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Associations between mental health disorder symptoms and cardiac function among Royal Canadian Mounted police cadets during the Cadet training program

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ABSTRACT

Cardiac regulation is a complex process involving interplay between neuroautonomic and neuroendocrine systems. Occupations frequently exposed to potentially psychologically traumatic events (PPTEs; e.g., fire or explosion, natural disaster, sexual assault), such as the Royal Canadian Mounted Police (RCMP), report elevated Posttraumatic Stress Injuries (PTSIs; e.g., Posttraumatic Stress Disorder [PTSD], Major Depressive Disorder [MDD], Generalized Anxiety Disorder [GAD], Social Anxiety Disorder [SAD], Alcohol Use Disorder [AUD]). Neurohormonal pathway dysfunction is associated with mental health disorder symptoms, but meaningful evaluations remain methodologically challenging, especially in high-stress occupations (e.g., police). The current study tested for associations among cardiac function and mental health disorder symptoms. Participants included RCMP cadets ($n = 81$; 28.4 % women) who completed self-report symptom measures at pre-training and pre-deployment of PTSD, MDD, GAD, SAD, and AUD. To test for longitudinal associations between cardiac function and mental health disorder symptoms, a series of paired-samples *t*-tests and bootstrapped partial correlations controlling for age and sex were conducted. The current study evidenced positive associations between changes in the myocardial performance index, the diastolic performance index, and isovolumic relaxation time comparable in magnitude to changes in MDD, GAD, and SAD symptoms (but not AUD symptoms), as well as between IVRT and PTSD symptoms, and rapid ejection time and GAD symptoms. The associations provide rationale for integrating cardiac rehabilitation exercise guidelines into occupational fitness programs as a method to mitigate the cumulative impact of occupational stressors.

1. Introduction

Effective cardiac function regulation is a complex process involving interplay between neuroautonomic and neuroendocrine systems, producing beat-to-beat adjustments in cardiac chronotropy and inotropy, as well as sustained adjustments in cardiac function in an attempt to appropriately respond to ongoing environmental demands or stressors (Roth et al., 2012; Faes et al., 2013; Tafet and Nemeroff, 2020). The balance of neuroendocrine and neuroautonomic processes moderates stress response fidelity and efficacy; accordingly, chronic exposure to environmental stressors can precipitate prolonged HPA axis dysfunction (Verma et al., 2010; Flandreau et al., 2012; Roth et al., 2012; Wood, 2014; Tafet and Nemeroff, 2020) increasing impedance on the cardiovascular system (Biering-Sørensen et al., 2015), and thereby increasing the risk of a major adverse cardiac event (MACE; Pereira et al., 2013).

Occupations involving frequent exposures to Potentially Psychologically Traumatic Events (PPTEs; e.g., fire or explosion, natural disaster, sexual assault; Heber et al., 2023) such as Royal Canadian Mounted

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Police (RCMP), report more symptoms of various Posttraumatic Stress Injuries (PTSIs), including Posttraumatic Stress Disorder (PTSD), Generalized Anxiety Disorder (GAD), Major Depressive Disorder (MDD), Social Anxiety Disorder (SAD), and correlates like Alcohol Use Disorder (AUD; Carleton et al., 2018, 2023). However, meaningful evaluations of HPA axis dysfunction on end-organ behaviour (e.g., cardiac function) remains methodologically challenging (Guilliams and Edwards, 2010; Verma et al., 2010; Menke, 2019), especially in high-stress occupations. Consistent with the contemporary biopsychosocial model of psychopathology (Bolton, 2023), appropriate identification of potential PTSI biomarkers has the potential to provide a strong rationale for integrating PTSI-specific cardiac rehabilitation exercise guidelines into occupational fitness and wellness programs, which in turn may mitigate the impact of occupational stressors including repeated PPTE exposures on cardiac function for professions where PPTE exposures are occupational necessities.

To date, few studies have demonstrably evidenced affiliations among mental health disorder symptom changes and functional changes in cardiac contractility, let alone among high-stress occupational samples (Chalmers et al., 2014; Ersbøll et al., 2014; Arri et al., 2016; Esler, 2017; Hieda et al., 2019). There is evidence that increasing mental health disorder symptoms, both in number and severity, can predict adverse outcomes in the wake of a MACE (Sowden and Huffman, 2009; Rutledge et al., 2013; Berg et al., 2018; Wilson et al., 2019), although this has not been reliably observed in high-stress occupational contexts. The relationship between cardiac function and mental health is difficult to explore due to individual differences (i.e., cardiovascular comorbidities, medication interactions, vagal reactivity, and adiposity; Steptoe et al., 2012), high rates of attrition from longitudinal studies (Ramirez et al., 2017; Sumner et al., 2017), and the relative absence of high fidelity historical and longitudinal data on cardiac function among populations that eventually experience a MACE, a PTSI, or both (Torp-Pedersen et al., 2020). Heart rate variability (HRV) analyses have been popularized in attempts to estimate HPA axis deviations as sequalae to acute and chronic environmental stress, but individual differences limit robust interpretations of any detected differences (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996; Sammito et al., 2024).

Seismocardiography (SCG) uses three-dimensional accelerometry to monitor myocardial contractility, providing reliable ambulatory measures of cardiac function that rely on mechanical rather than electrophysiological patterns, which may be characteristically defined within each cardiac contractile cycle (McKay et al., 1999; Vogt et al., 2012; Wick et al., 2015; Wiens et al., 2015). SCG has historically demonstrated efficacy by detecting cardiac movement with a similar accuracy to echocardiogram imaging (Sørensen et al., 2018). SCG is demonstrably more sensitive than 12-lead ECG in detecting physiologically significant CAD during exercise stress tests (Wilson et al., 1993; Dehkordi et al., 2019), primarily on the basis that mechanical and electrophysiological measurements of heart function differ in their clinical utility. Where ECG measures the electrophysiological conduction patterns of cardiac tissue and has long been considered the gold standard for measuring cardiac timing in ambulatory settings, SCG is able to measure individual cardiac timing intervals with the sensitivity and specificity of echocardiogram.

The RCMP Longitudinal PTSD Study (i.e., the RCMP Study; Carleton et al., 2022) provides a unique opportunity to address several gaps in the extant literature regarding the associations between mental health disorder symptoms and cardiac function among cadets and serving RCMP. The RCMP Study involves collecting mental health- and cardiac-related data in tandem during the Cadet Training Program (CTP) and for 5 years thereafter. The CTP is a highly structured 26-week training program wherein RCMP cadets train to become RCMP officers. The program requires well above 8 h of scheduled classroom time per day accompanied by a rigorous fitness training program (Hembroff and Kratzig, 2020). The RCMP Study uses a highly specialized data collection framework supporting pre-clinical assessments of cardiac function associated with a PTSI before chronic cardiac dysfunction or comorbidities may occur. Based on key limitations of existing literature, the current study was designed to test for: 1) changes in cardiac function from pre-training to pre-deployment that may be attributed to structured exercise training conditions during the CTP; and 2) both cross-sectional and longitudinal associations between cardiac function and mental health disorder symptoms within an occupational training program. Consistent with our *a-priori* pre-registered hypotheses (Carleton et al., 2022), we hypothesized that mental health disorder symptoms would be positively associated with specific changes in cardiac function previously evidenced as prognostic indicators of MACE.

