e.g., frequency, duration) of physical activity is most likely to confer benefits. Across study designs, hyperarousal symptoms seem to be most amenable to changes following increased physical activity, yet more studies are needed to understand the mechanisms explaining why this particular symptom cluster stands out. This

systematic review helps highlight the need for more frequent measurement occasions and emphasis on utilizing objective measures of physical activity.

Chapter 2: An examination of the day-to-day associations between physical activity and posttraumatic stress disorder symptoms: A daily diary study

Abstract

In recent years, there has been increasing research focused on the therapeutic effects of physical activity in individuals with post-traumatic stress disorder (PTSD). Evidence from observational and intervention research has demonstrated the individuals with PTSD who are more physically active report fewer PTSD symptoms than those who are less physically active. However, no studies have investigated within-person fluctuations at the daily level and therefore less is known about how physical activity influences or is influenced by PTSD symptoms at the intra-individual level. Additionally, very few studies have incorporated objective measures of physical activity such as accelerometry. This study aimed to better understand the day-to-day associations between physical activity and symptoms of PTSD by utilizing a daily diary design. Participants were fifteen adults with a current diagnosis of PTSD, recruited from local psychology clinics and peer support groups (73% male). For seven days, participants completed twice-daily surveys on their smartphones and continuously wore Fitbit accelerometers (Fitbit Charge HR) on their wrists to measure activity and sleep dysregulation. A series of multi-level models were run to evaluate the effects of multiple measures of daily physical activity (i.e., self-reported minutes, accelerometry-measured step counts, time spent in light and moderate-vigorous activity) and their associations with total PTSD symptoms, each sub-cluster of PTSD symptoms, sleep, positive and negative affect, and coping strategies. Findings revealed considerable day-to-day variability at the within-person level on all predictor and outcome variables. Overall, greater levels of physical activity were associated with fewer symptoms of PTSD, less negative affect, more positive affect, and more adaptive coping strategies within-days. Among measures of physical activity, self-reported time spent in moderate to vigorous physical activity was the most consistent predictor of same-day PTSD symptoms, affect, and

coping. No associations were observed between physical activity and sleep duration or sleep quality. Taken together, results suggest that even at the individual level, engagement in physical activity is associated with fewer PTSD symptoms that same day. Methodological considerations regarding the use of Fitbit accelerometers are also discussed. Overall, findings provide preliminary evidence for the within-person association between physical activity and PTSD symptoms, positive and negative affect, and use of coping strategies.

Introduction

Post-traumatic stress disorder (PTSD) is a prevalent, often chronic, psychiatric disorder that can develop following exposure to a traumatic event. PTSD is associated with adverse physical, psychological, and social outcomes (Marmar et al., 2015; Morris, Compas, & Garber, 2012; Ryder, Azcarate, & Cohen, 2018). In particular, individuals with a diagnosis of PTSD have an elevated risk of mood disorders, anxiety disorders, substance use disorders, suicidal ideation, and suicide attempts (Galatzer-Levy, Nickerson, Litz, & Marmar, 2013).

In addition to psychological outcomes, PTSD is associated with a heightened risk of physical health problems and medical conditions (Godfrey et al., 2013). In a systematic review and meta-analysis of nine studies investigating prevalence and risk of metabolic syndrome in individuals with PTSD, PTSD was associated with nearly double the risk of metabolic syndrome compared to matched controls in the general population (Rosenbaum et al., 2015b). In this review, 38.7% of all people with PTSD had metabolic syndrome and rates were consistently elevated independent of geographic location and population (i.e., military veterans vs. non-veterans). In a meta-analysis of 62 studies examining the association between PTSD and physical health, PTSD and elevated posttraumatic stress symptom severity were associated with general health problems, higher rates of medical conditions, poorer health-related quality of life, and increased frequency and severity of pain (Pacella, Hruska, & Delahanty, 2013).

A body of research provides evidence that individuals with PTSD are less likely to engage in health behaviours (Godfrey et al., 2013; Zen et al., 2012). Compared to non-PTSD controls, those with PTSD report significantly lower levels of vigorous exercise, lower fruit intake, increased guilt after over-eating, higher BMI, and higher alcohol use (Godfrey et al., 2013). Among patients with cardiovascular disease, individuals with PTSD are found to have

significantly higher rates of medication non-adherence, smoking, and physical inactivity relative to those without PTSD (Zen et al., 2012). Indeed, there is a need to better understand the pathways through which PTSD increases risk of these physical and mental health outcomes and for the development of interventions that reduce the risk of comorbidities, in addition to treating PTSD symptoms.

The most comment treatment approaches for PTSD include psychotherapy and pharmacological intervention (Cipriani et al., 2018; Tran & Gregor, 2016). In particular, the current American Psychological Association (APA) treatment practice guideline for the treatment of PTSD strongly recommends cognitive behavioral therapy (CBT), cognitive processing therapy (CPT), cognitive therapy (CT), and prolonged exposure therapy (PE) as front-line therapies for PTSD (American Psychological Association, 2017). For pharmacotherapy, fluoxetine, paroxetine, sertraline, and venlafaxine are recommended. Many individuals with PTSD experience barriers to seeking and/or maintaining treatment (e.g., cost, stigma, drop-out, side-effects). As highlighted in the previous chapter of this dissertation, physical activity may be a useful stand-alone or adjunctive intervention for individuals with PTSD.

Background: Physical Activity and Mental Health

There is considerable research associating physical activity with mental health and well-being (Bridle, et al., 2012; Haas et al., 2017; Herring, Jacob, Suveg, & O'Connor, 2011; Mammen & Faulkner, 2013; Panza, Taylor, Thompson, White, & Pescatello, 2019; Reed & Buck, 2009). In healthy adults, more frequent physical activity has been associated with better subjective well-being (Marques et al., 2016) and lower levels of perceived stress (Nguyen-Michel, Unger, Hamilton, & Spruijt-Metz, 2006) when examined cross-sectionally. In a recent cross-sectional study examining accelerometer-measured physical activity and self-reported

physical activity, Panza and colleagues (2019) found that accelerometer-measured light and moderate intensity physical activity were positively associated with psychological well-being, whereas vigorous intensity physical activity was not. Results indicated that subjective reports of physical activity were generally correlated with accelerometer-measured activity, except for light intensity physical activity. Results from intervention studies provide evidence that physical activity interventions have the potential to increase positive affect (Reed & Buck, 2009) and decrease negative affect (Parfitt, Rose, & Markland, 2000).

In addition to influencing in subjective well-being and affect, physical activity interventions have demonstrated efficacy in the treatment of psychological conditions such as depression (Josefsson et al., 2014) and anxiety (Asmundson et al., 2013). For example, Herring and colleagues (2011) found that both resistance training and aerobic exercise were associated with significant reductions in worry symptoms in individuals with generalized anxiety disorder (Herring, et al., 2011). Similar findings have been reported for individuals with panic disorder, OCD, and social anxiety (Asmundson et al., 2013). A 2014 systematic review and meta-analysis of 13 studies examining physical activity interventions in depressive disorders found a large overall effect in support of exercise interventions, particularly among studies that used a no treatment or placebo condition as the comparison group (Josefsson et al., 2014). The authors concluded that physical activity may be particularly well suited for individuals with mild to moderate levels of depression. Taken together, the extant literature supports the positive impact of physical activity on psychological well-being and mental health.

Physical Activity and PTSD

While the benefits of physical activity are relatively well-established for depression and anxiety disorders, research investigating the potential therapeutic benefits of physical activity on

symptoms of PTSD is relatively new. Yet, findings from existing literature are encouraging. Several cross-sectional studies support an inverse relationship between participation in physical activity and symptoms of PTSD (e.g., Harte et al., 2015; Vujanovic et al., 2013; Whitworth et al., 2017). Among these studies, discrepant findings were observed when different types of exercise were considered. For instance, Harte and colleagues (2015) found that only vigorous activity, and not moderate or light activity was associated with fewer symptoms of hyperarousal, whereas other studies found that sedentary behaviour is associated with more severe PTSD symptoms (Mason et al., 2019) and that greater PTSD symptoms are associated with less time spent walking (Rosenbaum et al., 2016). Regarding directionality, prospective studies suggest that greater levels of physical activity are associated with a reduced risk of future PTSD symptoms (LeardMann et al., 2011; Whitworth et al., 2017). The opposite direction also appears to be true, such that individuals with a diagnosis of PTSD or who have more severe symptoms are less likely to engage in future physical activity (Talbot et al., 2014; Winning et al., 2017).

To-date, the strongest evidence supporting physical activity as a treatment for PTSD symptoms comes from intervention studies that have demonstrated improvements in PTSD symptoms following a physical activity intervention. Most of these studies have been randomized controlled trials (RCTs), while some have utilized a pre-post design with only an intervention group. In terms of duration, the majority of interventions last approximately 10-12 weeks (e.g., Godstein et al., 2018; Manger & Motta, 2005; Power et al., 2015; Rosenbaum et al., 2015; Shivakumar et al., 2017). Aerobic exercise has been most frequently studied (Babson et al., 2015; Fetzner et al., 2015; Manger & Motta, 2005; Shivakumar et al., 2017), while two studies have utilized resistance-training exercises (Rosenbaum et al., 2015; Whitworth et al., 2019). All intervention studies found significant improvements in at least some (e.g.,

hyperarousal) or overall PTSD symptoms relative to control groups (Fetzner et al., 2015; Goldstein et al., 2018; Powers et al., 2015; Rosenbaum et al., 2015; Whitworth et al., 2019) or pre-treatment (Babson et al., 2015; Manger & Motta, 2005, Shivakumar et al., 2017). However, the improvements were not always maintained in studies that conducted follow-up evaluations weeks or months later (e.g., Fetzner et al., 2015). This is perhaps not surprising, particularly if participants did not remain physically active after the study ended. Studies that examined clusters of PTSD symptoms separately tended to find that hyperarousal symptoms (e.g., hypervigilance, heightened startle response, sleep problems, difficulty concentrating, irritability) exhibit the greatest reductions from physical activity (Babson et al., 2015; Goldstein et al., 2018; Whitworth et al., 2019).

Intensive Measurement Designs: Rationale

Intensive measurement designs (e.g., daily diary, ecological momentary assessment (EMA), experience sample methodology) can address some of the limitations of more traditional research methods by providing real-time, or near real-time, assessments in individuals' natural environments (Bolger, Davis, & Rafaeli, 2003). By measuring individuals more frequently, these designs have the advantage of greatly reducing recall bias, and therefore providing a more accurate sense of an individual's experience at a given moment or over the course of the day (Alpers, 2009; Sliwinski, 2008). Intensive measurement designs are particularly poised to answer questions about variables that tend to fluctuate on a day-to-day basis. By comparing an individual to their own unique baseline (e.g., average level), we can better understand the factors that may influence day-to-day variability of a particular outcome, which can shed light on potential mechanisms and identify targets for intervention. Modeling within-person processes not

only helps determine correlates, antecedents, and consequences of daily experiences, but can also indicate whether and how individuals differ in these processes (Bolgers et al., 2003).

Intensive measurement designs have good ecological validity, making the results more generalizable because the measurements are conducted in real-world settings (Marsalek, Morgulec-Adamowicz, Rutkowska, & Kosmol, 2014). This is an important consideration for studying mental health symptoms and physical activity (Alpers, 2009; Haas et al., 2017). As highlighted by Alpers (2009), anxiety disorder symptoms often occur in very specific situations that can be challenging to simulate and measure in a laboratory setting. By measuring individuals in their natural environment, researchers can gain insight into the context of the symptoms by measuring relevant behaviours, moods, and cognitions. Haas and colleauges (2017) note that most physical activity research has focused on studying individuals cross-sectionally or using intervention designs. Limitations of these approaches include recall bias (cross-sectional) and low ecological validity due to the structured nature of experimentally manipulated, and often supervised, physical activity that is part of a controlled intervention. While intervention studies have the advantage of strong internal validity and can shed light on cause and effect associations, the results do not necessarily extend to naturally, self-initiated activities in daily life, thereby limiting the inferences that can be made about how physical activity and mental health outcomes covary in daily life (Haas et al., 2017).

There are a number of different designs and approaches that fall under the intensive measurement design umbrella, each of which have their own strengths and weaknesses (Bolger et al., 2003; Schneider & Stone, 2006; Shiffman, Stone, & Hufford, 2008). EMA designs are considered a gold standard for the measurement of symptoms and experiences in the moment (Schneider & Stone, 2016). In EMA studies, participants typically complete multiple

assessments during the day and are asked to report their experience in that moment, or in the short time since the previous assessment. As a result of such frequent measurements, recall bias is greatly reduced and researchers can better capture the temporal association between variables. The primary limitation of EMA studies is the participant burden associated with completing multiple entries each day, which can influence how representative the sample is. Diary studies (e.g., one or two entries daily) are a viable alternative to EMA designs (Schnieder & Stone, 2016). Although asking participants to reflect on the day as a whole introduces more recall bias than in the moment responding, daily diary designs tend to be less burdensome to participants and therefore may be more feasible for certain populations or research questions. Broderick, Schwartz, Schneider, and Stone (2009) found near perfect overlap when they compared average EMA ratings ($\geq$ 5 ratings daily) of pain and fatigue with average of end of day ratings of the over the course of seven days. The authors concluded that end of day ratings are highly accurate representations of average levels of pain and fatigue symptoms. Schiffman and colleagues (2008) argue that although daily diaries have some additional recall bias when compared to EMA, they should be considered falling into the family of EMA designs based on shared characteristics such as repeated assessments over time and the capacity to capture dynamic processes, with the additional benefit of reducing participant burden.

Intensive measurement designs have been used in studies investigating the within-person associations between physical activity and mental health outcomes such as stress, affect, and depressive symptoms. For instance, Langguth and colleagues (2016) used intensive measurements to explore the relationship between physical activity and depressed mood in adolescents (Langguth, Schmid, Gawrilow, & Stadler, 2016). In this eight-day study, adolescents wore accelerometers measuring time spent in moderate-to-vigorous physical activity each day

and completed twice-daily (morning and evening) surveys. Findings revealed that on days that female participants engaged in more minutes of moderate-to-vigorous physical activity than their own average, they reported significantly less depressed affect the next morning. Specifically, a 60-minute increase in activity above an individual's mean activity predicted a 50% reduction in next-morning depressed mood. Interestingly, this relationship was observed on weekdays only. No significant associations between physical activity and depressed affect were observed for male participants. Although cross-sectional and widely spaced longitudinal designs generally show a negative correlation between physical activity and depressed mood, the specific findings from this study could not have been possible without using intensive measurements to understand within-person dynamics.

Recent studies have used intensive measurement designs to investigate within-person association between physical activity and positive and negative affect in healthy adults (Haas et al., 2017; Schultchen et al., 2019). In a ten-day study of 189 young adults, Haas and colleagues (2017) found that on days when participants engaged in more physical activity than usual, they reported more vigour and serenity, and less anger and depression that evening. In this study, participants wore accelerometers measuring time spent in moderate-to-vigorous activity and completed daily surveys before going to bed. In an EMA study, Schultchen and colleagues (2019) had 51 university students complete six daily surveys for seven days. They found that when participants reported higher negative affect and stress, and lower positive affect, they were less likely to engage in subsequent physical activity. They also found that when participants engaged in higher levels of physical activity, they later reported less stress and negative affect and more positive affect. These studies highlight the value of examining these associations

temporally, as this provides an opportunity to test hypotheses about the directionality of the relationships.

Intensive Measurement Designs and PTSD

In recent years, a growing number of studies have utilized intensive measurement designs to better understand the daily experiences of individuals with PTSD. To date, one review paper has summarized the published literature on daily diary/experience sampling methods assessing posttraumatic stress symptoms in daily life (Chun, 2016). This review of 15 studies concluded that experience sampling and daily diary methods are a feasible option for assessing posttraumatic stress symptoms and that these methods are associated with minimal reactivity among participants. Additional benefits highlighted in this review include the opportunity to better capture dynamic symptoms of PTSD, strong ecological validity, the ability to examine short- and long-term temporal associations at the within-person level, and reductions in retrospective biases that are commonly seen in single-occasion measurements. The following section will review a few key studies that have utilized daily diary methods to capture the day-to-day experiences of posttraumatic stress symptoms.