2. Methods

2.1. Procedure

Full details on the RCMP Study methods and measures have been published in a detailed protocol paper (Carleton et al., 2022). The RCMP Study was approved by the University of Regina Institutional Research Ethics Board (file No. 2019-055), the RCMP Research Ethics Board (file No. SKM_C30818021312580), and approved through a Privacy Impact Assessment as part of the overall approval including the National Administrative Records Management System (NARMS) file No. 201611123286 and Public Services and Procurement Canada (PSPC) file No. 201701491/M7594174191.

2.2. Sample and data

The current study included RCMP Study participants who completed the 26-week CTP (Carleton et al., 2022). All RCMP cadets, and therefore all participants, must be Canadian citizens or permanent residents; 19 years old by graduation from the CTP; and able to fluently read, write, and speak either English or French (Hembroff and Kratzig, 2020). Cadets must also meet several entrance requirements, including security clearances, medical examinations, and minimum physical standards; accordingly, the current participant sample is in excellent physical health. There were no conditions requiring exclusion of persons otherwise qualified for the CTP. The current paper focuses on data from RCMP Study participants who completed full assessment surveys at both pre-training ($n = 772$) and pre-deployment ($n = 449$) and captured at least one SCG recording within 7 days of their full assessment surveys ($n = 81$). There were 144 RCMP cadets who captured at least one SCG recording segment (described in detail below), but 63 participants were lost to attrition before pre-deployment, resulting in a current sample of 81 participants.

The small number of participants included in the current analyses ($n = 81$) relative to the total number of participants recruited for the study ($n = 772$) is attributable to a change in the biometric assessment tool used in the study during data collection. The original RCMP Study design used modified Hexoskin wearable biogarments (Carré Technologies Inc., Montréal, QC) with integrated ECG to measure HRV (Carleton et al., 2022), which produced limited results (Teckchandani et al., 2023). Participants reported logistical challenges and discomfort when using the Hexoskin biogarments; therefore, in 2021, data collection transitioned to the Recordis™ SCG device (LLA Technologies Inc., Vancouver, BC). All participants with an SCG device who recorded at least one data segment within 7 days of each full assessment survey also completed the full assessment surveys without missing data; accordingly, all available data were included without requiring missing value imputation to augment the data (i.e., complete case analysis).

All communications between the research team and participants, as well as survey administrations and SCG recordings, were coordinated through a tailored, dedicated, and secured online learning platform Moodle instance paired with an app downloaded to compliant smartphones and accessed using a secured Qualtrics account. Data transfers from participant devices to secured research servers in Canada were protected using Transport Layer Security. The RCMP Study employs a PKI Class 3 SSL Certificate, with a 2048-bit digital signature and 256-bit encryption.

2.3. Self-report symptom measures

Mental health disorder symptoms were measured using a web-delivered self-report survey at pre-training and pre-deployment. Self-report measures included the 7-item Generalized Anxiety Disorder scale (GAD-7; Spitzer et al., 2006); the 9-item Patient Health Questionnaire (PHQ-9; Kroenke et al., 2001); the 14-item Social Interaction Phobia Scale (SIPS; Carleton et al., 2009); the 10-item Alcohol Use Disorders Identification Test (AUDIT; Saunders et al., 1993); and the 20-item PTSD Checklist for DSM-5 (PCL-5; Weathers et al., 2013). Participants reported symptoms per standard published instructions for the following scales in their respective psychometric evaluations as described above: PHQ-9 and GAD-7, past 14 days; SIPS, no specific time window; and AUDIT, past 12 months. All measures have been validated as tools to identify individuals who may require further clinical attention, rather than validated as definitive diagnostic assessments. All self-report measures in the current sample demonstrated adequate internal consistency (PCL-5, $\alpha = .97$; PHQ-9, $\alpha = .85$; GAD-7, $\alpha = .83$; SIPS, $\alpha = .92$; AUDIT, $\alpha = .82$).

2.4. Measures of cardiac function

Measures of cardiac function were collected using the LLA Recordis™ SCG device. Participants were provided with the SCG device free of charge for use during the study and were asked to capture a recording at the same time each day. All recordings featured within the current analyses were captured between the hours of 06:00 and 10:00, and therefore structurally reduced the effects of circadian rhythm on cardiac function. Participants were asked to abstain from alcohol and nicotine use for at least 12 hours prior to the recording, and were asked to capture the recordings in a resting state. Participants were asked to rest in a supine position for 60-seconds prior to placing the device on their sternum, subsequently capturing a 60-second segment for analysis. Participants were asked to record at least one 60-second segment each day, but logistical challenges with their training inhibited perfect participation. The current study includes values from a single recording captured within 7 days of a participant's full assessment survey at each assessment interval (i.e., one recording from pre-training and one recording from pre-deployment). If multiple recordings were captured within 7 days of a full assessment survey, the recording captured closest to the date of the full assessment was used for the current analyses.

Analyses of the SCG device signals collected at the sternum have been reported elsewhere (Teckchandani et al., 2024; Singh et al., 2023a; 2024b, 2024). Specific methodologies regarding identification of fiducial points from the signal have also been reported elsewhere (Sørensen et al., 2018; Teckchandani et al., 2020; Singh and Carleton, 2024). Key fiducial points of the cardiac cycle include mitral valve closure (MVC), aortic valve opening (AVO), aortic twist time (ATT), atrial systole (AS), rapid ejection period (REP), aortic valve closure (AVC), ventricular untwisting, mitral valve opening (MVO), and early diastole (E). The fiducial points translate to temporal features: diastole (MVC−MVO timing), systole (AVO−AVC timing), isovolumic contraction time (IVCT; MVC−AVO), isovolumic relaxation time (IVRT; AVC−MVO), atrial systole to mitral valve closure (AS to MVC), mitral valve open to E wave (MVO to E), and rapid ejection period duration (RET). Heart rate was calculated using the interval length between each successive opening of the aortic valve (AVO), represented in beats per minute. Twist force (TF) was measured in milligravity (mG) and assessed the magnitude of global longitudinal strain. Atrial systole (AS) was also measured in mG and assessed the magnitude of atrial contractility (Teckchandani et al., 2020; Singh et al., 2023; Singh and Carleton, 2024; Singh and Carleton, 2024). The cardiac twisting during isovolumic compression prior to valve opening, or the "I" wave, (i.e., the isovolumic maximum compression) is recorded as both acceleration (mG) and duration (ms). Lastly, the Myocardial Performance Index (MPI; [IVRT + IVCT]/systolic time), Systolic Performance Index (SPI; [IVCT/systolic time]), and Diastolic Performance Index (DPI; [IVRT/systolic time]) were calculated as index values analogous to echocardiogram derived values of the same physiological interpretation (Singh and Carleton, 2024).

2.5. Statistical analyses

All *a-priori* power analyses estimates are detailed in the RCMP Study protocol paper (Carleton et al., 2022). Study participants were grouped into sociodemographic categories (i.e., sex, gender) for descriptive statistics on self-reported mental health disorder symptoms at pre-training and pre-deployment. Age was included in the models as a scale covariate. Sex (i.e., male, female, Other – Please Specify) and gender (i.e., Man, Woman, Two Spirit, Non-binary, or Other – Please Specify) were collected in the self-report surveys; however, statistical analyses with gender diverse participants (i.e., those identifying as Two Spirit, Non-binary, or Other – Please Specify) was impossible because all participants self-identified as either man or woman and self-identified as cisgender ($n = 81$); therefore, only sex was included in the statistical models.