Naragon-Gainey and colleagues compared daily and retrospective symptom reports over the course of a month in a sample of female college students with a history of sexual assault (Naragon-Gainey, Simpson, Moore, Varra, & Kaysen, 2012). There was strong agreement between average daily symptom reports and retrospective reports at the end of the month for all symptom clusters except for avoidance symptoms. Although agreement was strong, there was also substantial variability in daily PTSD symptoms *within* individuals. This variability, which cannot be captured using single-assessment recall, can be used to identify mechanisms that

maintain or reduce symptoms, thereby informing potential intervention targets (Shiffman et al., 2008).

Another study sought to better understand daily experiences of PTSD symptoms using more frequent measurements, prompting participants to complete brief surveys five times per day for one week (Pfaltz, Michael, Meyer, & Wilhelm, 2013). Participants were individuals with PTSD in the general population and rated the occurrence and intensity of each symptom. On average, participants reported 17 trauma memories and 18 avoidance behaviours over the course of the week. While this study provides important insight into the frequency and intensity of PTSD symptoms experienced by participants in a 7-day period, the study failed to describe the within-person associations in detail. Rather, the focus of the analysis was on between-group comparisons with healthy controls and participants with panic disorder.

A recent intensive measurement study focused on sleep disturbance as a predictor of emotional functioning and posttraumatic stress symptom severity (Short, Allan, & Schmidt, 2017). Using an EMA design, participants completed four assessments over the course of eight days. Sleep quality was measured using an abbreviated version of the Pittsburgh Sleep Quality Index (PSQI), and PTSD symptoms were measured using an abbreviated version of the PTSD Checklist-5 (PCL-5). Poor sleep quality and reduced sleep efficiency predicted an increase in negative affect and PTSD symptoms the next day, even after controlling for the previous night's PTSD symptoms. Taken together, these studies highlight the feasibility and value of using repeated measures designs in PTSD populations.

The Current Study

The current study aims to expand upon and bridge the gap in the literature between: a) intensive measurement designs used to capture symptoms of PTSD within individuals, and b) the

role of physical activity in reducing PTSD symptoms. As previously noted, this type of design is essential to understanding how exercise is related to PTSD symptoms at the within-person and between-person levels. This work has the potential to inform future interventions for individuals with PTSD, whether exercise is incorporated into existing treatments (therapy or pharmacological intervention) or used as a standalone treatment or maintenance regimen. Given that hyperarousal seems to be particularly associated with improvements in relation to physical activity, a secondary objective of this study will be to examine whether hyperarousal symptoms are more strongly related to physical activity than other symptom clusters at the within-person level. Additionally, based on recommendations from past studies that have found discrepant results across physical activity measurement methods (Downs, Hoomissen, Lafrenz, & Julka, 2014; Panza et al., 2019), physical activity will be measured using both self-report and accelerometers in this study. The primary hypotheses focus on the within-person associations in each model. Between-person associations will also be examined, but will be considered more exploratory analyses given the small sample size and potentially limited ability to detect between-person differences.

Hypotheses.

1. Greater levels of physical activity will be associated with fewer symptoms of PTSD at the within-person level (same day) and the between-person level.

    1a. Greater levels of physical activity will be particularly associated with fewer symptoms of hyperarousal, relative to other symptom clusters at the within-person level (same day) and the between-person level.

2. Greater levels of physical activity will be associated with more positive affect and less negative affect at the within-person level (same day) and the between-person level.

3. Greater levels of physical activity will be associated with better sleep outcomes at the within-person level (physical activity predicting sleep that evening) and the between-person level.
4. Greater levels of physical activity will be associated with more adaptive coping strategies and fewer maladaptive coping strategies at the within-person level (same day) and the between-person level.
5. Greater levels of morning PTSD symptoms will be associated with lower levels of physical activity at the within-person level (morning symptoms predicting same-day physical activity) and the between-person level.

Methodology

Participants

Participants were recruited through poster advertisements and pamphlet handouts from psychologists at local psychology clinics, facilitators of peer support groups for individuals with PTSD, and a rehabilitation center for veterans and first responders. Eligible participants were at least 18 years of age, had a current diagnosis of PTSD, and owned a smart phone compatible with the required survey applications (android or iPhone). Data collection took place from May 2019 to September 2019. All study protocols were approved by the University of Victoria's Research Ethics Board. The final sample consisted of 15 participants. A total of 16 interested individuals attended an intake session and one individual was deemed ineligible due to smartphone incompatibility with required applications. The majority of participants were male (73%) and Caucasian (93%). Participants were between 27 and 75 years of age (M = 50.21; *SD* = 14.35). In terms of work status, 33.3% were currently working, 20% were recovering from illness/on disability, and 40% were retired. With respect to educational attainment, 20% of participants had completed high school or some high school, 40% had completed a certificate/diploma (i.e., vocational, trade) program, and 40% had completed a bachelor's and/or graduate university degree. Regarding marital status, 46.7% of participants were married or in a common law relationship, 33.3% were single, and 20% were separated/divorced.

Procedure

Interested participants contacted the principal investigator by telephone or email and underwent telephone screening for eligibility. Eligible participants attended a baseline session in-person at the University of Victoria's Integrative Lifespan (iLifespan) Laboratory to complete intake measures and to receive training for the daily survey software and accelerometer usage.

Participants then completed twice-daily surveys on their smartphones (morning and evening) for seven days before returning to the iLifespan laboratory for a debriefing session.

Baseline Session. The baseline session took approximately one hour to complete. Upon arrival, participants were provided with a detailed description of the study procedures, including confidentiality and types of questions included in the daily surveys, and they were given the opportunity to ask questions. Participants were told that the purpose of the study was to better understand the day-to-day associations between physical health and mental health in individuals with PTSD. They were informed that although the Fitbit accelerometer would be used to collect data pertaining to sleep and exercise patterns (i.e., daily steps, heart rate), the study was not an intervention and they were not being asked to change or increase their exercise patterns. With respect to symptoms of posttraumatic stress, participants were informed that they although they would be asked to rate severity of specific symptoms, they would not be asked to reflect on or share specific details about their trauma history. They were provided with contact information for the mental health crisis line in the event they experienced distress over the course of the study and wished to speak to someone about it. Upon providing informed consent, participants completed a questionnaire package including demographic information and baseline measures of relevant variables. Each participant subsequently had their blood pressure, height, and weight measured. Participants were required to download two applications on their smartphones during the intake session (MetricWire and Fitbit) and de-identified accounts were created for each participant. Participants were given instructions for how to use the survey software for daily morning and evening surveys and were provided with instructions for wearing and caring for the wrist-worn Fitbit Charge HR accelerometers. Each participant was provided with a handout

summarizing the information discussed in the baseline session and contact information for the researchers in the event they required troubleshooting during the daily diary portion of the study.

Daily Assessments. Following the baseline session, participants completed brief surveys on their smartphones using the MetricWire survey application (MetricWire Inc, 2019; Version 4.1.2) twice daily for seven days, with day one being the day after the baseline appointment. Additionally, they were instructed to wear the Fitbit accelerometer on their non-dominant wrist throughout each day and night. In terms of survey timing, participants were instructed to complete the morning survey within an hour of waking up and the evening survey within an hour of going to bed. Each morning at 7:00am, participants received a notification on their phone via the survey application reminding them to complete the morning survey. The survey then remained available for five hours, until 12:00pm. To account for individual differences in sleep schedules, participants were permitted to complete the survey at any point during this time frame. Similarly, participants were alerted via Metricwire notification to complete the evening survey at 9:00pm and it remained available for five hours, until 2:00am. To reduce participant burden, abbreviated measures were used for each construct, and each survey took approximately three to five minutes to complete. Both the morning and evening surveys included questions about severity of PTSD symptoms, positive and negative affect, and coping, The morning survey specifically asked about the previous night's sleep and the evening survey included questions about daily physical activity.

Debriefing Session. Upon completion of the daily diary portion of the study, participants returned to the iLifespan laboratory for a debriefing session that lasted approximately 30 minutes. Participants were provided with more details about the study purpose and were invited to provide feedback about their experience as a participant. In particular, the researcher asked

semi-structured questions about the methodology (e.g., frequency of surveys, usability of accelerometer and survey software), and content of the questions. Participants also returned the accelerometers and ensured the data from their phones had properly synced before removing the applications from their personal devices. Upon completion of the study, participants received at $50 honorarium as a thank you for their time.

Measures

Baseline.

PTSD Symptoms. PTSD symptoms were measured using the PTSD Checklist for the DSM-5 (PCL-5; Weathers, 2013). The PCL-5 is a widely used self-report measure for assessing the presence and severity of PTSD symptoms as they map onto DSM-5 criteria. The scale consists of 20 items that are rated using a 5-point Likert scale ranging from 0 (*not at all*) to 4 (*extremely*). Participants responded based on the extent to which they had been bothered by each problem in the past month. In addition to a total score, the scale yields scores for each of the four DSM-5 symptom clusters. In terms of psychometric properties, the PCL-5 has demonstrated strong internal consistency, test-retest reliability, and convergent and discriminant validity in previous research (Blevins, Weathers, Davis, Witte, & Domino, 2015). In the present study, the PCL-5 demonstrated excellent internal consistency ($\alpha = .90$).

Physical Activity. The Godin Leisure-Time Exercise Questionnaire (GLTEQ ; Godin, 2011) was used to measure self-reported leisure-time exercise that participants engage in in a typical week. Participants were asked to indicate how many times per week they typically participate in mild (e.g., easy walking, yoga), moderate (e.g., fast walking, easy swimming), and strenuous exercise (e.g., running, soccer). Total scores were calculated by multiplying mild, moderate, and strenuous exercise frequencies by 2, 5, and 9, respectively and summing the totals.

Higher scores represent greater levels of engagement in physical activity. Scores of less than 14 on this measure are considered sedentary, scores between 14 and 23 are considered moderately active, and a score of 24 or above is considered active. Additionally, participants were asked to indicate the frequency in which they engage in any regular activity long enough to work up a sweat (*never/rarely*, *sometimes*, *often*) in a typical week. In this sample, internal consistency of the GLTEQ was good ($\alpha = .75$).

Sleep. Sleep quality during the past month was measured using the Pittsburgh Sleep Quality Index (PSQI; (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989). This 19-item measure is widely used in the sleep literature and has demonstrated good psychometric properties in previous research (Buysse et al., 1989; Short et al., 2017). In addition to a global score, seven component scores can be calculated, including: subjective sleep quality, sleep latency, sleep duration, sleep efficiency, sleep disturbance, use of sleep medication, and daytime dysfunction. Due to missing data for four participants' total scores, Cronbach's alpha could not be calculated for this measure.

Daily Measures.

PTSD Symptoms. PTSD symptoms were measured each morning and evening using ten items from the PCL-5 (Weathers, 2013). Instructions were modified to ask about symptom severity *since the previous survey*. Each item maintained the same rating scale as the PCL-5 and was rated from 0 (*not at all*) to 4 (*extremely*). The ten items were selected based on those used by Short and colleagues (2017) in their EMA study examining sleep disturbances in a PTSD sample. These researchers adapted the PCL-5 for their daily surveys by including the ten items that loaded most strongly onto the four PTSD symptom clusters in the DSM-5 (American Psychiatric Association, 2013). Also consistent with Short and colleagues (2017), PCL-5

questions pertaining to sleep were not included to avoid redundancy with PSQI items. See Appendix B for specific items. Multilevel factor analysis was used to compute reliability estimates for the daily survey measures. Within-person reliability estimates for the daily PCL-5 ranged from .80 on the morning survey to .84 on the evening survey, while between person reliability estimates were .96 on the morning survey and .93 on the evening survey.

Physical Activity. Self-reported physical activity was measured in the evening survey using two items. Participants were asked "*Approximately what duration of time was spent participating in moderate to vigorous physical activity today?*" and were provided with the following response options: "*None*", "*less than 30 minutes*", "*30-45 minutes*", "*45-60 minutes*", "*60-90 minutes*", and "*more than 90 minutes*". Additionally, participants were asked to indicate the specific types of physical activities that they participated in each day, using a checklist format. Response options included: *Walking/hiking, running/jogging, cycling, weights/resistance exercise, yoga/Pilates, swimming, team sports, other*, or *none of the above*. For the analysis, these activities were summed based on number of activities each day.

Sleep. The morning survey included questions about the previous night's sleep using items from the PSQI (Buysse et al., 1989) that were modified for daily use based on Short and colleagues' (2017) EMA study. Self-reported sleep quality was measured using a 4-point Likert scale ranging from 0 (*Very bad*) to 3 (*Very good*). Trauma-related sleep disturbances were measured using items from the PSQI's PTSD addendum (Germain, Hall, Krakow, Shear, & Buysse, 2005), and were rated as present (*yes*) or not (*no*). Specific items included: "*Had memories or a nightmare of a traumatic experience*", "*Had episodes of terror or screaming during sleep without fully awakening*", and "*Had episodes of "acting out" your dreams, such as kicking, punching, running, or screaming*".

Positive and Negative Affect. Positive and negative affect were measured in the morning and evening surveys using eight items from the 20-item Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988). This reduced scale was based on the items used by Short et al., (2017) who selected items based on those that loaded the strongest onto positive and negative affect factors of the PANAS, including emotions relevant to sleep or PTSD. Participants were asked to rate each item based on how they have been feeling since the last survey and each item was rating using a 5-point Likert scale ranging from "*Very slightly or not at all*" to "*Extremely*". Negative affect items were: "*upset*", "*guilty*", "*scared*", and "*irritable*", and positive affect items were: "*enthusiastic*", "*interested*", "*alert*", and "*determined*". Within-person and between-person reliability estimates for morning positive affect were .65 and .85, respectively. On the evening survey, within-person and between-person reliabilities for positive affect were .72 and .88, respectively. For negative affect, morning within-person and between-person reliabilities were .73 and .91, respectively. Finally, evening survey negative affect reliability estimates were.76 at the within-person level and .92 at the between-person level.

Coping strategies. In both the morning and evening surveys, participants were asked to indicate which coping strategies (if any) they had engaged in since the previous survey. A list of adaptive and maladaptive coping strategies was developed by the research team in consultation with a clinician with expertise in providing psychological services to individuals with PTSD. Items were presented in a random order and participants were instructed to select as many that applied. Specifically, adaptive coping strategies were: "*seeking social support*", "*spending time in nature*", "*cognitive reappraisal*", "*humour*", and "*yoga/meditation*". Maladaptive coping strategies were: "*distraction (e.g., watching TV)*", "*self-medicating with alcohol or drugs*", "*behaviours such as gambling, online shopping, over-eating*", and "*emotional suppression*".

Scores were summed to create total scores for both adaptive coping strategies and maladaptive coping strategies.

Fitbit Measures.

Physical Activity. In addition to self-reported physical activity, Fitbit Charge HR accelerometers were used to measure daily exercise patterns. In particular, the accelerometer measured daily steps, and using heartrate information automatically tracks minutes lightly active, minutes fairly active, and minutes very active. For the purpose of analysis, minutes fairly active and minutes very active were summed to create a single variable representing time spent in moderate to vigorous activity. Several studies have examined the usability and validity of this particular Fitbit model (Bai, Hibbing, Mantis, & Welk, 2018; Deka, Pozehl, Norman, & Khazanchi, 2018; Lee et al., 2017; Stahl, An, Dinkel, Noble, & Lee, 2016). When measured against a Polar RS400 chest strap during a 30-minute treadmill exercise with continuous bouts of walking and running, the Charge HR yielded overall error rates of 6.2%, with less error observed in higher intensity exercise at 2.46% (Stahl et al., 2016). In a sample of community dwelling patients with heart failure, Deka and colleagues (2018) evaluated the Fitbit Charge HR in relation to self-reported exercise diaries over the course of eight weeks. Their findings indicated that self-reported exercise data was validated with data from the Charge HR devices. They also elicited participant feedback and concluded that these devices are both acceptable and feasible for use in a community sample.