Normality assumptions were assessed with Kolmogorov-Smirnov tests and confirmed with measures of central tendency (i.e., skewness and kurtosis). Independent samples *t*-tests assessed for statistically significant differences between sexes on mental health disorder symptom total scores and cardiac function. Paired-samples *t*-tests assessed for differences between pre-training and pre-deployment in self-reported mental health disorder symptom total scores and cardiac function. Bootstrapped partial correlations controlling for age and sex assessed for 1) cross-sectional associations at pre-training and pre-deployment between mental health symptom total scores and cardiac function; and 2) longitudinal associations in mental health disorder symptoms and cardiac function from pre-training to pre-deployment. Bootstrapped partial correlations controlling for age and sex assessed for 1) cross-sectional associations at pre-training and pre-deployment between mental health symptom total scores and measures of cardiac function; and 2) longitudinal associations from pre-training to pre-deployment among changes in mental health disorder symptoms and measures of cardiac function. Additionally, a series of sex-stratified bootstrapped *post-hoc* correlations were conducted to test for pooled-sample model stability by evaluating statistically significant associations within each sex category, independently. For each linear model, 5000 bootstrap random samples were computed to augment the model fitment criteria, and determine the stability and replicability of the results without making strong assumptions about the potential differences in distribution between the current sample and the true representative population. With the recognition that multiple comparisons inherently increase the risk of Type I errors, corrections for multiple comparisons were not conducted on an aggregate level on the basis of: 1) the current analyses are primarily exploratory and provide evidence to guide future analyses; 2) the associations between mental health disorder symptoms and individual measures of cardiac function, as well as combinations of measures of cardiac function may allude to specific physiological mechanisms that warrant additional analyses; 3) the complimentary nature of the measures of cardiac function, where all calculated measures of cardiac function exist as component or nested parts of a single full contractile cycle of the heart and should not be interpreted independently; and 4) the onset of non-traumatic cardiac dysfunction from sustained HPA axis deviations typically follows a characteristic temporal cascade where individual measures of cardiac function that indicate a level of impairment can co-occur with compensatory increases in contractility. All included measures of cardiac function are considered complimentary and biologically plausible, and therefore interpretations of independent associations do not inherently increase the risk of a type I error from multiple comparisons. Effect size estimates for comparisons used Cohen's d values (i.e., small, d = .20; medium, d = .50; large, d = .80; Cohen, 2013). SPSS v.29 Premium (IBM, 2021 New York, United States) was used to conduct the quantitative analyses.

3. Results

Kolmogorov-Smirnov tests indicated no data distributions departed from normality; accordingly, parametric statistical tests were used. Participant sociodemographic characteristics, mental health disorder symptom total scores, and measures of cardiac function are presented in Table 1. Descriptive analyses indicated that participants were mostly male (71.6 %), men (71.6 %), with a mean age of 29.63 ± 6.37 years. Changes in mental health disorder symptoms among RCMP cadets in the full RCMP Study sample, as well as detailed sociodemographic comparisons have been reported elsewhere (Carleton et al., 2023, 2024). Pairwise and independent sample comparisons indicated that only symptoms of SAD statistically significantly decreased from pre-training to pre-deployment (d = 0.58), with no sex differences. Statistically significant increases in the MPI (d = −0.31), DPI (d = −0.33), and IVRT (d = −0.22) were observed from pre-training to pre-deployment, with no sex differences (see Table 1).

Cross-sectional bootstrapped partial correlations between mental health disorder symptoms and cardiac function controlling for age and sex are reported in Table 2, and evidenced no statistically significant associations at pre-training; however, pre-deployment symptoms of MDD were statistically significantly inversely associated with MVO to E time (R = −0.67[−0.87,-0.30]). GAD symptoms at pre-deployment were also statistically significantly inversely associated with RET (R = −0.45 [−0.76,-0.02]) and MVO to E (R = −0.52[−0.79,-0.06]) and positively associated with twist force (R = 0.39[0.09,0.73]). Longitudinal bootstrapped partial correlations between changes in mental health disorder symptoms and cardiac function from pre-training to pre-deployment,

Table 1
Sociodemographic characteristics and comparisons of mental health disorder symptoms and cardiac function (n = 81).

	Total Sample			Pre-training			Pre-Deployment		
	Pre-training (n = 81)	Pre-deployment (n = 81)	Effect Size	Male (n = 58)	Female (n = 23)	Effect Size	Male (n = 58)	Female (n = 23)	Effect Size
	M(SD)	*M(SD)*	(Cohen's *d*)	*M(SD)*	*M(SD)*	(Cohen's *d*)	*M(SD)*	*M(SD)*	(Cohen's *d*)
Mental Health Disorder Symptom Measures									
Posttraumatic Stress Disorder (PCL-5)	3.22(5.33)	2.26(4.31)	0.17	3.27(5.09)	4.79(8.69)	−0.24	2.65(4.86)	1.00(1.92)	0.39
Major Depressive Disorder (PHQ-9)	2.84(3.30)	2.75(2.99)	0.03	2.79(3.03)	2.96(3.91)	−0.05	2.70(2.76)	2.75(3.52)	−0.02
Generalized Anxiety Disorder (GAD-7)	3.28(3.52)	2.63(3.03)	0.19	3.38(3.31)	3.04(4.03)	0.09	2.53(3.22)	2.88(2.47)	−0.12
Social Anxiety Disorder (SIPS-14)	4.88(6.15)	2.05(3.83)	0.58***	4.48(5.84)	5.79(6.85)	−0.21	1.91(3.81)	2.29(3.90)	−0.10
Alcohol Use Disorder (AUDIT)	3.17(1.86)	3.14(1.58)	0.02	3.18(1.85)	2.86(1.80)	0.18	3.00(1.66)	3.05(1.47)	−0.03
Measures of Cardiac Function									
Heart Rate (bpm)	64.45(9.66)	66.82(11.84)	−0.22	64.00(10.28)	65.53(8.07)	−0.16	66.31(12.30)	68.02(10.84)	−0.14
Myocardial Performance Index (MPI)	0.38(0.05)	0.40(0.06)	−0.31**	0.39(0.05)	0.37(0.04)	0.25	0.40(0.06)	0.41(0.07)	−0.07
Systolic Performance Index (SPI)	0.10(0.02)	0.11(0.02)	−0.17	0.11(0.02)	0.10(0.01)	0.26	0.11(0.02)	0.11(0.02)	−0.01
Diastolic Performance Index (DPI)	0.28(0.04)	0.30(0.05)	−0.33**	0.28(0.04)	0.27(0.04)	0.16	0.29(0.04)	0.30(0.05)	−0.09
Systolic Time (ms)	325.72(35.65)	318.28(35.65)	0.16	325.41(37.21)	326.11(32.38)	−0.03	322.37(42.09)	308.55(37.76)	0.34
Diastolic Time (ms)	507.16(23.78)	495.59(143.72)	0.09	517.21(130.63)	483.28(104.42)	0.28	499.53(155.77)	486.24(112.43)	0.09
Isovolumic contraction time (IVCT; ms)	33.81(6.69)	34.61(6.93)	−0.10	34.19(6.94)	32.90(6.09)	0.19	35.13(6.86)	33.40(7.07)	0.25
Isovolumic relaxation time (IVRT; ms)	89.46(10.71)	92.93(13.65)	−0.22*	90.02(10.88)	88.13(10.40)	0.18	93.98(14.42)	90.44(11.49)	0.26
Rapid ejection time (RET; ms)	81.59(13.47)	80.49(14.88)	0.07	81.76(13.82)	81.19(12.90)	0.04	80.04(15.76)	81.58(12.78)	−0.10
MVO to E (ms)	48.57(7.16)	47.54(7.40)	0.13	48.85(7.92)	47.91(5.00)	0.13	47.96(7.91)	46.55(6.04)	0.19
AS to MVC (ms)	23.55(7.68)	22.28(7.11)	0.14	24.45(8.55)	21.40(4.52)	0.40	22.61(7.48)	21.50(6.23)	0.16
AVO to ATT (ms)	17.36(5.97)	19.03(6.26)	−0.21	17.32(6.36)	17.45(5.04)	−0.02	19.22(6.34)	18.56(6.18)	0.11
I to AVO (ms)	11.88(3.10)	12.40(3.45)	−0.11	11.95(3.07)	11.72(3.23)	0.07	12.40(3.28)	12.39(3.92)	0.00
Twist Force (mG)	16.17(9.21)	14.02(7.76)	0.20	16.78(10.31)	14.71(5.74)	0.22	13.92(6.27)	14.25(10.66)	−0.04
Atrial Systole (mG)	5.51(5.12)	4.47(2.73)	0.20	5.77(5.94)	4.89(2.20)	0.17	4.46(2.66)	4.50(2.96)	−0.02