Sleep. Participants wore Fitbit Charge HR accelerometers each night for the duration of the study. In addition to measuring subjective sleep quality and self-reported sleep disturbances, the Fitbit was used to capture device-measured sleep patterns. Fitbit uses an algorithm to analyze sleep patterns including minutes asleep, minutes awake, number of awakenings, with the time

and date recorded for each start time and end time. For the present analysis, sleep variables included total time asleep and number of awakenings, which was defined as the total number of awakenings after initial sleep onset. Fitbits are a cost-effective and user-friendly tool for estimating sleep patterns. In a study of health young adults, the Fitbit Charge HR was compared with the Actiwatch 2 for sleep evaluation and circadian rest-activity rhythm measurement (Lee et al., 2017). Participants wore both devices on the same wrist for a total of 14 days. The results indicated that while the Fitbit Charge HR tended to overestimate sleep duration by 20 to 30 minutes relative to the Actiwatch 2, there were no significant differences between the two devices and correlations between them were strong, ranging from .80 and .98. In a sample of healthy adolescents, de Zambotti and colleagues (2016) found the Fitbit Charge HR devices overestimated total sleep time by eight minutes, and sleep efficiency by 1.8%, while they underestimated wake and sleep onset by 5.6 minutes, when compared to polysomnography (de Zambotti et al., 2016).

It is important to note that the majority of studies examining the validity of Fitbit accelerometers do not focus on within-person change over time, but rather tend to compare the devices to other sources of data such as the gold standard Actigraphy devices. While it is important to evaluate the accuracy of these devices, the degree of measurement error poses less of a problem in within-person designs, so long as the degree of error is consistent. In other words, if a Fitbit device is known to overestimate sleep by 20 minutes, as long as this deviation is consistent, the device has the potential to be a valuable tool when the purpose is to compare an individual to their own personal average.

Data Analytic Strategy

Data Preparation. SPSS Version 26 was used for data management and descriptive analyses and MPlus Version 8.3 (Muthen & Muthen, 1998-2019) was used for multilevel modeling. Continuous within-person variables were person-mean centred and between-person variables were grand-mean centered. Daily scores on measures of PTSD symptoms and positive and negative affect were represented using the mean of each scale instead of the total raw score. This approach is more robust at handling missing data if any items on a given subscale are missing, and can facilitate interpretation by adhering to the same scale as the original items (e.g., 1-5 scale). Additionally, when using the mean scale scores, the meaning of a 1-unit change is not dependent on the number of items in a given scale.

Multilevel Models. Multilevel modeling was used to account for nested data and missing data. First, unconditional random intercept-only models were run to examine the contributions of within-person and between-person variances. Intraclass correlation coefficients (ICCs) were computed for each variable to determine how much of the variance occurred at the between-person level. Next, within-person coupling models were estimated to examine within-person fluctuations across days and between-person differences in physical activity, PTSD symptoms, and their associations (i.e., affect, coping, sleep). In all models, age, sex, and body mass index (BMI) were included as covariates.

Results

Descriptive Statistics

Of a possible 105 morning surveys (7 days x 15 participants), 93 morning surveys were completed (response rate = 88%), with an average of 6.2 completed surveys per participant. Evening survey response rates were somewhat lower, with 89 out of 105 possible evening surveys completed (response rate = 84%) and an average of 5.9 evening surveys per participant. These response rates were consistent with or better than response rates observed in other daily diary studies in PTSD samples. For instance, Short and colleagues (2017) reported their sample completed 80% of possible EMA surveys, and Gehram and colleagues (2015) reported sleep diary response rates between 82.9% and 83.8% in a sample of Vietnam Veterans (Gehrman, Harb, Cook, Barilla, & Ross, 2015; Short et al., 2017).

Means, standard deviations, and ICCs for daily variables are presented in Table 4. By determining how much of the variance originates at the between-person level, inferences can be made regarding how much variance is due to within-person variation plus residual error. The ICC analyses for physical activity variables ranged from .30 to .66, indicating that 30-66% of the variance occurred at the between-person level. Less than half of the variability occurred at the between-person level for self-reported time spent in moderate to vigorous physical activity, number of physical activities, and accelerometer-measured time spent in moderate to vigorous activity. This suggests that a large proportion of the variance occurred at the within-person level. For total PCL-5 scores, there was more between-person variability in the morning survey (ICC = .76) than in the evening survey (ICC = .56). Self-reported sleep quality exhibited the least between-person variability (ICC = .24). Figures 1-4 illustrate within- and between-person variability for the sample for each predictor and outcome variable.

Table 4. *Means, standard deviations (SD) and intraclass correlations (ICCs) for daily variables.*

Variable	Mean	SD	ICC
Morning Survey			
PCL-5 Total	0.99	0.84	0.76
Sleep Quality	1.64	0.79	0.24
Evening Survey			
PCL-5 Total	1.14	0.75	0.56
PCL-5 Re-experiencing	0.89	0.92	0.56
PCL-5 Avoidance	1.12	0.99	0.40
PCL-5 Hyperarousal	1.26	0.89	0.56
PCL-5 Cognition/Mood	1.20	0.92	0.60
Positive Affect	1.50	0.84	0.68
Negative Affect	0.92	0.87	0.68
Adaptive Coping	2.03	1.49	0.42
Maladaptive Coping	1.20	0.85	0.45
Time spent Mod-Vig activity	1.50	1.64	0.47
Number of Physical Activities	1.06	0.90	0.35
Fitbit Measures			
Steps	7731.46	5469.31	0.62
Light Activity (minutes)	207.31	119.09	0.66
Moderate-Vigorous Activity (minutes)	43.28	53.73	0.30

Note. PCL-5 = PTSD Checklist for DSM-5; Self-reported time spent in moderate to vigorous activity in evening survey was rated on a 6-point Likert-type scale where 0 = none, 1 = < 30 minutes, 2 = 30-45 minutes, 3 = 60 minutes, 4 = 60-90 minutes, and 5 = > 90 minutes; Fitbit light and moderate-vigorous activity is presented in terms of total minutes over the course of the day.

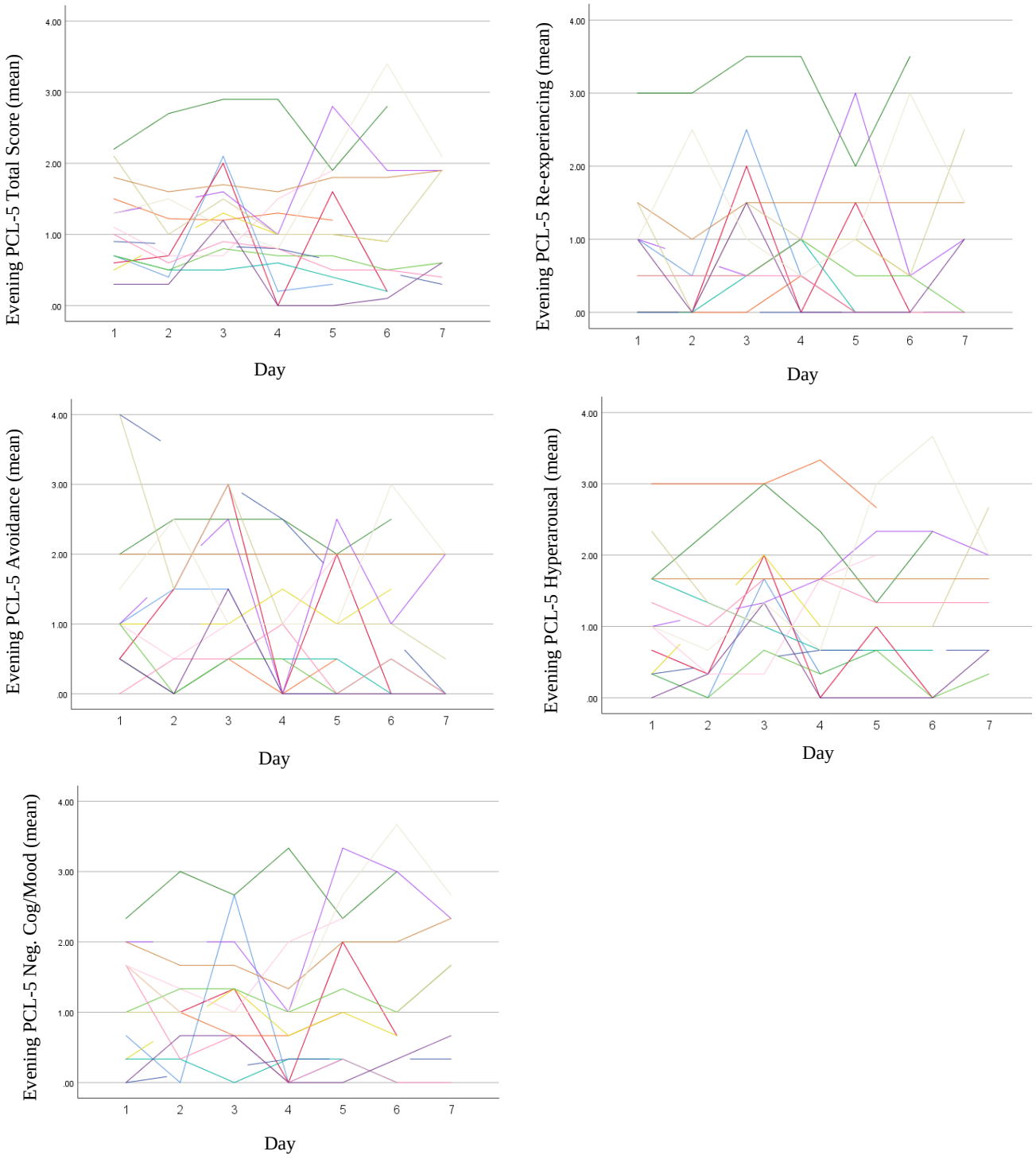

Figure 1. Spaghetti plots illustrating participant variability on evening survey PTSD symptoms: total score and sub-scale scores for each symptom cluster.

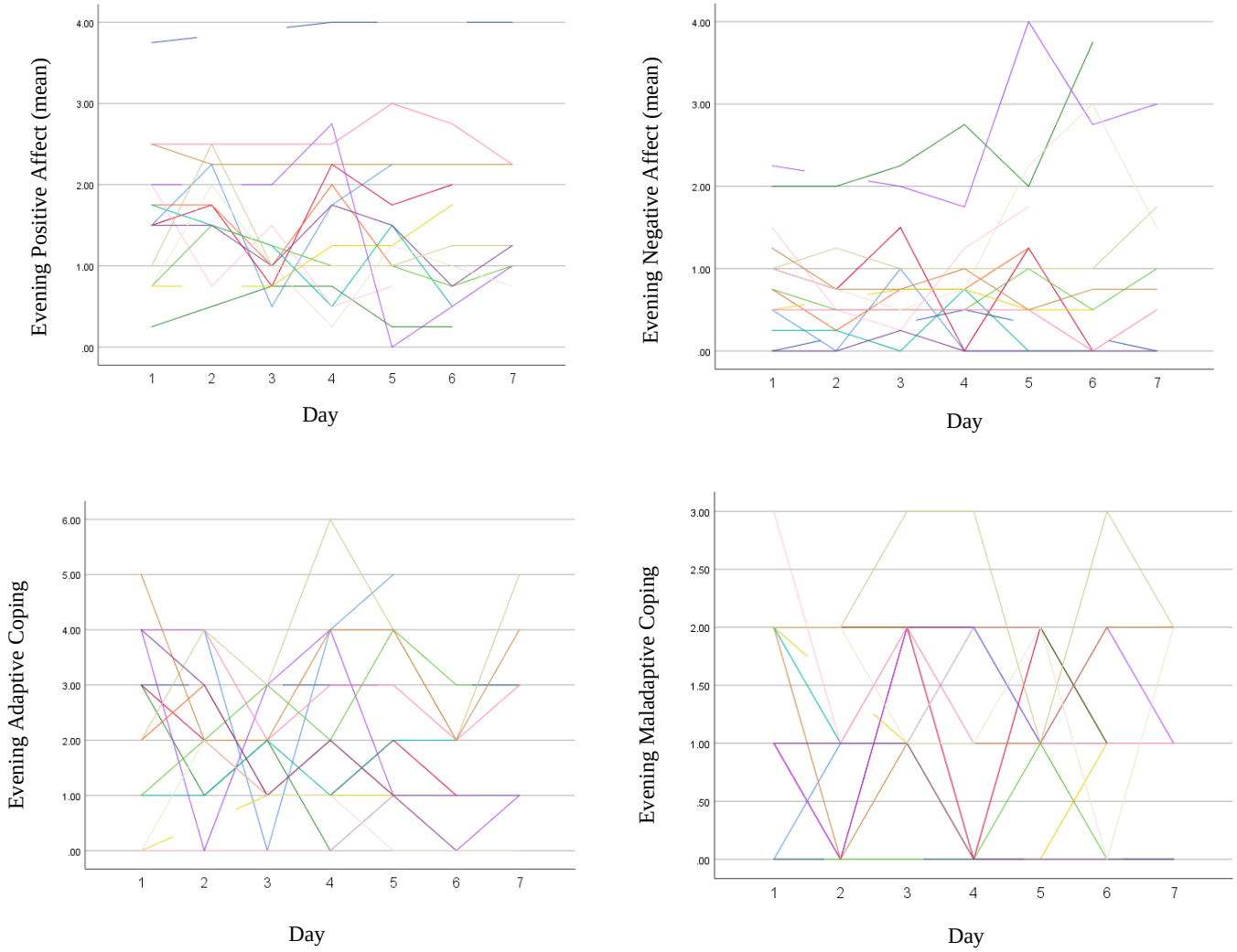

Figure 2. Spaghetti plots illustrating participant variability on evening survey positive and negative affect and adaptive and maladaptive coping strategies.

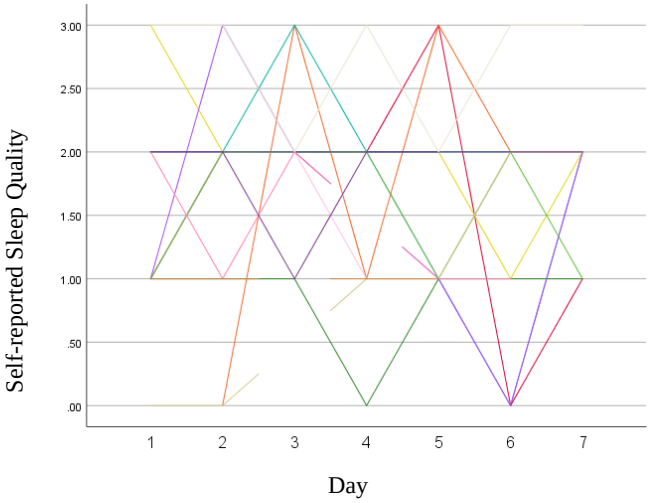

Figure 3. Spaghetti plot illustrating daily variability in self-reported sleep quality in morning survey.

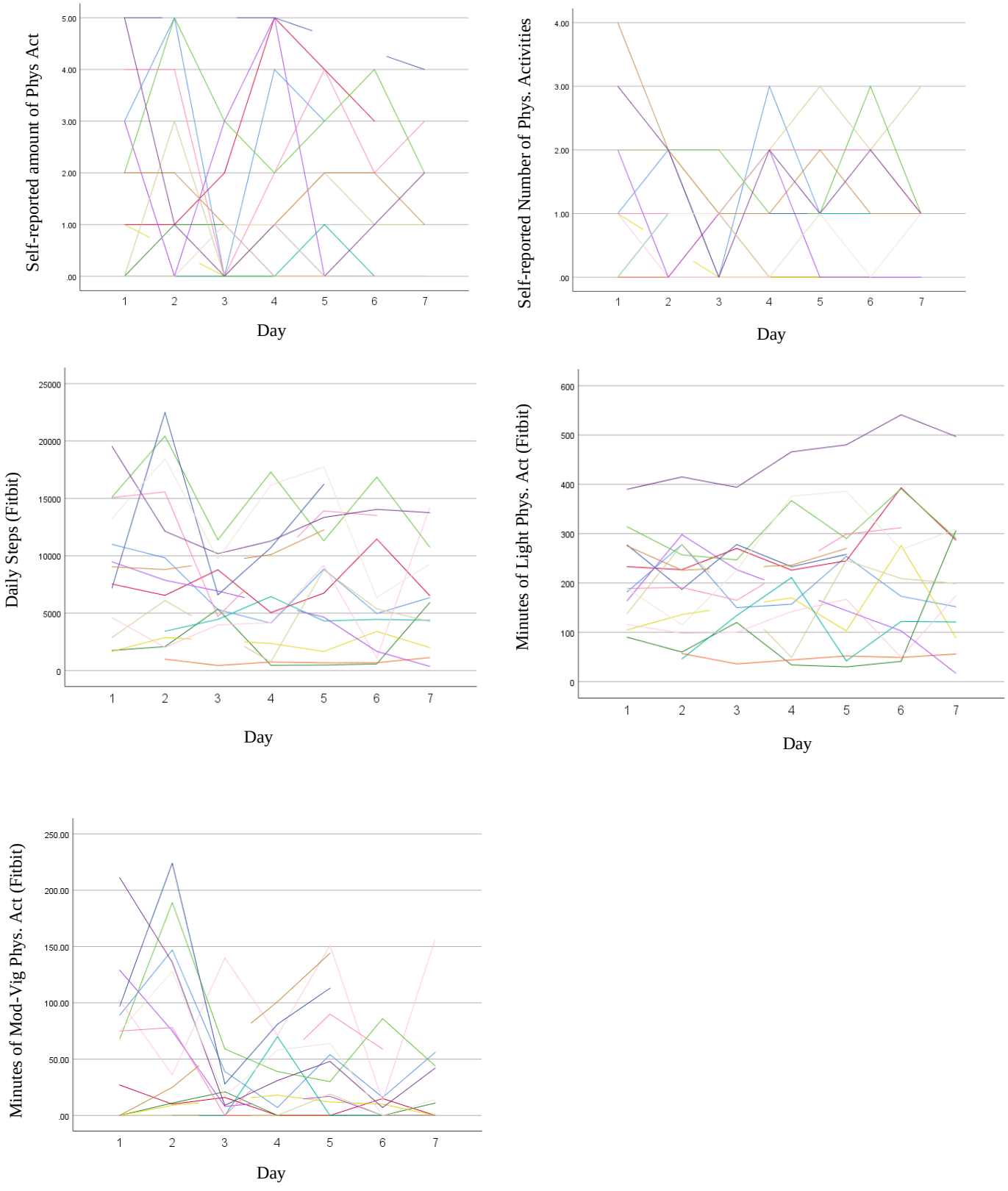

Figure 4. Spaghetti plots illustrating participant daily variability in physical activity measures.

Multilevel Modelling

Hypothesis 1: Greater levels of physical activity will be associated with fewer symptoms of PTSD at the within-person level (same day) and the between-person level (Table 5):

To test the first hypothesis, separate models were run for each measure of physical activity predicting total PCL-5 scores in the evening survey. In terms of self-reported physical activity, on days when participants reported spending more time in moderate to vigorous activity than usual, they reported significantly fewer PTSD symptoms on the evening survey (b = -.16, SE = .05, p <.01). Similarly, findings indicated that on days that participants reported engaging in a greater number of physical activities than their calculated average, they reported fewer PTSD symptoms on the evening survey (b = -.18, SE = .09, p <.05). With respect to accelerometer-measured activity data, on days when time spent in moderate to vigorous activity was greater than their calculated average, participants reported fewer symptoms of PTSD on the evening survey (b = -.002, SE = .001, p < .05). However, time spent engaging in light physical activity and daily steps did not significantly predict same-day PTSD symptoms at the within-person level. It is important to note that accelerometer estimates are based on each additional minute of physical activity. To facilitate interpretation, the above estimate would be .02 for each additional ten minutes of physical activity or .06 for each additional 30 minutes of physical activity. These estimates more closely reflect the scale used for the self-reported time spent in moderate-to-vigorous activity.

At the between-person level, all physical activity measures except for Fitbit-measured moderate-to-vigorous activity were significantly and negatively associated with PTSD symptoms. Thus, findings revealed that individuals who reported spending more time engaging in moderate-to-vigorous physical activity on average (b = -.22, SE = .08, p < .01) and who

participated in a greater number of physical activities on average (b = -.45, SE = .16, p < .01) reported significantly fewer PTSD symptoms overall on the evening surveys.

Hypothesis 1a: Greater levels of physical activity will be particularly associated with fewer symptoms of hyperarousal, relative to other symptom clusters at the within-person level (same day) and the between-person level (Table 5):

To test this exploratory hypothesis, separate models were run for each physical activity predictor variable on each of the four PCL-5 symptom cluster sub-scales entered in separate models (re-experiencing, avoidance, hyperarousal, and negative alterations in cognition and mood).

Re-experiencing. At the within-person level, only time spent in light activity was significantly associated with self-reported re-experiencing symptoms in the evening survey (b = -.003, SE = .001, p < .01). At the between-person level, self-reported time spent in moderate to vigorous activity was significantly, negatively associated with re-experiencing symptoms (b = -.22, SE = .10, p < .05), as were daily steps (b = -.02, SE = .006, p < .01).

Avoidance. Two indicators of physical activity were significantly associated with self-reported avoidance symptoms at the within-person level. On days when participants self-reported more time in moderate to vigorous activity, they also reported significantly fewer symptoms of avoidance that evening (b = -.16, SE = .05, p < .01). Similarly, on days when participants engaged in a greater amount of light activity than usual, they reported significantly fewer avoidance symptoms (b = -.001, SE = .00, p < .001). There were no significant between-person associations between any of the physical activity variables and avoidance symptoms.

Hyperarousal. At the within-person level, only self-reported time spent in moderate to vigorous activity was significantly related to lower levels of hyperarousal symptoms (b = -.17,

SE = .03, p <.001). However, at the between-person level all indicators of physical activity were significantly and negatively related to hyperarousal symptoms. Specifically, participants who report greater levels of time spent in moderate to vigorous physical activity on average also endorse significantly fewer symptoms of hyperarousal (b = -.35, SE = .09, p <.001). Similarly, participation in a greater number of physical activities overall significantly predicted fewer hyperarousal symptoms (b = -.46, SE = .22, p < .05). All three accelerometer measures of physical activity revealed similar patterns (steps: b = -.01, SE = .005, p < .05; light activity: b = -.009, SE = .003, p < .01; moderate to vigorous activity: b = -.01, SE = .005, p < .05).

Negative Alterations in Cognition and Mood. In models examining the associations between daily physical activity and the cluster of negative alterations in cognition and mood symptoms, both self-reported moderate to vigorous activity (b = -.18, SE = .07, p <.05) and number of physical activities (b = -.25, SE = .11, p < .05) were significantly related to lower levels of these symptoms. In terms of between-person effects, individuals who report spending more time engaging in moderate to vigorous physical activity and a greater number of activities on average endorsed significantly fewer symptoms of negative alterations in cognition and mood (b = -.24, SE = .09,p < .01; b = -.62, SE = .18, p < .01, respectively).

Table 5. *Within-person and between-person estimates of the effects of physical activity on evening PTSD symptoms.*

	Outcome									
	PCL5-Total		Re-experiencing		Avoidance		Hyperarousal		Neg. Cog & Mood	
Predictor	Within	Between	Within	Between	Within	Between	Within	Between	Within	Between
	b (SE)	*b* (SE)	*b* (SE)	*b* (SE)	*b* (SE)	*b* (SE)	*b* (SE)	*b* (SE)	*b* (SE)	*b* (SE)
Self-Report										
PA Amount	-.16 (.05)**	-.22 (.08)**	-.12 (.07)	-.22 (.10)*	-.16 (.05)**	.024 (.18)	-.17 (.03)***	-.35 (.09)***	-.18 (.07)*	-.24 (.09)**
PA Sum	-.18 (.09)*	-.45 (.16)**	-.14 (.08)	-.44 (.30)	-.20 (.11)	0.187	-.13 (.11)	-.46 (.22)*	-.25 (.11)*	-.62 (.18)**
Fitbit										
Steps	-.004 (.003)	-.01 (.005)*	-.001 (.004)	-.02 (.006)**	-.002 (.002)	.002 (.013)	-.005 (.007)	-.01 (.005)*	-.004 (.003)	-.010 (.007)
Light Activity	-.001 (.001)	-.007 (.003)*	-.003 (.001)**	-.006 (.009)	-.001(.00)***	-.001 (.000)	.000 (.001)	-.009 (.003)**	-.001 (.001)	-.008 (.004)*
Mod-Vig Activity	-.002 (.001)*	-.004 (.003)	.000 (.000)	-.005 (.005)	.000 (.001)	.005 (.009)	-.004 (.003)	-.01 (.005)*	-.003 (.01)	-.001 (.005)

Note: *b* = parameter estimate, SE = standard error, PA = physical activity, PCL-5 = PTSD Checklist for DSM-5; Fitbit steps are based on each additional step and Fitbit activity estimates are based on each additional minute of physical activity. *** p <.001, ** p <.01, * p <.05

Hypothesis 2: Greater levels of physical activity will be associated with more positive affect and less negative affect at the within-person level (same day) and the between-person level (Table 7):

To test this hypothesis, separate models were run for each physical activity variable predicting positive affect and negative affect in the evening survey. Among the five measures of physical activity, two significantly predicted negative affect and four significantly predicted positive affect. Within-person models indicated that on days when participants spent more time than usual in moderate to vigorous physical activity, as measured by self-report (b = -.13, SE = .05, p <. 05) and accelerometer (b = -.002, SE = .001, p <. 05), they reported significantly lower negative affect. Negative affect was not significantly associated with number of physical activities reported, time spent in light activity, or daily steps at the within-person level. With respect to positive affect, on days when individuals self-reported spending more time engaging in moderate to vigorous activity than usual (b = .19, SE = .06, p < .01) and a greater number of activities than usual (b = .23, SE = .10, p < . 05), they also reported significantly greater levels of positive affect. Similarly, accelerometer-measured time spent in moderate to vigorous activity was associated with significantly higher positive affect (b = .003, SE =.001, p <.001) within individuals. Daily steps also significantly predicted positive affect, such that on days that participants took more steps than usual, they reported higher levels of positive affect (b = .004, SE = .001, p < .01). No significant within-person associations were observed between light activity and positive or negative affect.

Between-person estimates revealed that participants who report spending more time in moderate to vigorous physical activity and participating in a greater number of physical activities on average tended to report less negative affect (b = -.17, SE = .07, p < .05; b = -.51, SE = .17, p

< .01, respectively) and more positive affect on average (b = .38, SE = .15, p < .05, b = .35, SE = .16, p < .05, respectively).

Hypothesis 3: Greater levels of physical activity will be associated with better sleep outcomes at the within-person level (physical activity predicting sleep that evening) and the between-person level (Table 6):

Separate models were run with each of the five physical activity predictor variables on each sleep metric. Self-reported sleep quality was measured using a 4-point Likert scale with higher scores indicative of better sleep quality. Models examined whether physical activity was associated with better sleep quality that evening, based on self-report from the next morning's survey. At the within-person level, none of the physical activity variables significantly predicted sleep quality that evening (see Table 6). At the between person level, daily steps emerged as the only measure of physical activity that was significantly related to self-reported sleep quality, revealing that individuals with a higher average daily step count tend to report better sleep quality on average.

Additional models were run predicting two accelerometer-measured sleep variables: sleep duration (total minutes asleep) and total number of awakenings following sleep onset. No significant associations were found at the between or within-person level for any of the physical activity predictor variables in relation to sleep duration or number of awakenings. Model results are presented in Table 6.

Table 6. *Within- and between-person estimates of the effects of physical activity on sleep parameters.*

	Outcome					
	Sleep Quality		Sleep Duration		Number of Awakenings	
Predictor	Within *b* (SE)	Between *b* (SE)	Within *b* (SE)	Between *b* (SE)	Within *b* (SE)	Between *b* (SE)
Self-Report						
Phys Act. Amount	.03 (.03)	-.08 (.12)	-5.77 (5.36)	-13.94 (21.60)	.21 (.17)	-.28 (.24)
Phys Act. Sum	.005 (.07)	-.47 (.26)	-4.26 (7.94)	51.28 (15.09)	.07 (.23)	-.30 (.53)
Fitbit						
Steps	.000 (.002)	.008 (.003)*	-.22 (.20)	-1.82 (.91)	-.001 (.006)	.009 (.01)
Light Activity	.000 (.004)	(.002) (.002)	.07 (.16)	-.39 (.56)	-.001 (.002)	-.004 (.006)
Mod-Vig Activity	.001 (.003)	.003 (.003)	-.09 (.16)	-.43 (.90)	.001 (.003)	.01 (.01)

Note: b = parameter estimate, SE = standard error, PA = Phys act; Fitbit steps are based on each additional step and Fitbit activity estimates are based on each additional minute of physical activity; Sleep Quality is self-reported using a 4-point Likert scale; Sleep Duration is based on total minutes of sleep from Fitbit data (including broken sleep); *** p <.001, ** p <.01, * p <.05

Hypothesis 4: Greater levels of physical activity will be associated with more adaptive coping strategies and fewer maladaptive coping strategies (Table 7):

Separate analyses were run predicting number of adaptive coping strategies or maladaptive coping strategies for each physical activity predictor variable. On days when time spent in moderate to vigorous activity was greater than usual as indicated by self-report (b = .37, SE = .14, p <.01) and accelerometer (b = .009, SE = .003, p < .05), participants reported engaging in significantly more adaptive coping strategies. On days when participants reported a greater number of physical activities than usual (b = .61, SE = .24, p <.05) and took more steps that usual (b = .01, SE = .005, p < .05), they endorsed significantly more adaptive coping strategies. Between-person effects were observed for both self-report physical activity variables, with individuals who tend to report more time spent in moderate to vigorous activity and a greater number of physical activities each day significantly more likely to engage in adaptive coping strategies (b = .46, SE = .16, p < .01; b = 1.84, SE = .19, p < .001, respectively).

Models predicting maladaptive coping strategies did not reveal any significant within person associations with any of the physical activity measures. However, three models were significant at the between-person level. Individuals who tend to engage in higher levels of moderate to vigorous physical activity were significantly less likely to engage in maladaptive coping strategies, based on self-report (b = -.32, SE = .09, p < .001) and accelerometer-measured moderate to vigorous activity (b = -.009, SE = .004, p < .05). Those with higher average daily step counts also were significantly less likely to use maladaptive coping strategies on average (b = -.01, SE = .005, p < .05).

Table 7. *Within- and between-person estimates of the effects of physical activity on evening survey affect and coping.*

	Outcome							
	Positive Affect		Negative Affect		Adaptive Coping		Maladaptive Coping	
Predictor	Within	Between	Within	Between	Within	Between	Within	Between
	b (SE)	*b* (SE)	*b* (SE)	*b* (SE)	*b* (SE)	*b* (SE)	*b* (SE)	*b* (SE)
Self-Report								
Phys Act. Amount	.19 (.06)**	.38 (.15)*	-.13 (.05)*	-.17 (.07)*	.37 (.14)**	.46 (.16)**	.04 (.07)	-.32 (.09)***
Phys Act. Sum	.23 (.10)*	.35 (.16)*	-.13 (.10)	-.51 (.17)**	.61 (.24)*	1.84 (.19)***	.09 (.11)	-.01(.29)
Fitbit								
Steps	.004 (.001)**	.01 (.009)	-.003 (.06)	-.01 (.005)	.01 (.005)*	-.007 (.013)	-.001 (.003)	-.01 (.005)*
Light Activity	.001 (.001)	.000 (.006)	.000 (.001)	-.007 (.004)	-.001 (.002)	-.006 (.005)	-.002 (.001)	-.005 (.002)
Mod-Vig Activity	.003 (.001)***	.006 (.008)	-.002 (.001)*	-.004 (.003)	.009 (.003)*	-.006 (.01)	.000 (.002)	-.009 (.004)*

Note: *b* = parameter estimate, SE = standard error, PA = Phys act; Fitbit steps are based on each additional step and Fitbit activity estimates are based on each additional minute of physical activity *** p <.001, ** p <.01, * p <.05

Hypothesis 5: Greater levels of morning PTSD symptoms will be associated with lower levels of physical activity at the within-person level (morning symptoms predicting same-day physical activity) and the between-person level (Table 8):

To examine the reverse association, separate models were run with morning PTSD symptoms as the predictor variable and each of the five measures of physical activity as outcome variables. At the within-person level, morning PTSD symptoms did not significantly predict any of the five physical activity variables. However, at the between-person level, individuals who tend to report greater PTSD symptoms in the morning on average also report significantly less time spent in moderate to vigorous activity over the course of the day on average (b = -.80, SE = .30, p <.01). With respect to accelerometer measurements, greater morning PTSD symptoms were associated with significantly less time spent in light activity (b = -37.55, SE = 5.29, p <.001) and fewer steps (b = -19.13, SE = 7.17, p <.01) on average.