Note. *p < .05, **p < .01, ***p < .001. AS to MVC: atrial systole to mitral valve closure; AVO to ATT: aortic valve open to aortic twist; bpm: beats per minute; I to AVO: isovolumic compression to aortic valve open; MVO to E: mitral valve open to E wave; AUDIT = Alcohol Use Disorder Identification Test; GAD-7 = Generalized Anxiety Disorder Scale - 7; SIPS = Social Interaction Phobia Scale; PHQ-9 = Patient Health Questionnaire - 9; PCL-5 = Posttraumatic Stress Disorder Checklist for DSM-5.

Table 2
Cross-sectional bootstrapped partial correlations between mental health disorder symptoms and cardiac function at pre-training and pre-deployment controlling for age and sex.

	Posttraumatic Stress Disorder (PCL-5)		Major Depressive Disorder (PHQ-9)		Generalized Anxiety Disorder (GAD-7)		Social Anxiety Disorder (SIPS)		Alcohol Use Disorder (AUDIT)	
	R[95 % CI]		*R*[95 % CI]		*R*[95 % CI]		*R*[95 % CI]		*R*[95 % CI]	
Measures of Cardiac Function	Pre-training	Pre-deployment	Pre-training	Pre-deployment	Pre-training	Pre-deployment	Pre-training	Pre-deployment	Pre-training	Pre-deployment
Heart Rate (bpm)	0.02 [-0.24,0.28]	0.21 [-0.28,0.62]	0.19 [-0.07,0.43]	0.40[-0.08,0.73]	0.00 [-0.26,0.26]	0.44[0.04,0.75]*	0.13 [-0.13,0.38]	0.13 [-0.36,0.56]	−0.04 [-0.30,0.22]	0.03 [-0.44,0.49]
Myocardial Performance Index (MPI)	0.10 [-0.16,0.35]	−0.06 [-0.51,0.42]	−0.06 [-0.31,0.21]	0.14[-0.35,0.57]	−0.11 [-0.36,0.15]	0.03[-0.45,0.49]	−0.03 [-0.29,0.23]	0.35 [-0.14,0.70]	0.04 [-0.22,0.29]	0.31 [-0.18,0.68]
Systolic Performance Index (SPI)	0.03 [-0.02,0.29]	−0.06 [-0.51,0.42]	−0.03 [-0.28,0.24]	−0.05[-0.50,0.43]	−0.05 [-0.30,0.22]	−0.01 [-0.47,0.46]	−0.01 [-0.26,0.25]	0.18 [-0.31,0.60]	0.03 [-0.23,0.29]	0.11 [-0.38,0.55]
Diastolic Performance Index (DPI)	0.10 [-0.17,0.35]	−0.05 [-0.50,0.43]	−0.08 [-0.33,0.19]	0.24[-0.26,0.63]	−0.13 [-0.37,0.13]	0.07[-0.41,0.52]	−0.04 [-0.30,0.22]	0.37 [-0.12,0.71]	0.04 [-0.22,0.30]	0.34 [-0.16,0.69]
Systolic Time (ms)	−0.14 [-0.38,0.12]	0.27 [-0.23,0.65]	−0.00 [-0.26,0.26]	0.05[-0.43,0.51]	0.13 [-0.14,0.37]	−0.07 [-0.52,0.41]	0.06 [-0.20,0.32]	−0.15 [-0.58,0.34]	−0.15 [-0.39,0.11]	−0.43 [-0.75,0.05]
Diastolic Time (ms)	−0.04 [-0.30,0.22]	−0.26 [-0.65,0.24]	−0.15 [-0.39,0.11]	−0.45[-0.76,0.02]	0.06 [-0.20,0.31]	−0.39 [-0.72,0.10]	−0.09 [-0.34,0.18]	−0.15 [-0.57,0.35]	0.09 [-0.17,0.34]	0.08 [-0.41,0.52]
Isovolumic contraction time (IVCT; ms)	−0.02 [-0.28,0.24]	0.15 [-0.35,0.57]	0.01 [-0.25,0.26]	−0.03[-0.49,0.45]	0.08 [-0.18,0.33]	−0.02 [-0.48,0.45]	0.09 [-0.17,0.34]	0.11 [-0.38,0.55]	−0.08 [-0.33,0.18]	−0.05 [-0.50,0.43]
Isovolumic relaxation time (IVRT; ms)	−0.01 [-0.92,0.27]	0.25 [-0.24,0.64]	−0.12 [-0.37,0.14]	0.38[-0.11,0.72]	−0.05 [-0.31,0.21]	0.06[-0.42,0.51]	−0.02 [-0.28,0.24]	0.29 [-0.20,0.67]	−0.07 [-0.32,0.19]	−0.06 [-0.52,0.42]
Rapid ejection time (RET; ms)	−0.05 [-0.30,0.22]	−0.18 [-0.60,0.32]	−0.12 [-0.37,0.14]	−0.34[-0.70,0.15]	0.04 [-0.22,0.30]	−0.45[-0.76,-0.02]*	0.06 [-0.20,0.32]	0.08 [-0.40,0.53]	−0.05 [-0.30,0.21]	−0.20 [-0.61,0.29]
MVO to E (ms)	−0.08 [-0.33,0.19]	−0.24 [-0.64,0.26]	−0.15 [-0.40,0.11]	−0.67[-0.87,-0.30]**	0.01 [-0.25,0.27]	−0.52[-0.79,-0.06]*	−0.03 [-0.29,0.23]	−0.33 [-0.69,0.16]	0.12 [-0.15,0.36]	−0.20 [-0.61,0.29]
AS to MVC (ms)	−0.14 [-0.38,0.13]	0.35 [-0.14,0.70]	−0.10 [-0.35,0.16]	0.23[-0.27,0.63]	−0.07 [-0.32,0.19]	0.36[-0.13,0.71]	−0.03 [-0.29,0.23]	−0.18 [-0.60,0.32]	−0.16 [-0.40,0.10]	−0.45 [-0.76,0.02]
AVO to ATT (ms)	−0.15 [-0.40,0.11]	−0.11 [-0.55,0.38]	0.03 [-0.23,0.29]	−0.00[-0.47,0.46]	−0.05 [-0.30,0.21]	−0.18 [-0.60,0.31]	−0.00 [-0.26,0.26]	−0.00 [-0.47,0.46]	−0.07 [-0.32,0.20]	−0.20 [-0.62,0.29]
I to AVO (ms)	0.11 [-0.15,0.36]	−0.01 [-0.47,0.46]	0.10 [-0.16,0.35]	0.06[-0.42,0.52]	0.12 [-0.14,0.37]	0.14[-0.35,0.57]	0.16 [-0.10,0.40]	0.11 [-0.38,0.55]	−0.16 [-0.40,0.11]	0.51 [-0.06,0.79]
Twist Force (mG)	−0.14 [-0.38,0.13]	0.39 [-0.10,0.72]	−0.22 [-0.46,0.04]	−0.03[-0.49,0.45]	−0.21 [-0.45,0.05]	0.39[0.09,0.73]*	−0.18 [-0.42,0.08]	−0.04 [-0.50,0.43]	0.18 [-0.09,0.42]	0.26 [-0.24,0.65]
Atrial Systole (mG)	−0.01 [-0.26,0.26]	0.41 [-0.07,0.74]	−0.08 [-0.33,0.18]	0.01[-0.46,0.48]	−0.11 [-0.36,0.15]	0.40[-0.09,0.73]	−0.11 [-0.36,0.16]	−0.09 [-0.54,0.39]	0.30 [-0.04,0.51]	0.28 [-0.22,0.66]