Table 8. *Within- and between-person estimates of the effect of morning PTSD symptoms on daily physical activity.*

	Outcome									
Predictor	PA Amount		PA Sum		Steps		Light Activity		Mod-Vig Activity	
	Within	Between	Within	Between	Within	Between	Within	Between	Within	Between
	b (SE)	*b* (SE)	*b* (SE)	*b* (SE)	*b* (SE)	*b* (SE)	*b* (SE)	*b* (SE)	*b* (SE)	*b* (SE)
PCL-5 Total (morning)	.07 (.90)	-.80 (.30)**	.08 (.47)	-.06 (.22)	-.89 (9.55)	-19.14 (7.17)**	-.04 (8.8)	-37.56 (5.29)***	.005 (15.43)	-11.34 (10.99)

Note: b = parameter estimate, SE = standard error, PA = physical activity; PCL-5 = Posttraumatic Stress Disorder Checklist for DSM-5; *** p <.001, ** p <.01, * p <.05

Discussion

The primary aim of this study was to investigate the within-person associations between physical activity and symptoms of PTSD in a community sample of adults diagnosed with PTSD. A secondary aim was to evaluate the ways in which physical activity is associated with mood, coping, and sleep on a daily level. This study used a daily diary methodology with fifteen participants completing surveys on their smartphones twice daily for seven days, while also wearing Fitbit accelerometers for measuring activity levels and sleep. An additional aim of this study was to compare different ways of operationalizing physical activity through self-report (i.e., time spent in moderate to vigorous activity and number of physical activities per day) and accelerometer-based data (i.e., steps, light activity, and moderate to vigorous activity) in order to investigate how physical activity variables differ in their association with PTSD symptoms and other relevant outcomes (e.g., positive and negative affect, sleep, and coping strategies). Response rates were considered excellent for the morning and evening surveys, with 84% and 88% completion rates, respectively.

Multilevel modeling permitted the simultaneous examination of within-person and between-person associations and shed light on the extent to which the proportion of variance could be attributed to between-person variation on each outcome measure. Findings suggest that there was considerable day-to-day variability at the within-person level on all outcome and predictor variables. When considering total PTSD symptoms, there was more between-person variability in the morning survey than the evening survey. Regarding sub-clusters of PTSD symptoms on the evening survey, more than half of the variance was due to between-person variability for re-experiencing, avoidance, and negative cognitions/mood symptoms, whereas avoidance symptoms exhibited more variability at the within-person level. More than half of the

variance of the evening survey positive and negative affect ratings was attributed to between-person differences, while the opposite was true for number of adaptive and maladaptive coping strategies used. The ICCs for physical activity differed depending on how activity was operationalized: using accelerometer metrics, more than half of the variance was attributed to between-person differences for daily steps and minutes of light activity. However, less than half of the variance occurred at the between-person level for accelerometer-measured minutes of moderate to vigorous activity, self-reported time spent in moderate to vigorous activity, and number of self-reported activities. Taken together, these findings suggest that individuals exhibit more fluctuation in moderate to vigorous activity levels across days than they do with less intense types of physical activity such as daily steps or minutes spent engaging in light activity.

Within-person Associations

While there has been a growing body of research suggesting that greater levels of physical activity are associated with fewer symptoms of PTSD (e.g., Goldstein et al., 2018; LeardMann et al., 2011; Rosenbaum et al., 2015; Whitworth et al., 2017), this is the first study to examine these relationships at the within-person level using a daily diary methodology. Descriptive analyses provided evidence that self-reported symptoms of PTSD and physical activity levels fluctuate within individuals across days, even over a relatively short period of time (i.e., one week). This highlights the importance of utilizing a repeated measures design in order to more closely approximate individuals' true score versus relying on a single-occasion measurement score. By examining these within-person fluctuations, we can begin to understand contextual factors that influence an individual's experience.

Each multilevel model used a metric of physical activity to predict symptoms of PTSD reported in the evening survey. In particular, participants reported on the severity of each

symptom since their morning survey, reflecting their experiences over the course of each day. Models predicting total PTSD symptom scores on the abbreviated PCL-5 revealed that three of the five physical activity measures were significantly related with fewer PTSD symptoms. That is, on days when participants spent more time engaging in moderate to vigorous physical activity than usual (self-reported and device measured) or reported engaging in more types of physical activity than usual, they also reported significantly fewer symptoms of PTSD that evening. These findings are consistent with cross-sectional, longitudinal, and intervention studies that have found relationships between greater levels of physical activity and fewer symptoms of PTSD (e.g., LeardMann et al., 2011; Rosenbaum et al., 2015; Shivakumar et al., 2017; Whitworth et al., 2017). This study expands upon previous research by demonstrating that physical activity and symptoms of PTSD are significantly and negatively associated at the within-person level. These findings are important because they provide evidence that fluctuations in naturally occurring, self-initiated physical activity are associated with lower symptoms of PTSD at the daily level.

In order to build upon previous studies suggesting that among the PTSD symptom clusters, symptoms of hyperarousal are particularly related to physical activity (Goldstein et al., 2018; Harte et al., 2015; Vujanovic et al., 2013), additional multilevel models were run with each physical activity predictor variable and each of the four PTSD symptom cluster scores as an outcome. At the within-person level, self-reported time spent in moderate to vigorous activity was significantly and negatively associated with three of the four symptom clusters: avoidance, hyperarousal, and negative alterations in cognition and mood. Additionally, on days that participants reported engaging in a greater number of physical activities, they also reported significantly fewer symptoms in the negative alterations in cognition and mood cluster. In terms of accelerometer-measured variables, on days when participants spent more time engaging in

light activity than usual, they also reported significantly fewer re-experiencing and avoidance symptoms. Based on these results, there was no evidence that hyperarousal symptoms are uniquely attenuated by participation in physical activity at the daily within-person level. This finding is contrary to expectations based on between-person studies that have found hyperarousal symptoms to be particularly associated with physical activity (Babson et al., 2015; Goldstein et al., 2018; Harte et al., 2015; Vujanovic et al., 2013; Whitworth et al., 2017). It is possible that these previous studies have identified a between-person effect that is not replicable at the within-person level and further within-person studies are needed to further explore this possiblity.

While examining the role of physical activity predicting PTSD symptoms was the primary research question, the reverse association was also examined. That is, on days when morning PTSD symptoms are greater than usual, are individuals less likely to participate in physical activity that day? Contrary to hypotheses, no significant within-person associations were found when testing whether morning PTSD symptoms predict that day's physical activity. These findings are inconsistent with results from cross-sectional research demonstrating that individuals with PTSD engage in less physical activity compared to control groups (Godfrey et al., 2013; Zen et al., 2012) and prospective studies indicating that PTSD symptom severity predicts steeper declines in physical activity over time (i.e., 20 years; Winning et al., 2017). However, this was the first study to examine these associations at the within-day level. One potential explanation for these findings could be that day-to-day fluctuations in PTSD symptoms do not lead individuals to alter their exercise patterns that same day. It is also possible that elevations in morning PTSD symptoms may make some individuals more likely to engage in physical activity as a means to cope with their symptoms. Overall, participants tended to report fewer PTSD symptoms in the morning survey compared to the evening survey and one reason

for this could be that the morning survey was completed early in the day, within an hour of awakening. As such, it is possible that the timing of the morning survey reduced the ability to detect elevations in PTSD symptoms that occurred later in the morning/afternoon, thereby reducing the potential strength of an association between PTSD symptoms early in the day and subsequent exercise. It is possible that each individual's symptoms returned to their own baseline each morning and over the course of the day, their individual experiences (including level of physical activity) impacted symptom severity reported in the evening survey.

This study examined whether greater levels of physical activity predict fluctuations in self-reported positive and negative affect. On days when participants spent more time in moderate to vigorous physical activity (self-reported and device-measured), engaged in a greater number of activities, and took more steps than usual, they reported significantly greater levels of positive affect on the evening survey. These findings are consistent with the broader literature examining the relationship between physical activity and positive affect. For example, in a 7-day EMA study of individuals with major depressive disorder, Mata and colleagues (2012) prompted participants on eight random occasions per day and found that higher intensity and longer duration of physical activity were associated with increases in positive affect. Similarly, in another EMA study, Wichers and colleagues (2012) found evidence of increases in positive affect up to 180 minutes after engaging in physical activity. With regards to negative affect in the present study, only time spent in moderate to vigorous exercise (self-reported and accelerometer-measured) significantly predicted reductions in negative affect on the evening survey. This finding differed from previous EMA research that did not find an association between physical activity and negative affect in a sample of female twins (Wichers et al., 2012). Overall, these findings suggest that on days that participants are more physically active, they also report

elevated levels in well-being as indicated by overall symptoms of positive and negative affect. Additionally, these results suggest that positive affect, but not negative affect, may be particularly influenced by less intense forms of physical activity, such as walking.

In addition to specific symptom and mood fluctuations, this study provides evidence that on days when individuals engage in more physical activity than usual, they are more likely to report using more adaptive ways of coping (e.g., seeking social support, spending time in nature, using cognitive reappraisal strategies, humour, and yoga/meditation). With regards to specific measures of physical activity, all indicators except for light activity significantly predicted greater utilization of adaptive coping methods. Contrary to hypotheses, no measures of physical activity, whether self-reported or accelerometer-measured, were related to fluctuations in maladaptive coping strategies. One possible reason for this finding could be that participants reported engaging in fewer maladaptive coping strategies each day ($M = 1.20$, $SD = .85$) than they did adaptive coping strategies ($M = 2.03$, $SD = 1.49$). More research is needed to understand why fluctuations in physical activity may be more strongly related to use of adaptive but not maladaptive coping strategies.

This study also assessed the associations between daily physical activity and sleep. Contrary to hypotheses, results did not support an association between physical activity and self-reported sleep quality at the intra-individual level. Similarly, physical activity was not significantly related to device-measured sleep duration or number of awakenings. Although there is research highlighting the benefits of physical activity on sleep in individuals with PTSD symptoms (Bosch et al., 2017), it is possible that these effects are not detectable at the daily level. This finding is consistent with past daily diary research examining associations between physical activity and device-measured sleep in a non-PTSD sample of adult women (Mitchell et

al., 2016). In this study, physical activity and sleep were not associated with each other in either direction and the authors concluded that physical activity may not necessarily improve sleep outcomes on a day-to-day basis.

Between-person associations

Although the sample size for this study was small, between-person estimates in multilevel models were also investigated. Because of the small sample size, these findings should be interpreted with caution and may not be generalizable beyond this study. With respect to symptoms of PTSD, participants who engaged in greater amounts of physical activity overall also tended to report fewer symptoms of PTSD over the course of the day (based on reports from the evening survey questions). These results were consistent with previous between-person studies that have found support for an association between physical activity and symptoms of PTSD (e.g., Godfrey et al., 2013; Vujanovic et al., 2013; Whitworth et al, 2017), but differed from studies that did not find support for an association (e.g., Mason et al., 2019).

Of the five physical activity predictor variables, four were significantly associated with total PCL-5 symptoms, three with negative alterations in cognition and mood, and two each with avoidance and re-experiencing symptoms (see Table 2 for details). Hyperarousal was most strongly related to measures of physical activity, with all five activity variables emerging as significantly and negatively related to hyperarousal symptoms. This finding is consistent with previous research investigating the between-person effects of physical activity and specific clusters of PTSD symptoms (Harte et al., 2015; Vujanovic et al., 2013; Whitworth et al., 2017). For example, in trauma-exposed adults not meeting full PTSD criteria, Vujanovic and colleagues (2013) found that greater levels of physical activity were associated with lower hyperarousal symptoms only.

Significant between-person associations were also found when considering the relationship between physical activity and positive and negative affect, and with adaptive and maladaptive coping. In these models, self-reported time spent in moderate to vigorous activity was most strongly related to affect and coping and findings were in the expected direction. Accelerometer measures were not significantly related to positive affect, negative affect, or adaptive coping at the between person level. However, individuals with higher average daily step counts and who spend more time in moderate to vigorous physical activity in general, also tended to report using fewer maladaptive coping strategies over the course of the study.

While there was no evidence of within-person associations between morning levels of PTSD symptoms and that day's physical activity, some between person effects emerged in these models. Participants who reported greater levels of PTSD symptoms in the morning also tended to report spending less time in moderate to vigorous physical activity, took fewer steps, and spent less time engaging in light activity. These results suggest that more severe PTSD symptoms are associated with less activity overall, which is in line with findings from previous studies (Godfrey et al., 2013; Winning et al., 2017, Zen et al., 2012).

Clinical Implications

The findings from this study have important implications for clinical settings. First, the demonstrated within-person variability in symptoms and affect is important to consider in the context of assessment. Often, clinicians will have clients complete symptom measures at only one occasion or repeatedly over widely spaced occasions for treatment monitoring. Assuming that an individual's responses on a particular scale are representative of their true score may lead to inaccurate conceptualization or diagnosis. By repeatedly measuring individuals, clinicians can better understand how their clients vary on particular symptoms and thus be able to better

understand that person's true average score. There is evidence to suggest that using intensive measurement designs (e.g., EMA) before and after an intervention may be more sensitive at detecting changes in key variables, compared to more typical paper and pencil administration of assessment measures pre- and post-intervention (Moore et al., 2016).

There are also important clinical implications for interventions. The findings from this study suggest that both moderate to vigorous physical activity and lighter forms of physical activity are associated with fewer symptoms of PTSD at the intra-individual level. The results from this study support the benefits of incorporating a lifestyle intervention such as physical activity into traditional interventions (e.g., Cognitive Behavioural Therapy) for the treatment of PTSD. Using a daily diary design such as this may be of utility to clinicians for the purpose of monitoring fluctuations in symptoms in order to better understand how symptoms relate to other variables. In particular, understanding the within-person links between lifestyle behaviours (e.g., physical activity, diet, sleep) and mental health symptoms could help identify target intervention areas that may otherwise be missed.

In addition to informing treatment planning and monitoring, daily diary design in a clinical setting may be of utility in terms of being able to provide feedback to clients in order to better help them understand the patterns that unfold within their daily lives. While some of this information can indeed be obtained via clinical interview and completion of in-depth questionnaires in a clinic setting, this traditional approach may be limited by factors such as recall bias and social desirability (Althubaiti, 2016; Latkin et al., 2016). Daily diary methods would provide clinicians with a more ecologically valid way of understanding how these associations play out for their clients in their daily lives.

Limitations and future directions

Several limitations should be considered when interpreting the results of this study. First, the generalizability of the results is limited by the small sample size, particularly with respect to the between-person findings. Given that statistically significant results were obtained in components of the within-person and between-person models is encouraging and similar studies with larger sample sizes are needed to help clarify or confirm the strength of these associations. Studies with larger samples would also benefit from the ability to test potential moderating and mediating variables (e.g., gender, sleep). A second limitation is the fact that the majority of recruitment occurred in treatment settings; this sample represents a group of individuals who were treatment-seeking at the time of the study (either in the form of psychotherapy, peer support, or physiotherapy) and therefore the findings may not extend to a broader population of individuals with PTSD who are not actively engaged in treatment. Future research in this area would benefit from targeting a more diverse sample of participants by advertising in a range of settings. Third, the sample lacked diversity in terms of ethnic background and gender (i.e., the majority of participants identified as Caucasian and were predominantly male). Additionally, the study did not measure duration since traumatic event or collect data relating to the number of traumatic exposures. These factors may play important roles in individuals' symptom severity and it would be interesting to see if they moderate the relationships between physical activity and PTSD symptoms.