Note. $^{*}p < .05$, $^{**}p < .01$. AS to MVC: atrial systole to mitral valve closure; AVO to ATT: aortic valve open to aortic twist; bpm: beats per minute; I to AVO: isovolumic compression to aortic valve open; MVO to E: mitral valve open to E wave; AUDIT = Alcohol Use Disorder Identification Test; GAD-7 = Generalized Anxiety Disorder Scale - 7; SIPS = Social Interaction Phobia Scale; PHQ-9 = Patient Health Questionnaire - 9; PCL-5 = Posttraumatic Stress Disorder Checklist for DSM-5.

Table 3
Bootstrapped partial correlations between changes in mental health disorder symptom and cardiac function from pre-training to pre-deployment controlling for age and sex.

Measures of Cardiac Function	PTSD (PCL-5)	Major Depressive Disorder (PHQ-9)	Generalized Anxiety Disorder (GAD-7)	Social Anxiety Disorder (SIPS)	AUD (AUDIT)
	R [95 % CI]	*R* [95 % CI]	*R* [95 % CI]	*R* [95 % CI]	*R* [95 % CI]
Heart Rate (bpm)	−0.37 [-0.75,0.20]	−0.27[-0.70,0.31]	−0.27[-0.70,0.30]	0.12[-0.44,0.61]	−0.13 [-0.62,0.43]
Myocardial Performance Index (MPI)	0.34[-0.24,0.74]	0.54[0.02,0.83]*	0.44[0.12,0.79]*	0.49[0.06,0.81]*	0.11[-0.45,0.60]
Systolic Performance Index (SPI)	0.16[-0.40,0.64]	0.21[-0.37,0.66]	0.16[-0.41,0.64]	−0.15[-0.63,0.42]	0.24[-0.33,0.68]
Diastolic Performance Index (DPI)	0.36[-0.22,0.75]	0.56[0.04,0.84]*	0.43[0.13,0.78]*	0.63[0.14,0.87]*	−0.02 [-0.54,0.52]
Systolic Time (ms)	0.11[-0.45,0.60]	0.08[-0.47,0.58]	−0.01[-0.54,0.52]	−0.12[-0.61,0.44]	0.00[-0.53,0.53]
Diastolic Time (ms)	0.12[-0.44,0.61]	−0.01[-0.54,0.52]	0.34[-0.23,0.74]	−0.28[-0.71,0.29]	0.23[-0.34,0.68]
Isovolumic contraction time (IVCT; ms)	0.28[-0.30,0.70]	0.25[-0.33,0.69]	0.11[-0.45,0.60]	−0.10[-0.60,0.45]	0.22[-0.35,0.67]
Isovolumic relaxation time (IVRT; ms)	0.38[0.19,0.76]*	0.59[0.09,0.85]*	0.38[0.19,0.76]*	0.51[0.03,0.82]*	−0.01 [-0.54,0.53]
Rapid ejection time (RET; ms)	0.23[-0.34,0.68]	0.18[-0.39,0.65]	0.44[0.12,0.79]*	0.04[-0.50,0.56]	0.32[-0.26,0.73]
MVO to E (ms)	0.08[-0.47,0.59]	−0.08[-0.58,0.47]	0.25[-0.33,0.69]	0.07[-0.48,0.58]	−0.09 [-0.60,0.46]
AS to MVC (ms)	−0.50 [-0.81,0.04]	−0.01[-0.53,0.53]	−0.09[-0.59,0.47]	−0.64[-0.88,0.17]	−0.05 [-0.56,0.50]
AVO to ATT (ms)	−0.33 [-0.73,0.24]	0.35[-0.22,0.74]	0.29[-0.28,0.71]	0.02[-0.52,0.54]	0.12[-0.44,0.61]
I to AVO (ms)	0.30[-0.27,0.72]	−0.13[-0.62,0.43]	−0.30[-0.72,0.28]	0.63[-0.15,0.87]	−0.33 [-0.73,0.25]
Twist Force (mG)	−0.35 [-0.74,0.23]	−0.27[-0.70,0.31]	−0.02[-0.54,0.52]	0.01[-0.52,0.54]	0.28[-0.30,0.71]
Atrial Systole (mG)	−0.21 [-0.67,0.36]	−0.36[-0.75,0.21]	0.04[-0.50,0.56]	0.08[-0.47,0.59]	0.14[-0.42,0.62]

Note. *$p < .05$. AS to MVC: atrial systole to mitral valve closure; AVO to ATT: aortic valve open to aortic twist; bpm: beats per minute; I to AVO: isovolumic compression to aortic valve open; MVO to E: mitral valve open to E wave; AUDIT = Alcohol Use Disorder Identification Test; GAD-7 = Generalized Anxiety Disorder Scale - 7; SIPS = Social Interaction Phobia Scale; PHQ-9 = Patient Health Questionnaire - 9; PCL-5 = Posttraumatic Stress Disorder Checklist for DSM-5.

controlling for age and sex, are reported in Table 3 and evidenced that changes in MDD, GAD, and SAD symptoms were all statistically significantly positively associated with changes in the MPI ($R = 0.44$ to 0.54), DPI ($R = 0.43$ to 0.63), and IVRT ($R = 0.38$ to 0.59). IVRT changes were also statistically significantly positively associated with changes in PTSD symptoms (R = 0.38[0.19,0.76]). RET changes were statistically significantly positively associated with changes in GAD symptoms (R = 0.44[0.12,0.79]). Consistent with the absence of statistically significant sex differences reported in Table 1, sex-stratified bootstrapped *post-hoc* correlations indicated that when assessed independently, no sex-specific differences were observed between the pooled-sample partial and sex-stratified *post-hoc* correlations. All models that were statistically significant in the pooled-sample were also statistically significant, consistent in direction, and of approximately equal magnitude (i.e., within $R = 0.02$ of the pooled-sample models) in the sex-stratified models, indicating that the observed associations between mental health disorder symptoms, and changes in symptoms, are consistently observed among both sexes.

4. Discussion

The current study is the first longitudinal assessment of cardiac function among RCMP cadets during training, and of associations between changes in mental health disorder symptoms and cardiac function. The current results evidence moderate to strong cross-sectional and longitudinal associations between mental health disorder symptoms and cardiac function, and provide rationale for integrating PTSI-specific cardiac rehabilitation exercise guidelines into occupational fitness programs, thereby potentially mitigating the cumulative impact of occupational stressors including repeated PPTE exposures on cardiac function. The observed changes within the current sample are consistent in direction, but inconsistent in magnitude, with the larger RCMP Study sample evaluated at pre-deployment (i.e., cadets reported fewer mental health symptoms at pre-deployment compared to pre-training; Carleton et al., 2024). The cardiac function measures of MPI, DPI, and IVRT increased from pre-training to pre-deployment; however, the increases are small in magnitude, may be transient, and partially attributed to acute anxiety at pre-deployment not entirely captured by the self-report measures (Andrews et al., 2023). Individual physiological differences at baseline may have been partially ameliorated by exercise conditioning during the CTP and may have contributed to statistical regression to the mean.

Associations between changes in mental health disorder symptoms and cardiac function from pre-training to pre-deployment indicate directionally consistent coupling of MPI, DPI, and IVRT of approximately equal magnitude for changes in symptoms of MDD, GAD, and SAD, with additional moderate to strong positive associations between changes in IVRT and changes in PTSD symptoms, and changes in RET with changes in symptoms of GAD. Elevations in MPI, DPI, and IVRT are also positively associated with age, and twist force is associated with sex (Biering-Sørensen et al., 2016); however, the statistical models in the current study controlled for both age and sex, evidencing an independent associative directional coupling relationship between increases in mental health disorder symptoms and poorer cardiac function, although the generalizability of the results is limited within the context of the current exploratory study design.

Interpretations of longitudinal associations are supported by the absence of statistically significant cross-sectional associations between mental health disorder symptom total scores and cardiac function at pre-training, indicating that individual differences potentially obfuscate associations that can only be detected in longitudinal study designs. At pre-deployment, there were moderate to strong statistically significant inverse associations between MDD symptoms and MVO to E time, and between GAD symptoms and both RET and MVO to E time. Contrastingly, twist force was statistically significantly positively associated with GAD symptoms. Twist force, a surrogate for cardiac contractility (Vogt et al., 2012; Sørensen et al., 2018), is augmented under conditions of adrenergic innervation. Therefore, the cross-sectional associations may reflect transient physiological changes consistent with symptoms of anxiety-related disorders (i.e., states of increased physiological arousal; Roth et al., 2012; Chalmers et al., 2014; Tafet and Nemeroff, 2020; Cheng et al., 2022); however, the associations may not be reliable given the wide bootstrapped confidence intervals. The current cross-sectional results echo previous challenges when assessing cardiac function in cross-sectional studies; specifically, that individual differences eclipse between-participant variance even in the controlled, predictable, and consistent CTP learning environment (Steptoe et al., 2012; Vogt et al., 2012; Torp-Pedersen et al., 2020). Individual differences in device placement and protocol familiarity may exist at pre-training and explain between-participant variance, but such differences should be attenuated with repeated use of the recording devices.

The RCMP Study overall has several strengths and limitations (for details see Carleton et al., 2022). Strengths of the current study specifically, include: 1) a comprehensive health assessment framework that includes self-report and biometric measurements; 2) the capacity to longitudinally collect mental health and measures of cardiac function at pre-specified intervals; and 3) a repeated-measures research design that that includes baseline and within-participant comparisons to better control for individual differences. Statistical comparisons of change scores from pre-training to pre-deployment inherently account for within-participant differences that remain relatively consistent during the observation period; therefore, associations between changes in mental health disorder symptoms and cardiac function may be particularly accurate given the narrow-bootstrapped confidence intervals. Individual differences that may change from pre-training to pre-deployment (e.g., body composition) considerably impact amplitude-derived measures captured in milligravity (i.e., twist force, atrial systole) because both subcutaneous and visceral adiposity can buffer the axial acceleration values measured by SCG devices. Measures captured as timing intervals, such as those included in the current study, appear less susceptible to such interference, but the susceptibility warrants additional research. Lastly, the absent statistically significant differences in global measures of cardiac chronotropy (i.e., heart rate, diastolic time) between pre-training and pre-deployment suggest participants were at rest and captured an SCG recording consistent with the data collection protocol.

Limitations of the current study include: 1) the possibility for socially desirable responding on the mental health disorder measures during the CTP career milestones, which may have obfuscated observable cross-sectional associations at both pre-training and pre-deployment by minimizing mental health disorder symptom total scores; 2) an unmeasurable potential for self-selection bias due to voluntary participation which may have resulted in a statistically biased sample where the extent of participation may be informed by prior mental health status (Teckchandani et al., 2024); 3) absent information regarding participant medical histories, general activity, level of exercise preconditioning, or acute exposure to changes in altitude before and during the CTP in Regina, Saskatchewan, all of which may have independently or cumulatively influenced cardiac function measurement (Teckchandani et al., 2020); 4) the presence of statistical floor effects may have attenuated effect sizes among mental health disorder symptoms, changes in symptoms, and thereby associations with measures of cardiac function; 5) although the current results provide consistent insight about early changes in cardiac function that occur in concert with mental health disorder symptoms, the clinical significance is reduced when interpreted in the context of the good overall health demonstrated by the current sample; and 6) a relatively high rate of attrition at pre-deployment among study participants that were provided with an SCG device at pre-training (43.8 % attrition rate) inherently reduces the generalizability of the results, although the remaining sample ($n = 81$) remains proportionally identical to the larger RCMP Study and by extension the RCMP generally. Future research efforts with data from the same participants after their first year of active service will help inform whether the relationships between mental health symptom changes and cardiac function are robust, and are to be informed by the current results to afford more robust statistical methods to account for the within-subject nature of the data.

5. Conclusion

The current study is the first of its kind in RCMP cadets that evidences an independent associative directional relationship between mental health disorder symptoms and cardiac function. The magnitude of changes from pre-training to pre-deployment were not clinically or statistically significant for many of the measures; nevertheless, the associations remain clinically important because diastolic dysfunction is robustly associated with an increased risk of MACE. The current study remains to be replicated after the first year of active service to determine reproducibility of the coupling relationship between mental health disorder symptoms and diastolic measures of cardiac function. In the interim, the associations provide important evidence towards identifying PTSI biomarkers in the context of biopsychosocial models of psychopathology (Bolton, 2023). The associations also provide a strong rationale for integrating cardiac rehabilitation exercise guidelines into occupational fitness and wellness programs to potentially mitigate the impact of occupational stressors, including repeated PPTE exposures, on cardiac function.