This study adds to the existing literature by incorporating accelerometer-measured physical activity. Although previous research has demonstrated that the Fitbit Charge HR can be a valid tool for measuring physical activity (Stahl et al., 2016) and sleep, these devices are not without measurement error. In particular, they may not be as accurate as devices more commonly

used in a medical research context, such as actigraphy (Chue et al., 2017; Dominick, Winfree, Pohlig, & Papas, 2016). It is not clear why self-reported time spent in moderate-to-vigorous activity was significantly associated with PTSD symptoms and affect in more of the models than accelerometer-measured moderate-to-vigorous activity. It is possible that these findings were influenced by self-reporting bias, given that previous research has found that individuals tend to overestimate their activity level when self-reported data is compared to accelerometer-measured data (Downs, et al., 2014; Matthews et al., 2002).

While this study represents an important contribution to the literature as the first of its kind to examine the daily associations between physical activity and PTSD, including more than two measurement occasions within the day could provide an opportunity to better capture the temporal associations between variables. For example, an EMA study design with three or four time points each day is a potential avenue for future research, as this would permit the examination of mediating variables at the within-day level, such as coping strategies or sleep quality. Additionally, future studies could utilize a measurement burst design with multiple intensive measurement periods spaced out in time. One example could be to incorporate a one-week daily diary study before and after a physical activity intervention. Due to the small sample size, statistical significance was interpreted with caution in this study, particularly the between-person effects. While this study focused on statistical significance, it is also worth considering the clinical significance of the findings. Future studies could incorporate this type of design in clinical practice with emphasis on investigating the clinical utility and clinical significance associated with providing clinicians with summary reports for individual clients/patients.

Conclusion

In summary, this is the first study to investigate the associations between physical activity and symptoms of PTSD using an intensive measurement design. Overall, greater levels of physical activity were associated with fewer symptoms of PTSD, less negative affect, more positive affect, and more adaptive coping strategies at the within-person level. Among measures of physical activity, self-reported time spent in moderate to vigorous physical activity was most consistently significantly associated with symptoms of PTSD, affect, and coping. These findings demonstrate that levels of physical activity and self-reported PTSD symptoms and its correlates fluctuate within individuals over the course of a seven-day study. This study highlights the importance of measuring individuals on more than one occasion, with implications for both research and clinical practice. The results of this study provide preliminary evidence of within-person associations between physical activity and symptoms of PTSD and additional research in larger samples will help clarify these findings.

Chapter 3: Utility of the N-of-1 study design in psychology and behavioural medicine: Case examples in the context of lifestyle behaviours in individuals with post-traumatic stress disorder

Abstract

Although not widely used in the behavioural sciences, N-of-1 study designs have many advantages for understanding intraindividual variability and within-person dynamics. This chapter aims to a) summarize the literature on N-of-1 studies in health psychology, b) highlight examples of three individuals with PTSD as a means of demonstrating variability in health behaviours and symptom severity, and c) propose future directions for implementation of this methodology in research and clinical practice. Using data from the study presented in Chapter 2 of this dissertation, three case examples were selected to closely illustrate intraindividual variability in health behaviours and PTSD symptom severity. While there were not enough measurement occasions to permit statistical analysis at the individual level, the data presented in this paper demonstrate the ways in which variables fluctuate over the course of a given week and allow for examination of initial descriptive patterns. Rational and suggestions for incorporating this type of methodology into clinical practice for monitoring and intervention are discussed.

Introduction

Background

N-of-1 studies involve the repeated measurement of variables within a particular individual to test hypotheses (McDonald et al., 2017). These studies allow for the collection of data for the purposes of informing individual treatment decisions (Karina W. Davidson, Peacock, Kronish, & Edmondson, 2014). In a recent review, Vieira and colleagues (Vieira, McDonald, Araujo-Soares, Sniehotta, & Henderson, 2017) clarify the definition of N-of-1 studies, noting that many different terminologies have been used to describe the same, or similar approaches (e.g., single-case, single-subject, time-series analysis). The authors further note that the definition can vary by discipline, such as how in medicine, N-of-1 designs typically refer to an intervention, whereas in psychology they may encompass pre-post interventions, alternating treatments, or observational studies. The following features of N-of-1 studies are highlighted in their review: 1) the main aim is to reach conclusions for the individual being studied, not to make population-level inferences, 2) there is always a time series and the predictor variables must vary over time, 3) the number of repeated measurements is the sample size of an n-of-1 study and more measurements lead to better parameter estimates, 4) each study is designed according to factors specific to the particular individual under study, and 5) it is possible to aggregate analysis of N-of-1 data. These designs align with the concept of personalized medicine, a term that was initially popularized for tailoring medications based on genetic variability. Traditionally, this type of study design has been more commonly used in other disciplines (e.g., education, economics), and is much less common in psychology and behavioural medicine (Kwasnicka et al., 2019).

While much research in psychology and behavioural medicine has focused on between-person associations such as those observed in RCTs, between-person methods are not without limitations. For example, some RCTs assume there is a homogenous treatment effect of a particular intervention and that this effect will apply to other individuals of the target population (Davidson et al., 2014). Additionally, in most interventions comparing overall group means, it is tacitly acknowledged that not all participants in the treatment condition benefit from the treatment. Moreover, some participants who did not receive the treatment are likely to show improvements in outcome variables. Thus, even when a treatment appears to exhibit a benefit on average, it is rare for there not to be some overlap across groups on the outcome variable (Davidson & Cheung, 2017). RCTs often feature strict exclusion criteria (e.g., comorbid conditions) due to the strong emphasis on internal validity; however, this often comes at the cost of reducing external validity (Kwasnicka et al., 2019). These factors can make it challenging for clinicians to evaluate and select the best intervention aimed at targeting individuals who are likely to exhibit their own unique response to the intervention (Davidson et al., 2014). In contrast, N-of-1 designs can be a useful tool when there is an assumption that intra-individual effects may differ from those observed in between-person studies (Kwasnicka et al., 2019).

There are many benefits associated with using N-of-1 study designs. McDonald and colleagues (2017) summarize the various ways in which N-of-1 designs can be used including testing theories about determinants of behaviour, evaluating interventions at the individual level and understanding their underlying processes, personalizing health psychology and behavioural medicine, and helping patients play a more active role in their health. N-of-1 studies provide an opportunity to tailor an intervention to a given individual and to evaluate its use in that particular person. They can also shed light on the pathways through which change occurs by incorporating

multiple observations before, during, and after the treatment (Borckardt et al., 2008). Additionally, these designs present an opportunity to bridge the gap between research and clinical practice (Borckhardt et a., 2008), thereby fostering important relationships between researchers and clinicians. It is now easier than ever to implement these methodologies with the available technological advances that make it possible to monitor participants remotely using unobtrusive devices such as accelerometers or smartphone-based surveys (Davidson et al., 2014). Technology has permitted the opportunity to measure associations within-individuals as they unfold in real time, or near real time, in daily life.

Despite the myriad advantages to using these designs, uptake remains low in the behavioural sciences such as psychology. Indeed, there are a number of challenges associated with conducting, analyzing, and interpreting data from N-of-1 studies. For example, participant adherence, carry-over or slow onset effects, calculation of power/sample size, and determining the optimal analytic approach have been identified as key challenges in this area (Kwasnicka et al., 2019). These authors additionally caution about risk of type-I error, which can happen if autocorrelation is not appropriately accounted for or if the findings are interpreted to extend beyond the individual being studied. In order to account for some of these challenges, the following recommendations were highlighted in the study: involve users in study design, use technology for less obtrusive data collection, do not generalize findings to the larger population, and using statistics that account for autocorrelation. McDonald and colleagues (2017) recommend at least 50 data points for N-of-1 studies that include statistical analysis. Davidson and colleagues (2014) emphasize that when using N-of-1 trials for the purpose of evaluating a particular treatment, it is essential that the treatment is reversible in order to be able to

counterbalance the intervention. Additionally, the outcome of interest must be able to be measured repeatedly.

In a systematic review of N-of-1 trials in schizophrenia, Marwick and colleagues (2018) identified six studies with a wide range of methodologies and analyses (Marwick, Stevenson, Davies, & Lawrie, 2018). They found a high risk of bias in most studies due to lack of counterbalancing. However, it was noted that these methods were well-tolerated among the participants. To improve upon existing studies, the authors recommended increasing the use of standardized methods, execution of interventions, and analysis. They also recommend combining self-reported measurements with objective measurements.

Examples from the literature

Several case examples featuring N-of-1 designs have been published in the fields of clinical and health psychology in recent years (Borckardt et al., 2008; O'Brien, Philpott-Morgan, & Dixon, 2016; Smith, Williams, O'Donnell, & McKechnie, 2019; Strahler & Luft, 2019). For example, Borckardt and colleagues (2008) presented a case study of an individual receiving psychotherapy for depressive symptoms. The clinician was interested in examining whether improvements in mood precede social engagement or vice-versa. Over the course of the 31-week treatment, the participant completed weekly mood ratings and reported the number of hours spent outside of the house. Through this intensive measurement design, cross-lagged correlations were conducted, and it was found that mood changes preceded behaviour change by approximately one week. Given that both outcomes changed relatively close together, this understanding of the ordering and potential mechanisms of change would not have been possible without such frequent measurements in this case. In another study, a pre-post design was used to compare theoretical models of walking behaviour in four individuals with osteoarthritis (O’Brien

et al., 2015). In this series of N-of-1 studies, participants completed twice daily diaries for twelve weeks with the intervention beginning at week 6. The findings indicated that cognitions such as self-efficacy were a better within-person predictor of walking than impairment variables such as pain level or joint stiffness.

An N-of-1 design was used to understand the impact of acute and chronic stress in a professional ballroom dancer (Strahler & Luft, 2019). Over the course of eight months, the participant completed self-reported measures of mood, stress and fatigue, as well as saliva samples (for cortisol and alpha amylase) every three days. Hair samples were provided every three months to measure cumulative cortisol secretions. Daily salivary cortisol predicted lower fatigue, and dance tournaments resulted in 3-fold and 2-fold increases in salivary cortisol and alpha amylase, respectively. Additionally, there was evidence of a drop in cortisol as measured via hair sample following a break from dancing due to surgery. Regarding self-report data, perceived stress was slightly higher during competition than non-competition days. The authors concluded that the N-of-1 design provided a unique opportunity to observe complex, dynamic associations that exist at the individual level. Their study provided support for both immediate and prolonged consequences of competitive stress on both self-reported well-being and physiological markers of stress.

In a study examining the associations between social cognitive theory (SCT) constructs and physical activity, Smith and colleagues (2019) conducted N-of-1 studies on six individuals with varying activity levels. Specifically, the SCT constructs examined were: barrier self-efficacy, goal setting, planning, social support, perceived barriers, enjoyment, and outcome expectations. In this four-week study, cross-sectional time-series analysis revealed that change in at least one SCT construct was associated with increased subsequent physical activity in five out

of the six participants. They found evidence for SCT constructs predicting subsequent physical activity on some days, while other days the reverse was observed. They concluded that tailored physical activity interventions may be more suitable than using a 'one size fits all' approach for physical activity, given that there was between-person variability with regards to which SCT construct was most strongly influenced physical activity.

Rationale for use in PTSD

Posttraumatic Stress Disorder (PTSD) is a common, often chronic, psychological condition with a lifetime prevalence of approximately 6.1% and past-year prevalence of 4.7% (Goldstein et al., 2016). PTSD is commonly associated with comorbid psychological conditions and medical illnesses. For example, there is an elevated risk of mood disorders, anxiety disorders, substance use disorders, suicidal ideation, and suicide attempts (Galatzer-Levy et al., 2014). Additionally, individuals with PTSD are at greater risk of medical conditions such as metabolic syndrome, as well as substance use disorders, lower levels of physical activity, lower fruit intake, and increased BMI (Godfrey et al, 2013; Rosenbaum et al., 2015). Recommended psychological interventions for PTSD include cognitive behavioural therapy (CBT), cognitive therapy (CT), and prolonged exposure therapy (PE) (American Psychological Association, 2017). Evidence from recent interventions also suggests that physical activity can improve symptoms of PTSD as either a standalone intervention or as an adjunctive component to psychotherapy (e.g., Babson et al., 2015; Fetzner et al., 2015; Shivakumar et al., 2017). However, the mechanisms of treatment are not well understood and existing interventions do not work for all individuals. The following sections of this chapter will provide preliminary data from three case studies of individuals with a diagnosis of PTSD to illustrate the ways in which

N-of-1 designs could be of value for both researchers and clinicians working with this population.

Methodology

Participants and Procedure

Details about the study procedure are presented in Chapter 2 of this dissertation. Briefly, participants in this illustration were adults with a current diagnosis of PTSD who were recruited as part of a larger daily diary study investigating the intra-individual associations between health behaviours and symptoms of PTSD. Participants completed morning and evening surveys on their smartphones for a total of seven days. They also wore Fitbit accelerometers on their wrists for the duration of the study, which tracked daily activity and sleep.

Measures

PTSD Symptoms. PTSD symptoms were measured each morning and evening using ten items from the PCL-5 (Weathers, 2013). Instructions were modified to ask about symptom severity *since the previous survey*. Each item maintained the same rating scale as the PCL-5 and was rated from 0 (*not at all*) to 4 (*extremely*). The ten items were selected based on those used by Short and colleagues (2017) in their EMA study examining sleep disturbances in a PTSD sample.

Physical Activity. Self-reported physical activity was measured in the evening survey using two items. Participants were asked "*Approximately what duration of time was spent participating in moderate to vigorous physical activity today?*" and were provided with the following response options: "*None*", "*less than 30 minutes*", "*30-45 minutes*", "*60 minutes*", "*60-90 minutes*", and "*more than 90 minutes*". Additionally, participants were also asked to indicate the specific types of physical activities that they participated in each day, using a check-list format. Response options included: *Walking/hiking*, *running/jogging*, *cycling*, *weights/resistance*

exercise, *yoga/Pilates*, *swimming*, *team sports*, *other*, or *none of the above*. For the analysis, these activities were summed based on number of activities each day and a dichotomous variable was also created to reflect whether participants reported any physical activity vs. none.

Adaptive and Maladaptive Coping. On each survey, participants were asked to indicate whether they engaged in a series of adaptive and maladaptive coping strategies. Adaptive coping strategies (i.e., seeking social support, spending time in nature, cognitive reappraisal, physical exercise, yoga/meditation, and humour) were intermixed with maladaptive (i.e., self-medicating with alcohol or drugs, distraction, emotional suppression, and behaviours such as gambling, online shopping, over-eating) and not identified as one or the other in the survey.

Rumination. Ruminative thinking patterns were assessed in each survey by asking participants the following questions: "*Since the last survey, how often did you think about personal problems or worries*", "*Since the last survey, how often did you experience a train of thought that was difficult to get out of your head*?", "*Since the last survey, how often were you preoccupied with thoughts about the future*?", "*Since the last survey, how often did you think about situations that upset you*?". These items were adapted from previous daily diary studies examining rumination (Slavish et al., 2018) and modified to reflect experience since the last survey, rather than over the course of the day. Each item was rated using a 5-point Likert scale ranging from 0 (*never*) to 4 (*constantly*).

Results

Below are three brief case studies of participants who took part in the 7-day study. These participants were selected from the larger sample based on their observable variability on relevant variables. Given that measurement occasions ranged from seven (daily measures) to 14 (twice daily measures), there were not enough data points to allow for statistical analysis using the N-of-1 design. As such, these cases are intended to illustrate descriptive trends that exist in individuals with PTSD on variables that fluctuate across days. Due to the small sample size, participant characteristics such as age and gender are not included in these results to prevent identification of the participants.

Case example 1:

The first case example is a participant who exhibited variability on evening PCL-5 symptoms and physical activity level. As illustrated in the below figures, this participant was inactive on most days, with exception of days one, three, and four, when they reported two activities each day, and 60 minutes and more than 90 minutes of moderate to vigorous physical activity, respectively. On these physically active days, the participant also reported fewer PTSD symptoms than all other days of the week (see Figures 5-7).

In terms of intervention targets in clinical practice, this individual may benefit from a physical activity intervention for the treatment of PTSD symptoms, as a standalone or adjunctive component to psychotherapy and/or pharmacotherapy. The data from this case example would provide a clinician with a better understanding of how these variables are related on a daily basis in this individual's life. In addition to helping the clinician understand these relationships for the purpose of informing case conceptualization and intervention design, the data could be shared with the individual client in order to provide them with individualized feedback about how their

own personal health behaviours are related to their trauma symptoms. It would be interesting to investigate whether this type of feedback influences adherence to a particular intervention protocol such as physical activity.

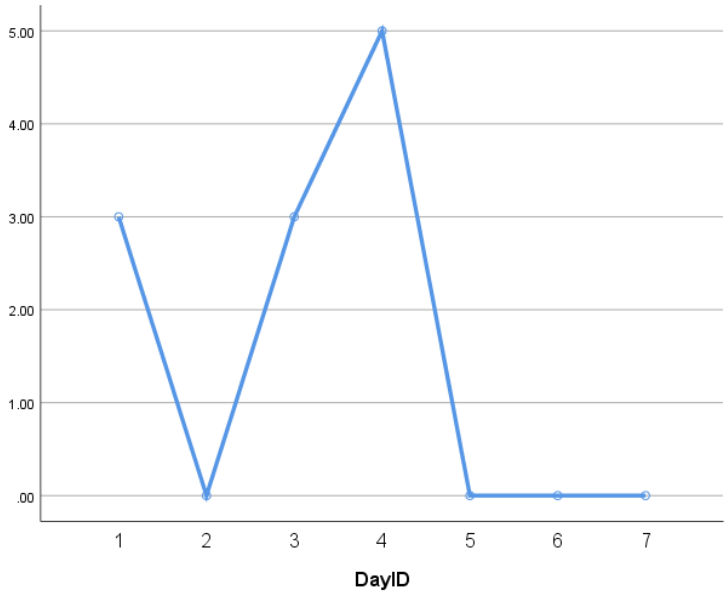

Figure 5. Case example 1: Seven-day variability in self-reported time spent in moderate-to-vigorous physical activity. *Note:* response options were presented in Likert-type scale with 0 = none, 1 = less than 30 minutes, 2 = 30-45 minutes, 3 = 45-60 minutes, 4 = 60-90 minutes, and 5 = >90 minutes.

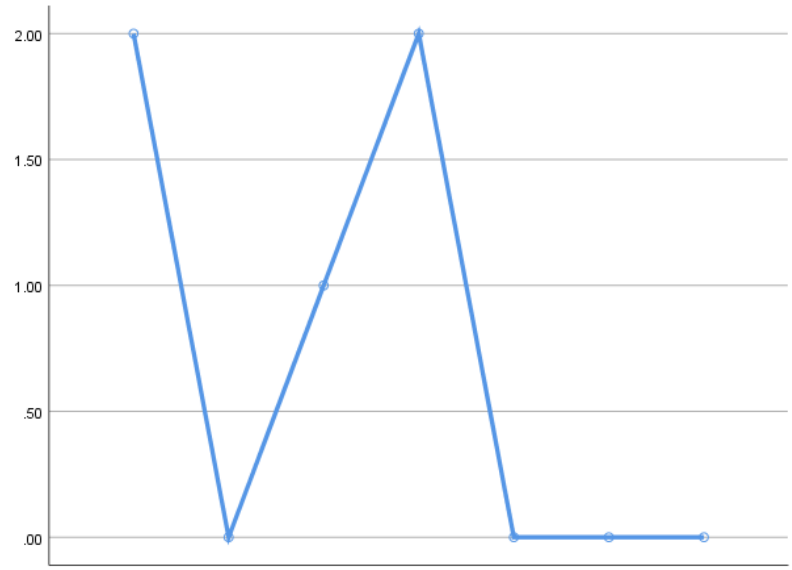

Figure 6. Case example 1: Seven-day variability in self-reported number of physical activities engaged in each day. Types of physical activity included walking/hiking, running/jogging, cycling, weights/resistance exercises, yoga/Pilates, swimming, team sports, and other.

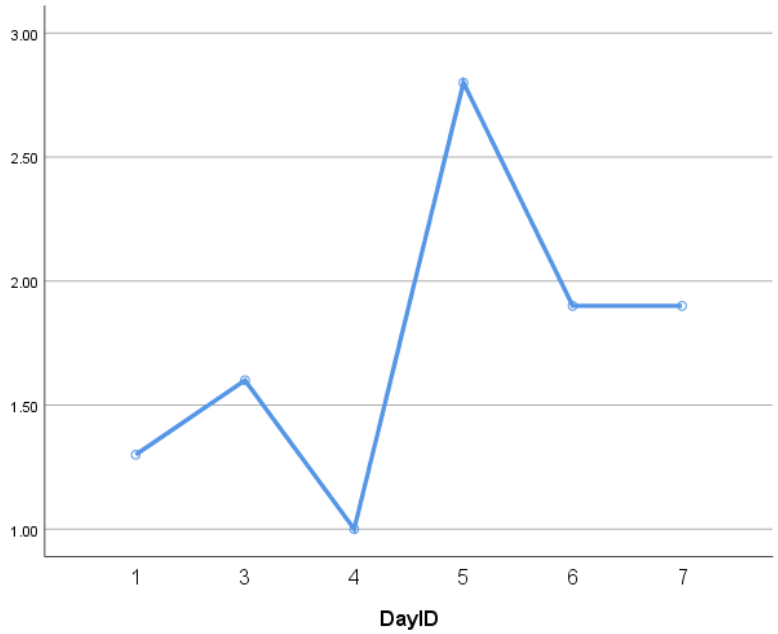

Figure 7. Case example 1: Seven-day variability in evening self-report PTSD symptoms. Scale represents average scores on the PCL-5 with each response option ranging from 0 (*not at all*) to 4 (*extremely*).

Case example 2:

For this participant, key variables presented are morning PCL-5 scores and subsequent time spent in moderate-to-vigorous activity that day, measured by the Fitbit accelerometer. On days four and five, the participant reported the highest PCL-5 scores in the morning (indicative of more severe symptoms) compared to other days. On these days the participant also engaged in lower levels of moderate-to-vigorous activity compared to other days of the week. This participant also reported the highest levels of rumination on the evenings that they engaged in the lowest levels of physical activity (see Figures 8-10).

With regards to clinical practice, ruminative thinking patterns may be one outcome that the client and clinician are working on reducing. With this data, the clinician is provided with information that may help understand factors that increase or decrease the severity of ruminative thinking. Given that this participant reported less rumination when they engaged in more

physical activity, the clinician could provide this feedback to the client, thereby encouraging a health behaviour that may help reduce the target behaviour. Similarly, if this individual had the goal of increasing their physical activity, the clinician may recommend strategies for reducing or managing PTSD symptoms in order improve adherence to an exercise program.

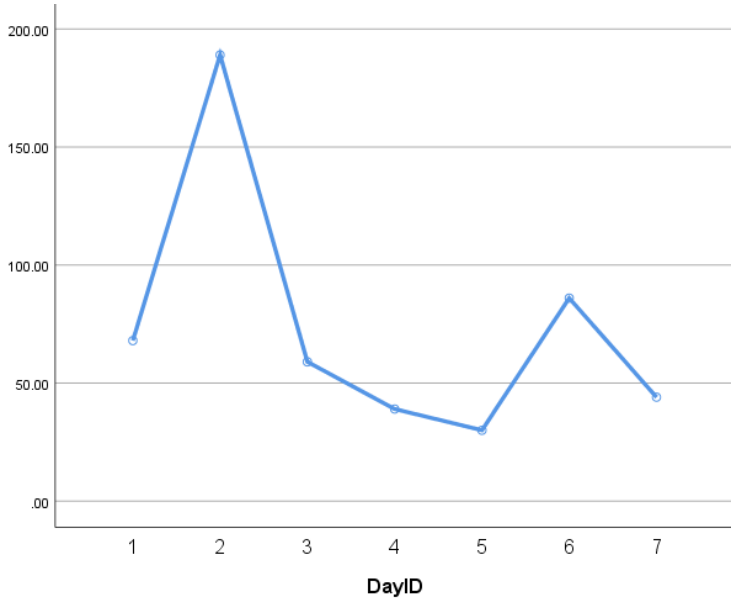

Figure 8. Case example 2: Seven-day variability of minutes spent in moderate-to-vigorous exercise measured by Fitbit accelerometer (Fitbit Charge HR).

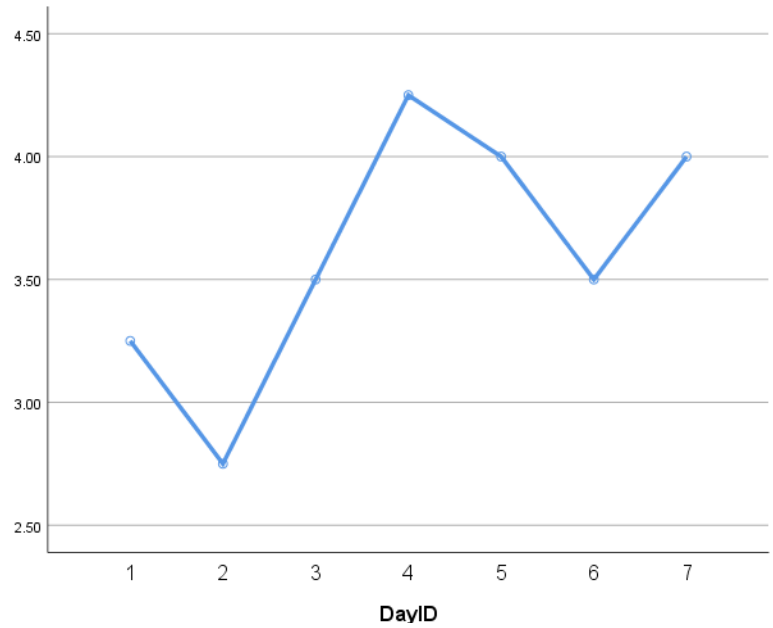

Figure 9. Case example 2: Seven-day variability in self-reported rumination and worry about the future on the evening survey. Scores represent the average of four items, each rated on 5-point Likert-type scale ranging from 1 (*never*) to 5 (*constantly*).

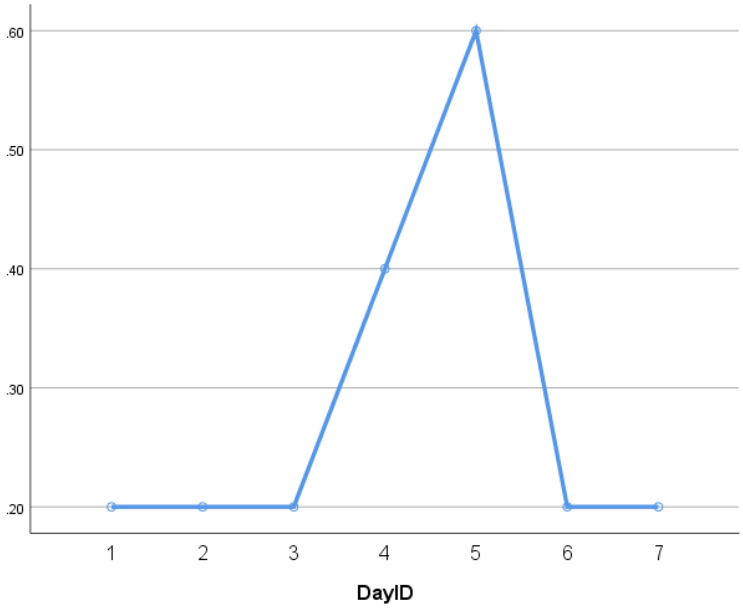

Figure 10. Case example 2: Seven-day variability in morning self-report PTSD symptoms. Scale represents average scores on the PCL-5 with each response option ranging from 0 (*not at all*) to 4 (*extremely*).

Case example 3:

In this example, on mornings when the participant reported more morning PTSD symptoms than other days, they were less likely to report using adaptive coping strategies over the course of that day. Similarly, on days when they do report using more adaptive coping strategies, they report lower PTSD symptoms on the evening survey (see Figures 11-13).

There are several ways in which the data from this case example could be used in clinical practice. For instance, a clinician could ascertain which coping strategies appear to confer the most benefit for the client in terms of attenuating symptoms of PTSD. These ways of coping could then be incorporated into the intervention. Providing this information back to the client could help them understand how their coping impacts their symptoms in real-time. Additionally, the clinician could discuss strategies for managing early morning PTSD symptoms in order to increase the likelihood of using adaptive coping strategies over the course of the day.

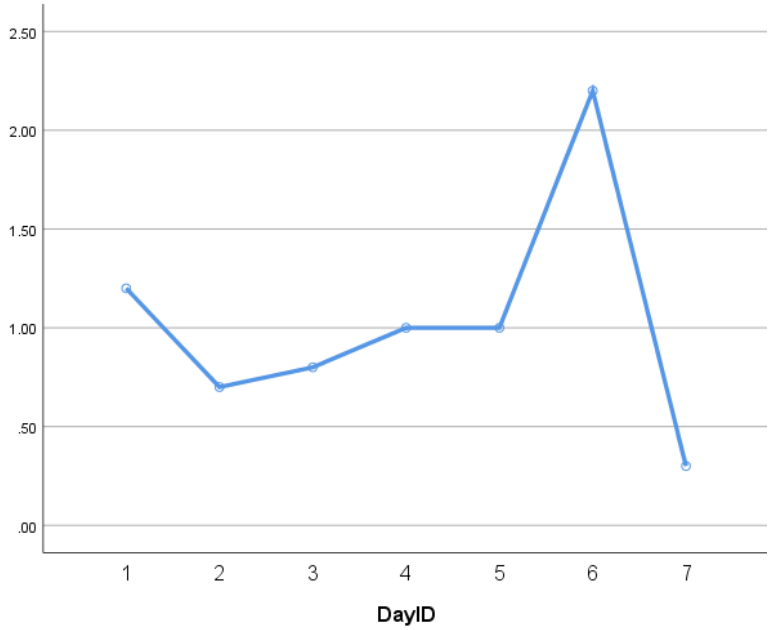

Figure 11. Case example 3: Seven-day variability in morning self-report PTSD symptoms. Scale represents average scores on the PCL-5 with each response option ranging from 0 (*not at all*) to 4 (*extremely*).

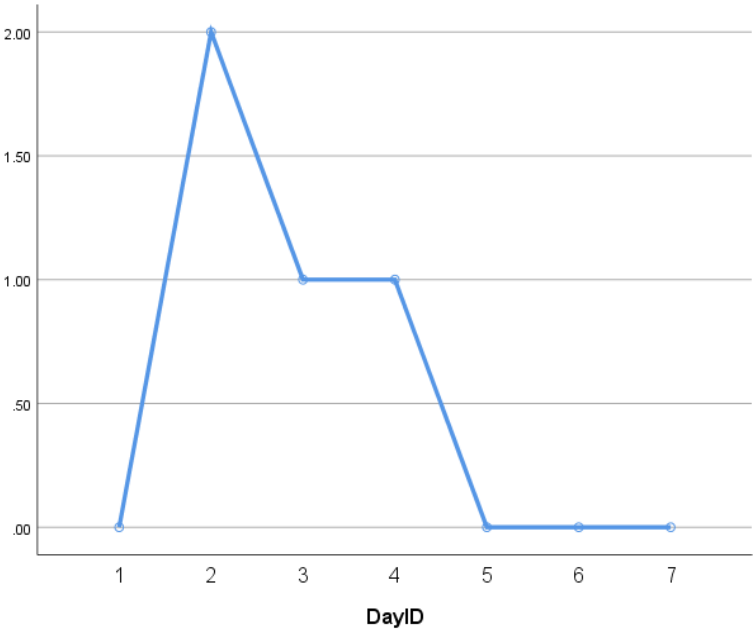

Figure 12. Case example 3: Seven-day variability in number of adaptive coping strategies used over the course of the day.