CRediT authorship contribution statement

R.N. Carleton: Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **T.A. Teckchandani:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **J.P. Neary:** Writing – review & editing, Validation, Methodology, Funding acquisition, Conceptualization. **J.E. Samayoa:** Writing – original draft. **J.M.B. Khoury:** Writing – review & editing. **K. Q. Maguire:** Writing – review & editing, Data curation. **G.P. Krätzig:** Writing – review & editing, Resources, Funding acquisition, Conceptualization. **G.J.G. Asmundson:** Writing – review & editing.

Data availability statement

The datasets presented in this article will be made available only for independent confirmation purposes and only to persons with the necessary ethical and security clearances as defined by the Research Ethics Board at the University of Regina and the contractual obligations with the Royal Canadian Mounted Police.

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: R. Nicholas Carleton reports financial support was provided by Royal

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jpsychires.2025.10.044.

References

Andrews, K.L., et al., 2023. Examining mental health knowledge, stigma, and service use intentions among Royal Canadian Mounted Police cadets. Front. Psychol. 14. https://doi.org/10.3389/fpsyg.2023.1123361. Available at:

Arri, S.S., et al., 2016. Mental stress-induced myocardial ischaemia. Heart 102 (6), 472–480. https://doi.org/10.1136/heartjnl-2014-307306. Available at:

Berg, S.K., et al., 2018. Mental health is a risk factor for poor outcomes in cardiac patients: findings from the national DenHeart survey. J. Psychosom. Res. 112, 66–72. https://doi.org/10.1016/j.jpsychores.2018.07.002. Available at:

Biering-Sørensen, T., et al., 2016. Cardiac time intervals by tissue doppler Imaging M-Mode: normal values and Association with established echocardiographic and invasive measures of systolic and diastolic function. PLoS One 11 (4), e0153636. https://doi.org/10.1371/journal.pone.0153636. Available at.

Biering-Sørensen, T., Mogelvang, R., Jensen, J.S., 2015. Prognostic Value of Cardiac Time Intervals Measured by Tissue Doppler Imaging M-mode in the General Population. https://doi.org/10.1136/heartjnl-2014-307137. Available at.

Bolton, D., 2023. A revitalized biopsychosocial model: core theory, research paradigms, and clinical implications. Psychol. Med. 53 (16), 7504–7511. https://doi.org/10.1017/S0033291723002660.

Carleton, R.N., et al., 2009. Refining and validating the social interaction anxiety Scale and the social Phobia Scale. Depress. Anxiety 26 (2), E71–E81. https://doi.org/10.1002/da.20480. Available at:

Carleton, R.N., et al., 2018. Mental disorder symptoms among public safety personnel in Canada. Can. J. Psychiatr. 63 (1), 54–64. https://doi.org/10.1177/0706743717723825. Available at:

Carleton, R.N., et al., 2022. The Royal Canadian Mounted Police (RCMP) Study: protocol for a prospective investigation of mental health risk and resilience factors. Health Promotion and Chronic Disease Prevention in Canada 42 (8), 319–333. https://doi.org/10.24095/hpcdp.42.8.02. Available at:

Carleton, R.N., et al., 2023. Mental health of royal Canadian mounted police at the start of the Cadet Training Program. Can. J. Psychiatr. 68 (9), 651–662. https://doi.org/10.1177/07067437221147425. Available at:

Carleton, R.N., et al., 2024. Mental health of royal Canadian mounted police cadets completing training. J. Police Crim. Psychol. https://doi.org/10.1007/s11896-024-09715-5 [Preprint]. Available at:

Chalmers, J.A., et al., 2014. Anxiety disorders are associated with reduced heart rate variability: a meta-analysis. Front. Psychiatr. 5 (JUL), 1–11. https://doi.org/10.3389/fpsyt.2014.00080. Available at:

Cheng, Y.-C., et al., 2022. Heart rate variability in patients with anxiety disorders: a systematic review and meta-analysis. Psychiatr. Clin. Neurosci. 76 (7), 292–302. https://doi.org/10.1111/pcn.13356. Available at:

Cohen, J., 2013. Statistical Power Analysis for the Behavioral Sciences, Statistical Power Analysis for the Behavioral Sciences. Routledge, New York, NY, US. https://doi.org/10.4324/9780203771587. Available at:

Dehkordi, P., et al., 2019. Identifying patients with coronary artery disease using rest and exercise seismocardiography. Front. Physiol. 10 (SEP), 1–10. https://doi.org/10.3389/fphys.2019.01211. Available at:

Ersbøll, M., et al., 2014. Impaired resting myocardial annular velocities are independently associated with mental stress-induced ischemia in coronary heart disease. JACC (J. Am. Coll. Cardiol.): Cardiovascular Imaging 7 (4), 351–361. https://doi.org/10.1016/j.jcmg.2013.10.014. Available at:

Esler, M., 2017. Mental stress and human cardiovascular disease. Neurosci. Biobehav. Rev. 74, 269–276. https://doi.org/10.1016/j.neubiorev.2016.10.011. Available at:

Faes, L., et al., 2013. Autonomic neuroscience : basic and Clinical investigating the mechanisms of cardiovascular and cerebrovascular regulation in orthostatic syncope through an information decomposition strategy. Auton Neurosci. Basic Clin. 178 (1–2), 76–82. https://doi.org/10.1016/j.autneu.2013.02.013. Available at:

Flandreau, E.I., et al., 2012. Chronic overexpression of corticotropin-releasing factor from the central amygdala produces HPA axis hyperactivity and behavioral anxiety associated with gene-expression changes in the hippocampus and paraventricular nucleus of the hypothalamus. Psychoneuroendocrinology 37 (1), 27–38. https://doi.org/10.1016/j.psyneuen.2011.04.014. Available at:

Guilliams, T.G., Edwards, L., 2010. Chronic stress and the HPA axis: clinical assessment and therapeutic considerations. Standard 9 (2), 1–12.

Heber, A., et al., 2023. Glossary of terms: a shared understanding of the common terms used to describe psychological trauma, version 3.0. Health Promot Chronic Dis Prev Can 43 (10/11). https://doi.org/10.24095/hpcdp.43.10/11.09. Available at:

Hembroff, C.C., Kratzig, G.P., 2020. A 5-Year Perspective of Attrition in Relation to Employment Equity. Royal Canadian Mounted Police: Research and Strategic Partnerships [Preprint].

Hieda, M., et al., 2019. Reduced left ventricular diastolic function in women with posttraumatic stress disorder. Am. J. Physiol. Regul. Integr. Comp. Physiol. 317 (1), R108–R112. https://doi.org/10.1152/ajpregu.00002.2019. Available at:

Kroenke, K., Spitzer, R.L., Williams, J.B., 2001. The PHQ-9: validity of a brief depression severity measure. J. Gen. Intern. Med. 16 (9), 606–613. https://doi.org/10.1046/j.1525-1497.2001.016009606.x. Available at:

McKay, W.P.S., et al., 1999. Sternal acceleration ballistocardiograpby and arterial pressure wave analysis to determine stroke volume. Clin. Invest. Med. 22 (1), 4–14.