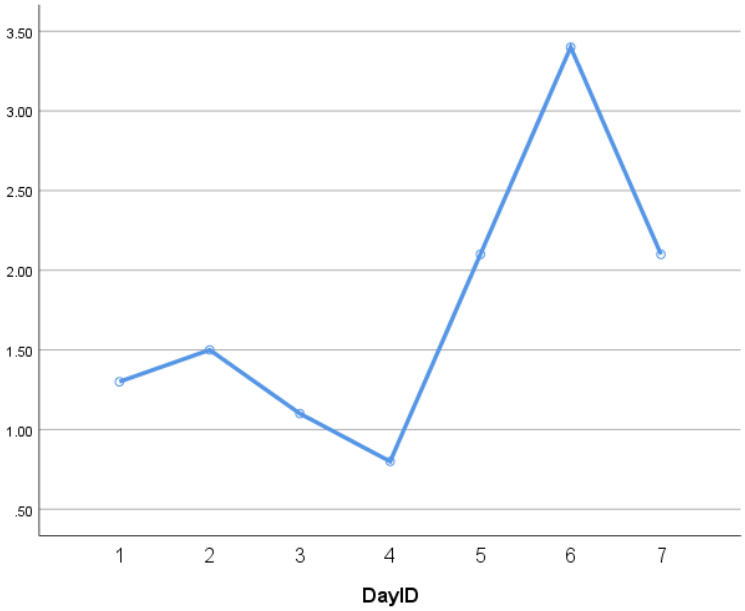

Figure 13. Case example 3: Seven-day variability in evening self-report PTSD symptoms. Scale represents average scores on the PCL-5 with each response option ranging from 0 (*not at all*) to 4 (*extremely*).

Discussion

The purpose of this chapter was to provide an overview of N-of-1 studies and how they can be used in the field of psychology and behavioural medicine. In general, this study design has not been commonly utilized in these fields. However, recent papers have summarized the value of these designs, particularly with respect to their use in clinical practice and evaluating interventions at the intra-individual level (Borckardt et al., 2008; Davidson et al., 2014; Marwick et al., 2018). This chapter incorporated three brief case studies to illustrate the within-person fluctuations that have been observed in terms of symptom severity, health behaviours, and coping strategies. Descriptive data from these case studies allowed for the visual examination of trends within the data, including the observation of possible patterns between variables. For instance, in one of the individuals, it was evident that on days when they engaged in more physical activity than others, they also reported fewer symptoms of PTSD that evening. In another participant, a reverse association was observed - on days when PTSD symptoms were more elevated in the morning, they engaged in less physical activity over the course of that day, as measured by the accelerometer. In a third participant, visual examination of the data indicated that on days when they reported engaging in more adaptive coping strategies, they also tended to report fewer symptoms of PTSD on their evening survey. Although these results were not evaluated for statistical significance, they provide an initial glimpse into the patterns occurring at the individual level. Indeed, studies with more data points (i.e., 50 or more) are needed to better understand these relationships using statistical analysis. This type of study design has important implications and applications for clinical practice settings.

One of the ways in which these designs could be used in clinical practice is for informing clinicians about intervention targets, intervention effectiveness, and providing feedback to clients

to help them understand their symptoms and behaviours. As Davidson and colleagues (2014) assert, there is often a gap between large-scale RCTs and individual clients seen in psychotherapy, and clinicians may struggle to ascertain which course of treatment is best suited to a given client, who is likely to have a unique response to the treatment based on their individual background and characteristics. Using an N-of-1 design, clinicians could collect data to help inform particular targets of an intervention. Then, upon beginning the intervention, they could continue to monitor symptom severity by incorporating frequent repeated measurements (e.g., daily or weekly surveys) to evaluate its impact. This approach could help clinicians understand the mechanisms of action and order in which certain symptoms and/or behavioural patterns begin showing changes. For example, in the context of PTSD symptoms, a clinician may be able to see which sub-symptoms of PTSD symptoms exhibit improvement first following a cognitive intervention. Similarly, if a clinician were to evaluate a lifestyle intervention such as physical activity, they could monitor adherence using accelerometry and factors that predict adherence, and be able to look at the day-to-day associations between exercise and PTSD symptoms. Additional components of an intervention could involve direct feedback to clients to help them understand factors that influence their own symptoms and overall health and well-being. For instance, if a clinician requested that a client completed daily surveys over the course of two months, and had them wear an accelerometer for sleep and activity tracking, they may be able to provide individualized feedback about how certain coping strategies and health behaviours influence their mood and well-being in real-time.

N-of-1 study designs also present an opportunity for collaboration between clinicians and researchers. As such, the gap between research and practice may be reduced if both parties have a sense that the other is more accessible. Because large sample sizes are not needed, data could

be collected more rapidly and efficiently. This would be beneficial to the clinician as they would benefit from statistical expertise of the researcher who could help evaluate and inform their interventions. Additionally, researchers would benefit by gaining access to rich, real-world data with multiple observations over time and would thus be able to better examine intraindividual associations. Over time, multiple N-of-1 cases could be combined in analyses, as demonstrated by Smith and colleagues (2019) in their examination of relationships between social cognitive theory constructs and physical activity behaviour in six individuals.

In summary, N-of-1 designs provide a rich opportunity to understand intraindividual variability and change over time in the context of interventions. This approach aligns with the recent focus on personalized medicine in healthcare (Davidson et al., 2014). Although few of these studies have been published in psychology and behavioural medicine, these approaches are easier to implement than ever before due to technological advances. Of course, these designs are not without limitations and challenges (e.g., participant adherence, carry-over effects, requirement of many observations for analysis, and selecting the best analytical approach). With sufficient planning and execution (e.g., adequate measurement occasions, use of technology, cross-correlation analysis), N-of-1 study designs can provide a rich opportunity to answer research questions that may not be possible to answer through the use of between-person studies or large-scale RCTs.

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Appendix A: Baseline Measures

HEALTH & WELL-BEING AFTER TRAUMA: BASELINE QUESTIONNAIRE

Participant ID#:_____
Date:_____

1. What is your age? _____
2. What is your relationship status?
   - ❑ Single
   - ❑ Married/Common Law
   - ❑ Separated/Divorced
   - ❑ Widowed
   - ❑ Other (please specify): _____

3. What is your highest level of education?
   - ❑ Some high school
   - ❑ High school diploma
   - ❑ Certificate/diploma (vocational, trade)
   - ❑ Bachelor's degree
   - ❑ Graduate university degree (masters, PhD)
   - ❑ Other:_____

3a. What is/was your occupation?
_____

4. What is your work status:
   - ❑ Working full-time
   - ❑ Working part-time
   - ❑ Going to school
   - ❑ Recovering from illness/on disability
   - ❑ Retired
   - ❑ Other (please specify):_____

5. What is your ethnicity? (Check as many as apply)
   - ❑ European (i.e., White)
   - ❑ Latin, Central, and South American
   - ❑ African
   - ❑ South Asian
   - ❑ East or Southeast Asian
   - ❑ Indigenous (First Nations, Inuit, Metis)
   - ❑ Caribbean
   - ❑ Arab
   - ❑ Other (please specify): _____

6. What is your biological sex?_____
7. With which gender do you most identify?_____

8. Do you have any ongoing physical health conditions?
   - ❑ No
   - ❑ Yes (please specify):

_____
_____
_____

Godin Leisure-Time Exercise Questionnaire:

1. During a typical **7-day period** (a week), how many times on average do you do the following kinds of exercise for more than 15 minutes during your free time (write on each line the appropriate number):

a) Strenuous Exercise (heart beats rapidly)

(e.g., running, jogging, hockey, football, soccer, squash, basketball, cross country skiing, judo, roller skating, vigorous swimming, vigorous long distance bicycling)
Times per week:_____

b) Moderate Exercise (Not exhausting)
(e.g., fast walking, baseball, tennis, easy bicycling, volleyball, badminton, easy swimming, alpine skiing, popular and folk dancing)
Times per week:_____

c) Mild Exercise (Minimal effort)
(e.g., yoga, archery, fishing from river bank, bowling, horseshoes, golf, snow-mobiling, easy walking)
Times per week:_____

2. During a typical 7-day period (a week), in your leisure time, how often do you engage in any regular activity long enough to work up a sweat (heart beats rapidly)?

Often ☐ Sometimes ☐ Never/Rarely ☐

PCL-5

Instructions: Below is a list of problems that people sometimes have in response to a very stressful experience. Please read each problem carefully and then circle one of the numbers to the right to indicate how much you have been bothered by that problem in the past month.

In the past month, how much were you bothered by:	**Not at all**	**A little bit**	**Moderately**	**Quite a bit**	**Extremely**
1. Repeated, disturbing, and unwanted memories of the stressful experience?	0	1	2	3	4
2. Repeated, disturbing dreams of the stressful experience?	0	1	2	3	4
3. Suddenly feeling or acting as if the stressful experience were actually happening again (as if you were actually back there reliving it)?	0	1	2	3	4
4. Feeling very upset when something reminded you of the stressful experience?	0	1	2	3	4
5. Having strong physical reactions when something reminded you of the stressful experience (for example, heart pounding, trouble breathing, sweating)?	0	1	2	3	4
6. Avoiding memories, thoughts, or feelings related to the stressful experience?	0	1	2	3	4
7. Avoiding external reminders of the stressful experience (for example, people, places, conversations, activities, objects, or situations)?	0	1	2	3	4
8. Trouble remembering important parts of the stressful experience?	0	1	2	3	4
9. Having strong negative beliefs about yourself, other people, or the world (for example, having thoughts such as: I am bad, there is something	0	1	2	3	4

seriously wrong with me, no one can be trusted, the world is completely dangerous)?					
10. Blaming yourself or someone else for the stressful experience or what happened after it?	0	1	2	3	4
11. Having strong negative feelings such as fear, horror, anger, guilt, or shame?	0	1	2	3	4
12. Loss of interest in activities that you used to enjoy?	0	1	2	3.	4
13. Feeling distant or cut off from other people?	0	1	2	3	4
14. Trouble experiencing positive feelings (for example, being unable to feel happiness or have loving feelings for people close to you)?	0	1	2	3	4
15. Irritable behavior, angry outbursts, or acting aggressively?	0	1	2	3	4
16. Taking too many risks or doing things that could cause you harm?	0	1	2	3	4
17. Being “superalert” or watchful or on guard?	0	1	2	3	4
18. Feeling jumpy or easily startled?	0	1	2	3	4
19. Having difficulty concentrating?	0	1	2	3	4
20. Trouble falling or staying asleep?	0	1	2	3	4

Pittsburgh Sleep Quality Index

Instructions:
The following questions relate to your usual sleep habits during the past month *only*. Your answers should indicate the most accurate reply for the *majority* of days and nights in the past month. Please answer all the questions.

1. During the past month, when have you usually gone to bed at night?

usual bed time_____

2. During the past month, how long (in minutes) has it usually taken you to fall asleep each night?

number of minutes_____

3. During the past month, when have you usually got up in the morning?

usual getting up time_____

4. During the past month, how many hours of *actual* sleep did you get at night? (This may be different than the number of hours you spend in bed).

hours of sleep per night_____

For each of the remaining questions, check the one best response. Please answer *all* questions.

5. During the past month, how often have you had trouble sleeping because you……

(a) Cannot get to sleep within 30 minutes

Not during the past month	Less than once a week	Once or twice a week	three or more times a week

(b) Wake up in the middle of the night or early morning

Not during the past month	Less than once a week	Once or twice a week	Three or more times a week

(c) Have to get up to use the bathroom

Not during the past month	Less than once a week	Once or twice a week	three or more times a week

(d) Cannot breathe comfortably

Not during the	Less than	Once or	three or more

past month____ once a week_____ twice a week_____ times a week_____

(e) Cough or snore loudly

Not during the past month____ Less than once a week_____ Once or twice a week_____ three or more times a week_____

(f) Feel too cold

Not during the past month____ Less than once a week_____ Once or twice a week_____ three or more times a week_____

(g) Feel too hot

Not during the past month____ Less than once a week_____ Once or twice a week_____ three or more times a week_____

(h) Had bad dreams

Not during the past month____ Less than once a week_____ Once or twice a week_____ three or more times a week_____

(i) Have pain

Not during the past month____ Less than once a week_____ Once or twice a week_____ three or more times a week_____

(j) Other reason(s), please describe_____

_____

_____

How often during the past month have you had trouble sleeping because of this?

Not during the past month____ Less than once a week_____ Once or twice a week_____ three or more times a week_____

6. During the past month, how would you rate your sleep quality overall?

Very good_____
Fairly good_____
Fairly bad_____
Very bad_____

7. During the past month, how often have you taken medicine (prescribed or " over the counter") to help you sleep?

Not during the past month____	Less than once a week_____	Once or twice a week_____	three or more times a week_____

8. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?

Not during the past month____	Less than once a week_____	Once or twice a week_____	three or more times a week_____

9. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?

No problem at all_____
Only a very slight problem___
Somewhat of a problem_____
A very big problem_____

Appendix B: Daily Measures

Morning & Evening Questions

PTSD Symptoms (abbreviated PCL-5)

Instructions: *Please read each of the following statements carefully, then select one response to indicate how much you have been bothered by that problem since your last survey*	
Item	**Response Options**
Repeated, disturbing, and unwanted memories of the stressful experience	Not at all, A little bit, Moderately, Quite a bit, Extremely
Having strong physical reactions when something reminded you of the stressful experience (e.g., heart pounding, trouble breathing, sweating)?	Not at all, A little bit, Moderately, Quite a bit, Extremely
Avoiding memories, thoughts, or feelings related to the stressful experience?	Not at all, A little bit, Moderately, Quite a bit, Extremely
Avoiding external reminders of the stressful experience (e.g., people, places, conversations, activities, objects, or situations)?	Not at all, A little bit, Moderately, Quite a bit, Extremely
Feeling distant or cut off from other people?	Not at all, A little bit, Moderately, Quite a bit, Extremely
Having trouble experiencing positive feelings (e.g., being unable to have loving feelings for people close to you or feeling emotionally numb)?	Not at all, A little bit, Moderately, Quite a bit, Extremely
Having difficulty concentrating?	Not at all, A little bit, Moderately, Quite a bit, Extremely
Being "superalert" or watchful or on guard?	Not at all, A little bit, Moderately, Quite a bit, Extremely
Feeling jumpy or easily agitated?	Not at all, A little bit, Moderately, Quite a bit, Extremely
Having strong negative feelings such as fear, horror, anger, guilt, or shame?	Not at all, A little bit, Moderately, Quite a bit, Extremely

Positive and Negative Affect (abbreviated PANAS)

Instructions: *For the following questions, please indicate the extent you have felt this way since your last survey*	
Item	**Response Options**
Interested	Very slightly or not at all, A little, Moderately, Quite a bit, Extremely
Upset	Very slightly or not at all, A little, Moderately, Quite a bit, Extremely
Scared	Very slightly or not at all, A little, Moderately, Quite a bit, Extremely
Guilty	Very slightly or not at all, A little, Moderately, Quite a bit, Extremely
Enthusiastic	Very slightly or not at all, A little, Moderately, Quite a bit, Extremely
Irritable	Very slightly or not at all, A little, Moderately, Quite a bit, Extremely
Alert	Very slightly or not at all, A little, Moderately, Quite a bit, Extremely
Determined	Very slightly or not at all, A little, Moderately, Quite a bit, Extremely

Coping

Instructions: *Please indicate if you have used any of the following ways of coping since the last survey:*

- Seeking social support
- Spent time in nature
- Distraction (e.g., watching TV)
- Cognitive re-appraisal
- Humour
- Self-medicating with alcohol or drugs
- Behaviours such as gambling, online shopping, overeating
- Yoga/meditation
- Emotional suppression

Morning Survey Specific Questions

Sleep (abbreviated PSQI)

Item	**Response Options**
How would you rate your quality of sleep overall?	Very good, Fairly good, Fairly bad, Very bad
Did you take medicine to help you sleep?	Yes, no
Did you have trouble sleeping because you:	□ Felt hot flashes □ Felt general nervousness □ Had memories or a nightmare of a traumatic experience □ Had severe anxiety or panic not related to traumatic memories □ Had bad dreams not related to traumatic memories □ Had episodes of terror or screaming during sleep without fully awakening □ Had episodes of acting out your dreams such as kicking, punching, running, or screaming

Evening Survey Specific Questions

Physical Activity

Item	**Response Options**
What type of physical activity have you participated in today (if any) (*check as many that apply)*	□ Walking/hiking □ Running/jogging □ Cycling □ Weights/resistance □ Yoga/Pilates □ Swimming □ Team sports □ Other □ None of the above
Approximately what duration of time was spent participating in moderate to vigorous physical activity today?	□ None □ Less than 30 minutes □ 30-45 minutes □ 45-60 minutes □ 60-90 minutes □ More than 90 minutes