Menke, A., 2019. Is the HPA axis as target for depression outdated, or is there a new hope? Front. Psychiatr. 10. https://doi.org/10.3389/fpsyt.2019.00101. Available at:

Pereira, V.H., et al., 2013. Stressed brain, diseased heart: a review on the pathophysiologic mechanisms of neurocardiology. Int. J. Cardiol. 166 (1), 30–37. https://doi.org/10.1016/j.ijcard.2012.03.165. Available at:

Ramirez, F.D., et al., 2017. Methodological Rigor in preclinical cardiovascular studies. Circ. Res. 120 (12), 1916–1926. https://doi.org/10.1161/CIRCRESAHA.117.310628. Available at:

Roth, M.K., et al., 2012. Effects of chronic plus acute prolonged stress on measures of coping style, anxiety, and evoked HPA-axis reactivity. Neuropharmacology 63 (6), 1118–1126. https://doi.org/10.1016/j.neuropharm.2012.07.034. Available at:

Rutledge, T., et al., 2013. A meta-analysis of mental health treatments and cardiac rehabilitation for improving clinical outcomes and depression among patients with coronary heart disease. Psychosom. Med. 75 (4), 335–349.

Sammito, S., Thielmann, B., Klussmann, A., Deußen, A., Braumann, K.-M., Böckelmann, I., 2024. Guideline for the application of heart rate and heart rate variability in occupational medicine and occupational health science. J. Occup. Med. Toxicol. 19 (1), 15. https://doi.org/10.1186/s12995-024-00414-9.

Saunders, J.B., et al., 1993. Development of the Alcohol Use Disorders Identification Test (AUDIT): WHO collaborative project on early detection of persons with harmful alcohol consumption-II. Addiction 88 (6), 791–804. https://doi.org/10.1111/j.1360-0443.1993.tb02093.x. Available at:

Singh, J., et al., 2023. Cardiac cycle timing intervals in university varsity athletes. Eur. J. Sport Sci. 23 (7), 1457–1462. https://doi.org/10.1080/17461391.2023.2178329. Available at:

Singh, J., Ellingson, C.J., et al., 2024. Cardiac cycle timing and contractility following acute sport-related concussion. Res. Sports Med. 32 (2), 260–267. https://doi.org/10.1080/15438627.2022.2102918.

Singh, J., Carleton, R.N., et al., 2024. Characterization of the cardiac cycle in Royal Canadian Mounted Police Cadets. Appl. Physiol. Nutr. Metabol. https://doi.org/10.1139/apnm-2024-0340.

Sørensen, K., et al., 2018. Definition of fiducial points in the normal seismocardiogram. Sci. Rep. 8 (1), 1–11. https://doi.org/10.1038/s41598-018-33675-6. Available at:

Sowden, G.L., Huffman, J.C., 2009. The impact of mental illness on cardiac outcomes: a review for the cardiologist. Int. J. Cardiol. 132 (1), 30–37. https://doi.org/10.1016/j.ijcard.2008.10.002. Available at:

Spitzer, R.L., et al., 2006. A brief measure for assessing generalized anxiety disorder: the GAD-7. Arch. Intern. Med. 166 (10), 1092–1097. https://doi.org/10.1001/archinte.166.10.1092. Available at:

Steptoe, A., Rüddel, H., Neus, H., 2012. Clinical and methodological issues in cardiovascular psychophysiology. Springer Science & Business Media.

Sumner, J., Harrison, A., Doherty, P., 2017. The effectiveness of modern cardiac rehabilitation: a systematic review of recent observational studies in non-attenders versus attenders. PLoS One 12 (5), e0177658. https://doi.org/10.1371/journal.pone.0177658. Available at:

Tafet, G.E., Nemeroff, C.B., 2020. Pharmacological treatment of anxiety disorders: the role of the HPA axis. Front. Psychiatr. 11 (May), 1–11. https://doi.org/10.3389/fpsyt.2020.00443. Available at:

Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996. Heart rate variability: standards of measurement, physiological interpretation and clinical use. Circulation 93 (5), 1043–1065.

Teckchandani, T.A., et al., 2020. Effects of normobaric hypoxia on cardiac mechanical function using seismocardiography. In: Biophotonics in Exercise Science, Sports Medicine, Health Monitoring Technologies, and Wearables. Biophotonics in Exercise Science, Sports Medicine, Health Monitoring Technologies, and Wearables, SPIE, pp. 50–56. https://doi.org/10.1117/12.2546378. Available at:

Teckchandani, T.A., et al., 2023. Cardioautonomic lability assessed by heart rate variability changes in Royal Canadian Mounted Police cadets during the cadet training program. Front. Psychol. 14. https://doi.org/10.3389/fpsyg.2023.1144783. Available at:

Teckchandani, T.A., Shields, R.E., Andrews, K.L., Maguire, K.Q., Jamshidi, L., Nisbet, J., Afifi, T.O., Lix, L.M., Stewart, S.H., Sauer-Zavala, S., Krakauer, R.L., Neary, J.P., Kratzig, G.P., Carleton, R.N., 2024. Trouble with the curve: the 90-9-1 rule to measure volitional participation inequalities among royal Canadian mounted police cadets during training. Front. Psychiatr. 15, 1297953. https://doi.org/10.3389/fpsyt.2024.1297953.

Torp-Pedersen, C., et al., 2020. "Real-world" observational studies in arrhythmia research: data sources, methodology, and interpretation. A position document from European Heart Rhythm Association (EHRA), endorsed by Heart Rhythm Society

(HRS), Asia-Pacific HRS (APHRS), and Latin America HRS (LAHRS). EP Europace 22 (5), 831–832. https://doi.org/10.1093/europace/euz210. Available at:

Verma, P., et al., 2010. Circadian phase and sex effects on depressive/anxiety-like behaviors and HPA axis responses to acute stress. Physiol. Behav. 99 (3), 276–285. https://doi.org/10.1016/j.physbeh.2009.11.002. Available at:

Vogt, E., MacQuarrie, D., Neary, J.P., 2012. Using ballistocardiography to measure cardiac performance: a brief review of its history and future significance. Clin. Physiol. Funct. Imag. 32 (6), 415–420. https://doi.org/10.1111/j.1475-097X.2012.01150.x. Available at:

Weathers, F.W., et al., 2013. The Life Events Checklist for DSM-5 (LEC-5) – Extended. [Measurement instrument], vol. 5. National Center for PTSD (April). Available at: http://www.ptsd.va.gov/professional/assessment/te-measures/life_events_checklist.asp.

Wick, C.A., et al., 2015. Seismocardiography-based detection of cardiac quiescence. IEEE (Inst. Electr. Electron. Eng.) Trans. Biomed. Eng. 62 (8), 2025–2032. https://doi.org/10.1109/TBME.2015.2411155. Available at:

Wiens, A.D., et al., 2015. Toward continuous, noninvasive assessment of ventricular function and hemodynamics: wearable ballistocardiography. IEEE Journal of Biomedical and Health Informatics 19 (4), 1435–1442. https://doi.org/10.1109/JBHI.2014.2359937. Available at:

Wilson, M.A., et al., 2019. Common pathways and communication between the brain and heart: connecting post-traumatic stress disorder and heart failure. Stress 22 (5), 530–547. https://doi.org/10.1080/10253890.2019.1621283. Available at:

Wilson, R.A., et al., 1993. Diagnostic accuracy of seismocardiography compared with electrocardiography for the anatomic and physiologic diagnosis of coronary artery disease during exercise testing. Am. J. Cardiol. 71 (7), 536–545. https://doi.org/10.1016/0002-9149(93)90508-A. Available at:

Wood, S., 2014. Individual differences in the neurobiology of social stress: implications for depression-cardiovascular disease comorbidity. Curr. Neuropharmacol. https://doi.org/10.2174/1570159x11666131120224413 [Preprint]. Available at: