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Heart Rate Variability Monitoring in Special Emergency Response Team Anaerobic-Based Tasks and Training

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Abstract: The Law enforcement profession is known to impart high stress. Members of Special Weapons and Tactics (SWAT) teams are allocated particularly demanding law enforcement operations and may therefore attain high fitness levels but may accumulate excessive stress. Heart rate variability (HRV), an assessment of time differences between heartbeats, likely indicates holistic load in field settings. To date, though, little research measuring HRV has been conducted involving SWAT units. The purpose of this study was to explore HRV measurements following (1) annual firearms qualification and (2) potential stress exposure with respect to completion time on an anaerobically taxing obstacle course. Officers with greater obstacle course performance were hypothesized to also exhibit greater HRV. HRV was also expected to stratify personnel more effectively than heart rate. Prospective 3-lead ECGs were obtained from a cohort of male SWAT operators (n = 15) with 5.2 ± 4.3 years of experience at three time points throughout one training day. HRV was assessed by time, frequency, and non-linear domains. Differences between baseline and post-training values were significant as assessed by the Wilcoxon signed-ranks test for heart rate, SDRR, LF, HF, and SD2. An enter-method linear regression model predicted post-training HF HRV by obstacle course time; $r^2 = 0.617$, $F(1,6) = 9.652$, $p = 0.021$. Anaerobic performance may be highly valuable in SWAT units. HRV analysis may also be beneficial in measuring the psychophysiological impact of SWAT activities.

Keywords: stress; fitness; biosignals; screening; police; occupational health

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1. Introduction

Law enforcement personnel are exposed to high levels of physical, cognitive, psychological, and social stress on a constant basis [1]. Beyond the typical occupational rigors of emergency response, police officers must also contend with internal organisational demands. These may include rotating or extended work hours, unexpected or undesired reassignment, and heavy occupational load carriage [2–4]. Employment within a Special Weapons and Tactics (SWAT) unit may further increase the severity of these occupational demands. The courses that aim to select sworn officers into SWAT units combine physical and technical challenges, in addition to demanding highly refined marksmanship, teamwork, leadership, and the ability to continue performing while deprived of food and rest [5]. After successful completion of a selection course, SWAT personnel may respond to the highest-risk incidents within their jurisdictions [6]. During these events, SWAT personnel may be required to perform tasks that lie outside the traditional scope of police work [7]. Such atypical tasks include management and de-escalation of potentially high-intensity conflicts, and exposure to atypical physical threats while wearing loads that may exceed 20 kg [8]. Specifically, these duties may range from counterterrorism operations to hostage rescue, search operations, crowd control, high-risk prisoner escort, personnel security details, and court protection, among others [9,10]. During such missions, SWAT personnel are expected to sustain optimal performance without compromise and within potentially hostile environments [11]. Additionally, in some regions, joining a SWAT unit may be a collateral duty undertaken in addition to their typical police work. This may, in turn, further extend duty and training hours, load carriage, and administrative duties [12]. These stressors may compound over time, manifesting as allostatic load. Bruce McEwen et al. initially described allostatic load as increased individual vulnerability to physical and psychological deterioration when exposed to chronic stress levels that cannot be tolerated [13,14]. The consequential prolonged state of overactivity, specifically in neuroendocrine, cardiovascular, and emotional responses as an effort to offset the impact of accumulated stressors, can lead to turbulent blood flow in critical anatomical regions, including the heart and brain. This, in turn, can result in conditions such as hypertension and depression, which are known concerns in law enforcement [3,15].

While the allostasis concept is still an evolving area of study in tactical populations, it is becoming increasingly evident in the general population that physical fitness plays a significant role in mitigating allostatic load [16,17]. Therefore, monitoring regulatory responses that may signal the onset of allostatic load may be valuable to SWAT units, particularly with respect to physical fitness. Applying heart rate variability (HRV) in athletics and the military is one increasingly popular tool as it can be utilised to obtain assessments of both psychological and physiological responses to physical and occupational training [18–20]. This is because HRV arises from a complex relationship between intrinsic cardiac factors, peripheral nervous system, and endocrine factors. These include, but are not limited to, the sympathetic and parasympathetic nervous system branches of the autonomic nervous system [21,22]. HRV is known to be associated with several outcomes of interest to tactical organisations, such as cardiorespiratory fitness, psychological stress, and overtraining syndrome, in addition to allostatic load [20,23–26]. In terms of psychological stress specifically, HRV has been posited as a 'U' distributed indicator, in which atypically (by individual) high or low HRV can be closely linked with psychological stress or illness. While most disorders are associated with low HRV, disordered eating has been show to be associated with high HRV [27]. However, of the studies identified in a recent systematic review considering aerobic fitness and HRV, the law enforcement population was not represented [28–31]. One study in the aforementioned review that followed a cohort of US police officers did find an association between self-reported physical activity levels and HRV [32], but no established link between directly measured physical fitness and HRV currently exists for the law enforcement community. As previous research has established only a tentative relationship between aerobic fitness and HRV during occupational task completion, the influence of anaerobic fitness on HRV merits further exploration as an additional factor affecting HRV in SWAT personnel. This hypothesis is supported by findings indicating anaerobic training may impart beneficial changes in HRV [33] that may, in turn, signal protection from allostatic load. This is relevant given that many police tasks rely extensively on anaerobic capacity [12,34]. Foot pursuits, for example, frequently conclude in under one minute [35]. Furthermore, grappling tasks, dragging an incapacitated colleague or victim, or rapidly disembarking from a vehicle, all rely chiefly on anaerobic metabolism [36,37].

Lethal force deployment is also a critical task for law enforcement personnel, particularly within SWAT units, as incidents involving firearms are allocated to these units when possible. Given the substantial recent interest by both the public and researchers in police lethal force events [38,39], it is crucial that SWAT personnel are afforded every means possible to enhance their proficiency. Physical fitness and autonomic regulation are potential domains that may be primary avenues for enhanced firearms proficiency and thereby a means of optimizing both officer and community safety as related to firearms deployment [40,41].

Despite the need for SWAT operators to meet high thresholds of occupational performance [31], human optimization strategies, such as HRV monitoring, remain sparsely reported. The nature of both stress volume, variety, and intensity in SWAT units may act to impose both physiological and psychosocial demand [31]. Many metabolic demands encountered may be anaerobic in nature. As such, anaerobic fitness may be more closely linked with HRV modulation under stress in SWAT personnel than aerobic fitness. Therefore, the purpose of this study was to explore what relationships may be present when comparing HRV measurements following an acute training session stress exposure and time to completion on a predominately anaerobically demanding occupational obstacle course. Personnel with greater performance on the occupational obstacle course were hypothesized to also exhibit greater HRV. A secondary hypothesis was that HRV would be more sensitive across time than heart rate (HR), and therefore a more detailed measure for exertion.

2. Materials and Methods

This research protocol was approved by the Messiah University Institutional review board (2019–2022) and the Bond University Research Ethics committee (2019–2022 amnd 2). All procedures were conducted in accordance with the Declaration of Helsinki of 1964 and its later amendments [42]. Data that were obtained both retrospectively and prospectively were combined for analysis. Specifically, the obstacle course was completed approximately 14 days prior to the ECG data collection. The methodology for the obstacle course, firearms qualification and training, and HRV data acquisition has been previously reported [43,44]. For HRV assessment, 3-lead electrocardiograms (ECGs) were collected at baseline (before qualification and training), after a firearms qualification course and then finally after a training exercise. See Figure 1 for additional detail on data collection timing. HRV was assessed as a dependent variable for linear regression modelling in which obstacle course time was the independent variable. Within-operator changes from baseline to post-qualification, and from baseline to post-training, were also assessed. HRV domains considered were those identified for occupational use by Sammito et al.: root-mean square of successive differences (RMSSD), standard deviation of all normal R-R intervals (SDNN), total spectral power (TP), low-frequency (LF), and high-frequency (HF) [45]. The non-linear indices SD1 (Poincare plot X–axis standard deviation) and SD2 (Poincare plot Y–axis standard deviation) were also considered as these are known robust HRV measures [21].

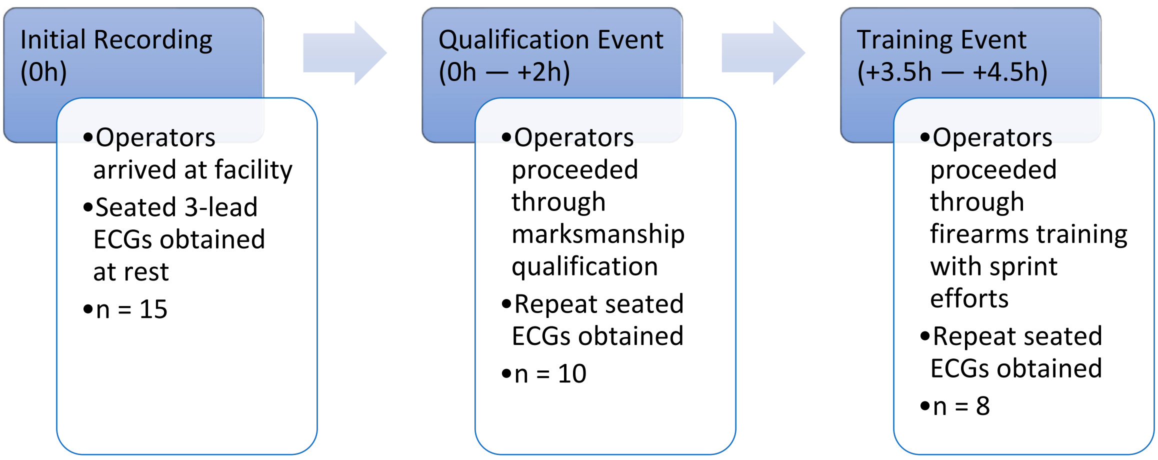

Figure 1. Flowchart of ECG data collection timing.

2.1. Participants

All fifteen available male SWAT personnel in this study volunteered for participation. The average years of experience in the cohort was 5.2 ± 4.3. Females were eligible to participate, but there were no female team members at the time of data collection. There were no exclusion criteria; all personnel present were eligible, recruited, and consented. Due to privacy considerations necessary for research access to the training event, no additional anthropometric data can be reported. These limitations in sharing of potentially sensitive personal data are not unusual in this population [46]. However, all personnel reported that they were taking no medication for cardiovascular, renal, or respiratory conditions as a requirement of participation in this study. All personnel provided written informed consent.

2.2. Procedures

The occupational obstacle course began with an 8.83 m sprint. Next, personnel hurdled across three benches (each one meter tall) placed approximately 6.07 m apart. This was followed by stepping through a series of nine tires, then a 29.87 m sprint to a 1.82 m wall obstacle which needed to be bounded over. After this, personnel completed a 40.84 m outdoor sprint to enter the training facility building. Personnel then needed to clear a 1.23 m wall, exit a window, and proceed down a flight of stairs. Once personnel reached the base of the stairs, they acquired a tactical battering ram (~15 kg) and proceeded with the ram to the second story. Once there, personnel placed the ram on the floor, and pulled a commercial 20 kg weight plate from the ground up to the second story by pulling an attached rope. Personnel next ran to the opposite end of the training facility roof and dragged an 81 kg dummy placed in a Sked litter. Once returning from this, personnel descended back down to the second story. At this time, the battering ram was recovered, and personnel returned to the ground level. The battering ram was utilized to exit a blocked door. After exiting, personnel were to sprint 10.67 m to another 1.23 m wall. After clearing the wall, personnel lifted two 20 kg commercial dumbbells and carried them, weaving through two sets of six cones spaced 9.75 m apart. This was followed by a sprint to a final set of cones. Finally, to complete the course, personnel weaved again around a set of three trees (approximately 30 m total). Three minutes (180 s) was the maximum allowable time for completion. Personnel were recorded by the unit commander on a manual stopwatch with times rounded to the nearest whole second [43,44] (see Figures 2 and 3 for further details).

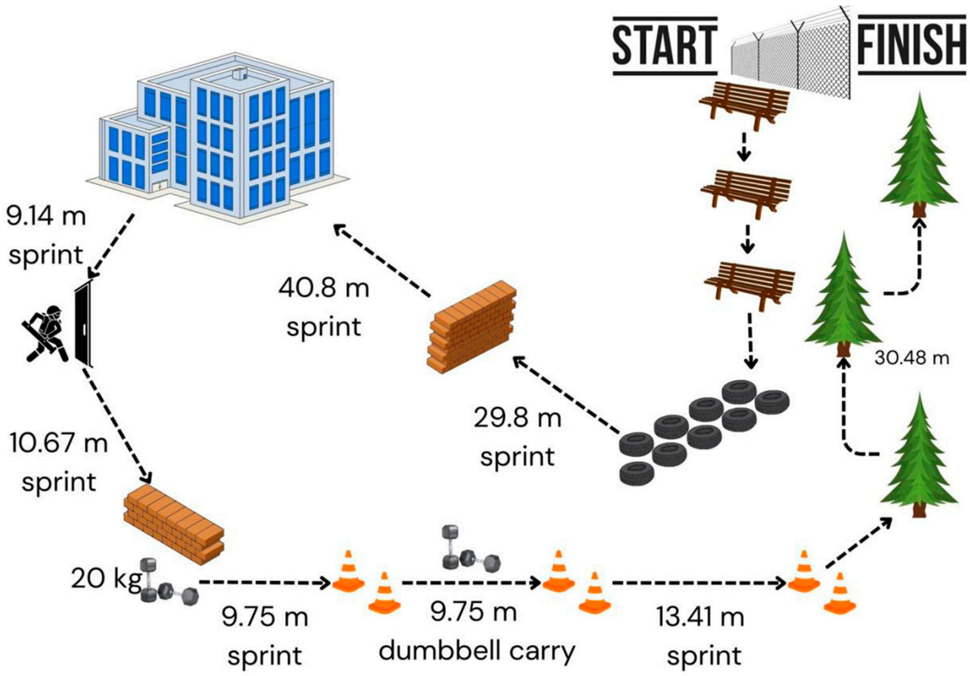

Figure 2. Exterior obstacle course schematic. Note that this diagram is for explanatory purposes only and is not drawn to scale.

The first event of the firearms qualification battery was an evaluation of static standing and dynamic handgun (0.40 calibre S and W Glock 22, Glock Ges.m.b.H., Deutsch-Wagram, LA, Austria) and rifle (5.56 mm NATO M4, various manufacturers, USA) engagements at 3, 5, 7, 10, 15, and 25 m. Only rifle engagements were conducted at 15 and 25 m. Personnel were required to wear all standard issue gear (boots, uniform, plate carrier vest, and helmet) and accurately place each shot on every target and at every distance.

Personnel were immediately dismissed from the unit if a shot was missed. Successful personnel were informed of their qualification score (pass/fail) and then underwent a training event. The training event consisted of handgun (0.40 calibre S and W Glock 22, Glock Ges.m.b.H., Austria) engagements against an array of 5 cm (2 inch) diameter targets as designated by the range instructor. Personnel completed shuttle runs (10 m) between target engagements. All standard issue equipment required for qualification was also required for the training procedure.

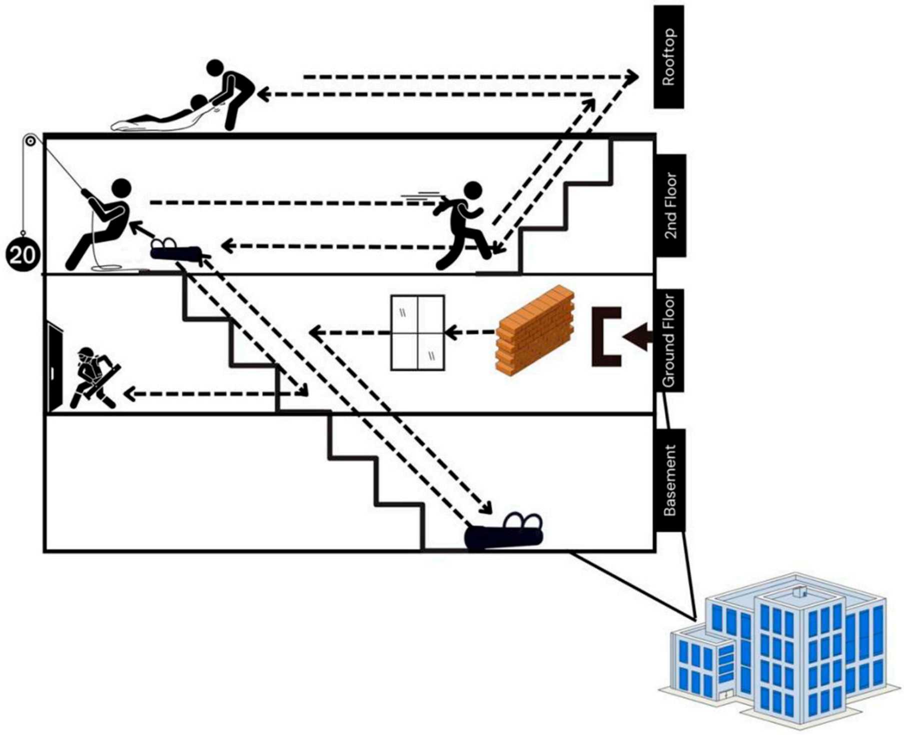

Figure 3. Interior obstacle course schematic. Note that this diagram is for explanatory purposes only and is not drawn to scale.

Three-lead seated ECGs were obtained over a minimum of five minutes using ADI Instruments, an Powerlab T7, and a Lab Chart v7 (ADInstruments, Sydney, Australia). All personnel entered a small briefing room for ECG collection at baseline (the initial report time) immediately after qualification, and immediately after conclusion of the training event described above. A seated posture was selected to reduce effects due to movement or postural sway, and to protect the equipment, as wired ECGs were utilised. However, a reasonably upright position was still desired to minimise potential confounding from orthostatic effects [47]. ECGs were processed with a LabChart v8 student license (ADInstruments, Sydney, Australia). A visual ECG examination was performed in combination with automated detection of irregularities completed by the LabChart Software version 8. ECG complexity, a measurement of QRS complex quality, was set between 1.0 and 1.5. Acceptable R-R intervals (RRI) were established as those between 272 ms and 1600 ms. This is equivalent to an HR between 220 bpm and 37.5 bpm [45]. Any RRI outside of this range was manually reviewed and included or excluded based on the visual features of the ECG.

2.3. Statistical Analyses

Once the HRV measurement was complete, a box plot analysis was conducted to determine the presence of outliers. The Shapiro–Wilk test was used to determine data normality. Within-subjects differences between baseline, post-qualification, and post-training measurements were assessed for significance using Wilcoxon signed-ranks tests. Power analysis revealed that, with a sample size of 15 (all available operators), an alpha level of 0.05, and a minimum power of 0.8, any statistically significant differences in HRV measures across conditions would be reliably detected, provided effect sizes reached at least 0.778.

Linear regression modelling (enter method) was completed to examine relationships between HRV at each time point, HRV changes from baseline to post-qualification, and baseline to post-training with respect to obstacle course time. In the event of loss to follow-up, data were eliminated case-wise in subsequent analyses. Although traditional between-subjects statistical inferences are not advised with regard to raw HRV data [48], this study utilized the method described by Buchheit [49,50], in which the total group mean ± 20% of the standard deviation was developed as an upper and lower bound for indication of the smallest worthwhile change (SWC) when the cohort was divided in two at the 50th percentile with respect to obstacle course time. Measures of HR and HRV were assessed for differences at baseline, post-qualification, and post-training. All analyses were conducted in JASP 0.17.2.1 (JASP Team, Amsterdam, The Netherlands).

3. Results

With an average completion time of 143 ± 12 s, the obstacle course likely imposed a substantial anaerobic burden [51]. All personnel completed the qualification successfully and progressed to the training event. However, some personnel were required for further operational duties, and so not all personnel for which baseline values were obtained were also present for the post-qualification and post-training ECG collection. In total, of the 15 operators recruited (n = 15), measures were obtained from 10 post-qualification (n = 10) and eight post-training (n = 8). Regarding the HRV data, signal quality was high; the total number of excluded beats was less than 1%. No statistically significant differences were identified between baseline and post-qualification values. The Wilcoxon signed-rank tests identified differences between baseline and post-training values for HR, SDNN, TP, HF, and SD2 that reached statistical significance. Effect sizes ranged from 0.778 (SD2) to 1.0 (TP, LF, and HF). The effect size for SDNN was 0.833. Descriptions of the baseline to post-qualification change, and the baseline to post-training change, data can be found in Table 1.

Table 1. Descriptive HRV values across time.

	HR (bpm)	RMSSD (ms)	SDNN (ms)	TP (ms^2)	LF (ms^2)	HF (ms^2)	SD1 (ms)	SD2 (ms)
Baseline (n = 15)	115 ± 124	64 ± 138.97	86.64 ± 132.85	2743.27 ± 3183.60	1057.48 ± 763.58	526.39 ± 1143.90	20.05 ± 15.41	69.30 ± 28.62
Post-Qualification (n = 10)	87 ± 16	52.68 ± 41.85	66.74 ± 34.57	3837.66 ± 4877.82	1188.89 ± 959.55	1143.05 ± 1650.94	37.30 ± 29.63	85.49 ± 41.73
Post-Training (n = 8)	105 ± 20 **	20.72 ± 13.66	39.12 ± 23.96 *	1807.66 ± 3409.85 **	432.13 ± 597.62 *	73.72 ± 93.30 *	14.66 ± 9.67	52.76 ± 33.55 *

Legend: Heart rate (HR); root-mean square of successive differences (RMSSD); standard deviation of R-R intervals (SDNN); total power (TP); low frequency (LF); high frequency (HF); Poincare plot X–axis standard deviation (SD1); Poincare plot Y–axis standard deviation (SD2). ** indicates $p < 0.01$ for difference from baseline. Wilcoxon signed rank test. * indicates $p < 0.05$ for difference from baseline. Wilcoxon signed rank test.

3.1. Smallest Worthwhile Change Analyses

Regarding the SWC analyses, at baseline, all HRV values for the top 50% subgroup were above the upper bound. Baseline HR values were within the SWC bounds. For the bottom 50% subgroup at baseline, all HRV values were below the SWC bounds, and HR was above the SWC upper bound. Two operators that provided baseline data had not completed the obstacle course and so were not included in the SWC or regression analyses (n = 13). Details of the analysis can be found in Table 2.

Table 2. Results of baseline SWC analysis.

	Mean HR (bpm)	RMSSD (ms)	SDNN (ms)	TP (ms^2)	LF (ms^2)	HF (ms^2)	SD1 (ms)	SD2 (ms)
Mean ± SD	81.19 ± 10.60	30.42 ± 22.67	53.47 ± 23.31	3056.99 ± 3318.32	1139.82 ± 783.55	600.34 ± 1217.41	21.55 ± 16.05	72.24 ± 29.43
20% SD	2.12	4.53	4.66	663.66	156.71	243.48	3.21	5.89
SWC Upper Bound	83.31	34.96	58.13	3720.66	1296.53	843.82	24.76	78.12
SWC Lower Bound	79.07	25.89	48.81	2393.33	983.11	356.86	18.34	66.35
Top 50% (*n* = 6) Mean ± SD	79.22 ± 12.75	37.58 ± 28.58 ‡	61.78 ± 26.18 ‡	3945.74 ± 4274.96 ‡	1397.60 ± 918.26 ‡	901.76 ± 1639.37 ‡	26.62 ± 20.22 ‡	82.83 ± 32.12 ‡
Bottom 50% (*n* = 7) Mean ± SD	83.50 ± 7.94 ‡	22.08 ± 9.89 ‡	43.78 ± 16.51 ‡	2020.12 ± 1449.38 ‡	839.07 ± 509.97 ‡	248.68 ± 237.40 ‡	15.62 ± 7.00 ‡	59.88 ± 22.37 ‡

Legend: Heart rate (HR); root-mean square of successive differences (RMSSD); standard deviation of R-R intervals (SDNN); total power (TP); low frequency (LF); high frequency (HF); Poincare plot X–axis standard deviation (SD1); Poincare plot Y–axis standard deviation (SD2); standard deviation (SD); smallest worthwhile change (SWC). ‡ indicates value outside of SWC bounds.

With respect to the post-qualification values, all HRV values for the top 50% subgroup were above the upper bound. HR values were within the SWC bounds for both subgroups. For the bottom 50% subgroup post-qualification, all HRV values were below the SWC bounds. Details of the analysis can be found in Table 3.

Table 3. Results of post-qualification SWC analysis.

	Mean HR (bpm)	RMSSD (ms)	SDNN (ms)	TP (ms^2)	LF (ms^2)	HF (ms^2)	SD1 (ms)	SD2 (ms)
Mean ± SD	85.15 ± 15.02	50.41 ± 43.39	67.68 ± 36.29	4101.83 ± 5058.05	1264.67 ± 976.15	1201.72 ± 1728.11	35.69 ± 30.72	87.94 ± 43.14
20% SD	3.00	8.68	7.26	1011.61	195.23	345.62	6.14	8.63
SWC Upper Bound	88.15	59.09	74.94	5113.44	1459.90	1547.34	41.83	96.57
SWC Lower Bound	82.14	41.73	60.43	3090.22	1069.44	856.10	29.54	79.31
Top 50% (*n* = 5)	84.27 ± 17.90	76.37 ± 47.96 ‡	86.986 ± 41.00 ‡	6470.6 ± 6432.44 ‡	1842.16 ± 1008.82 ‡	2013.26 ± 2183.81 ‡	54.07 ± 33.96 ‡	109.89 ± 48.7 ‡
Bottom 50% (*n* = 5)	86.02 ± 13.62	24.45 ± 15.82 ‡	48.38 ± 18.71 ‡	1733.06 ± 1469.58 ‡	687.18 ± 540.83 ‡	390.19 ± 551.17 ‡	17.31 ± 11.20 ‡	65.99 ± 24.68 ‡

Legend: Heart rate (HR); root-mean square of successive differences (RMSSD); standard deviation of R-R intervals (SDNN); total power (TP); low frequency (LF); high frequency (HF); Poincare plot X–axis standard deviation (SD1); Poincare plot Y–axis standard deviation (SD2); standard deviation (SD); smallest worthwhile change (SWC). ‡ indicates value outside of SWC bounds.

With respect to the post-training values, SDNN, TP, HF, and SD2 values for the top 50% subgroup were above the upper SWC bound. HR values were within the SWC bounds for both subgroups. For the bottom 50% subgroup post-qualification, SDNN, TP, HF, and SD2 values were below the SWC bounds. Details of the analysis can be found in Table 4.

Table 4. Results of post-training SWC analysis.

	Mean HR (bpm)	RMSSD (ms)	SDNN (ms)	TP (ms^2)	LF (ms^2)	HF (ms^2)	SD1 (ms)	SD2 (ms)
Mean ± SD	102.71 ± 19.93	22.32 ± 13.68	41.40 ± 24.55	2013.35 ± 3585.09	473.60 ± 624.88	82.06 ± 96.09	15.79 ± 9.68	55.72 ± 34.58
20% SD	3.99	2.74	4.91	717.02	124.98	19.22	1.94	6.92
SWC Upper Bound	106.70	25.05	46.30	2730.37	598.57	101.28	17.73	62.64
SWC Lower Bound	98.72	19.58	36.49	1296.33	348.62	62.85	13.86	48.81
Top 50% (*n* = 4)	101.52 ± 25.23	21.01 ± 16.97	46.51 ± 35.36 ‡	2826.98 ± 5075.67 ‡	454.89 ± 650.76	102.22 ± 131.28	14.87 ± 12.01	63.53 ± 49.52 ‡
Bottom 50% (*n* = 4)	103.90 ± 16.93	23.62 ± 12.00	36.28 ± 9.29 ‡	1199.73 ± 1569.20 ‡	492.30 ± 697.64	61.91 ± 56.80 ‡	16.72 ± 8.50	47.92 ± 13.23 ‡

Legend: Heart rate (HR); root-mean square of successive differences (RMSSD); standard deviation of R-R intervals (SDNN); total power (TP); low frequency (LF); high frequency (HF); Poincare plot X–axis standard deviation (SD1); Poincare plot Y–axis standard deviation (SD2); standard deviation (SD); smallest worthwhile change (SWC). ‡ indicates value outside of SWC bounds.

3.2. HR, HRV, and Obstacle Course Time

Regarding baseline HR and HRV, obstacle course time statistically significantly predicted RMSSD, HF, and SD1, but not HR or other HRV domains. The statistically significant models indicated that those HRV values were greater as obstacle course time was shorter. Regarding post-qualification HR and HRV, the obstacle course time statistically significantly predicted all analysed HRV domains, but not HR. The statistically significant models indicated that those HRV values became greater as obstacle course time grew shorter. Regarding post-training HR and HRV, no models were statistically significant.

Regarding the change in HR and HRV from baseline to post-qualification, obstacle course time was predictive of change in total power (TP) and the LF domain. The model for total power indicated that the total power increased as the obstacle course time decreased. The model for the LF domain indicated that the power decreased from baseline to post-qualification as obstacle course time was shorter. Regarding the change in HR and HRV from baseline to post-training, obstacle course time was predictive only of change in the HF domain. This model indicated that the HF domain power decreased from baseline to post-training as the obstacle course time grew shorter. Details of all regression modelling results can be found in Tables 5 and 6.

Table 5. Linear regression of raw HRV values and obstacle course time.

	Baseline			Post-Qualification			Post-Training		
Dependent	**r²**	**F**	***p***	**r²**	**F**	***p***	**r²**	**F**	***p***
HR	0.169	1,12 = 2.232	0.163	0.103	1,8 = 0.920	0.366	0.131	1,8 = 0.904	0.378
RMSSD	0.327	1,12 = 5.346	0.041 *	0.646	1,18 = 14.580	0.005 **	0.021	1,8 = 0.131	0.730
SDNN	0.305	1,12 = 4.838	0.050	0.665	1,8 = 15.847	0.004 **	0.395	1,8 = 3.909	0.095
TP	0.267	1,12 = 4.017	0.70	0.658	1,8 = 15.423	0.004 **	0.411	1,8 = 4.189	0.087
LF	0.033	1,12 = 0.378	0.551	0.522	1,8 = 8.741	0.018 *	0.062	1,8 = 0.397	0.552
HF	0.346	1,12 = 5.823	0.034 *	0.634	1,8 = 13.87	0.006 **	0.311	1,8 = 2.711	0.151
SD1	0.328	1,12 = 5.363	0.041 *	0.646	1,8 = 14.575	0.005 **	0.021	1,8 = 0.131	0.730
SD2	0.294	1,12 = 4.585	0.055	0.653	1,8 = 15.040	0.005 **	0.417	1,8 = 4.284	0.084

Legend: Heart rate (HR); root-mean square of successive differences (RMSSD); standard deviation of R-R intervals (SDNN); total power (TP); low frequency (LF); high frequency (HF); Poincare plot X–axis standard deviation (SD1); Poincare plot Y–axis standard deviation (SD2). * indicates $p < 0.05$ for model statistical significance. ** indicates $p < 0.01$ for model statistical significance.

Table 6. Linear regression of differential HRV values and obstacle course time.

	Change in HRV (Baseline to Post-Qualification)			Change in HRV (Baseline to Post-Training)		
Dependent	**r²**	**F**	***p***	**r²**	**F**	***p***
HR	0.024	1,8 = 0.194	0.671	0.002	1,8 = 0.000	0.968
RMSSD	0.233	1,8 = 2.435	0.157	0.438	1,8 = 4.669	0.074
SDNN	0.205	1,8 = 2.060	0.189	0.133	1,8 = 0.924	0.373
TP	0.419	1,8 = 5.763	0.043 *	0.356	1,8 = 3.314	0.119
LF	0.535	1,8 = 9.188	0.016 *	0.023	1,8 = 0.143	0.718
HF	0.113	1,8 = 1.015	0.343	0.617	1,8 = 9.652	0.021 *
SD1	0.233	1,8 = 2.433	0.157	0.439	1,8 = 4.705	0.073
SD2	0.183	1,8 = 1.796	0.217	0.211	1,8 = 0.279	0.616

Legend: Heart rate (HR); root-mean square of successive differences (RMSSD); standard deviation of R-R intervals (SDNN); total power (TP); low frequency (LF); high frequency (HF); Poincare plot X–axis standard deviation (SD1); Poincare plot Y–axis standard deviation (SD2). * indicates $p < 0.05$ for model statistical significance.

4. Discussion

The aim of this study was to document and explore HRV and HR measurements in a cohort of SWAT personnel. ECGs were obtained at baseline, following firearms qualification, and following a firearms training exercise. An analysis of the resultant HR and HRV values with respect to the consideration of time to completion on an anaerobically demanding occupational obstacle course was undertaken. Like the obstacle course, the training following qualification was also highly anaerobically taxing. No statistically significant differences were found between the baseline and post-qualification values (Table 1). However, there were significant differences identified between the baseline and post-training values (Table 1). Given the differences in physical exertion required for the training event relative to the qualification task, this finding is not unexpected. What was potentially unanticipated was the decrease in HR at the post-qualification measurement from the baseline measurement. As baseline measures were obtained before individuals were officially on duty, and while seated quietly, it may have been reasonable to expect this measure would exhibit the lowest HR. While sample attrition may explain some of these unexpected findings along with the high variance at baseline (SD 124 bpm), it is also plausible that anticipatory stress contributed to the higher HR at baseline relative to the other two conditions, despite the increase in physical activity during qualification and particularly during training [52,53]. This hypothesised explanation may also be supported by the high variance in years of experience; more experienced operators may have perceived less pressure than newer operators. Likewise, the decrease in HR following qualification may have signalled resolution of uncertainty, with operators knowing their position on the team had been secured.

4.1. SWC Analyses

While underpowered given the small sample size, when operators were stratified into two subgroups at the 50th percentile with respect to the obstacle course time, there were notable differences between subgroups. These differences were observed at baseline, at post-qualification, and at post-training, despite further loss of sample size across time points. However, not all measures of HRV identified a SWC across all measurement time points. Critically, the SDNN index and non-linear SD1 index did indicate SWC across all measurement time points. Therefore, while caution in interpretation is still necessary, with small cohorts and in tactical settings, these time and non-linear domain measures may be most preferable.

4.2. Regression Analyses

The SWC analyses were supported by linear regression modelling. When assessing the extent to which the raw HRV data were predicted by the obstacle course time, models consistently indicated that a faster obstacle course completion time would result in higher HRV metrics across time, frequency, and non-linear domains. Greater HRV metrics generally indicate a greater capacity for adaptive response and exchange between the sympathetic nervous system, parasympathetic nervous system, and other cardioregulatory inputs [21]. This finding agrees with the previous literature indicating that greater aerobic fitness results in greater HRV broadly [18], but it should be noted that the relationship between aerobic fitness and HRV in tactical populations specifically remains uncertain [31]. It may be possible that high anaerobic fitness is more closely linked with HRV.

Even with the sample size limitations, statistically significant linear regression models arose both from the raw data and the calculations of change in HRV, from baseline to post-qualification and post-training. Regarding the post-training data specifically, the change in HF HRV from baseline to post-training was statistically significantly predicted by obstacle course time. The HF range of the frequency domain approach to HRV calculation is associated with stress levels and respiratory activity [54,55]. It spans from 0.15 to 0.4 Hz, and may closely trend with aerobic capacity in the general population and increase in magnitude with elevated parasympathetic nervous system activity [21]. However, frequency-domain approaches to HRV assessment may be volatile and should be interpreted cautiously, particularly in small cohorts [48,56].

Notably, the models predicting change in HRV from obstacle course time indicated a relationship that was inverse from the raw data models. A faster obstacle course time predicted greater reduction in HRV metrics following qualification and following training. The baseline data may explain this phenomenon: given the already low HRV metrics in the bottom 50th percentile at baseline compared to the top 50th percentile, the decrease in HRV metrics following qualification and then following training was necessarily minimal. Conversely, those in the top 50th percentile began with much higher HRV metrics and thus a greater magnitude of change was possible. Indeed, the study by Mongin et. al found that individuals with greater cardiorespiratory fitness initiates exercise with a greater HRV as a result of increased vagal tone. They also exhibited a faster subsequent decrease in HRV when their heart rates increased during exercise due to the faster vagal withdrawal response to activity [57]. While personnel with greater anaerobic fitness, as measured by the occupational obstacle course, deviated more from their own baseline HRV values during activities demanding cognitive and fine motor aptitude (firearms qualification), they had a greater margin relative to less anaerobically fit peers. Further research may consider whether this 'HRV reserve' and vagal withdrawal rate can be linked with protection from allostatic load.

4.3. Strengths and Limitations

Another advantage of HRV analysis over HR analysis alone is the integration of stress sources beyond the purely physical. HRV is sensitive to influences, such as respiratory activity, that may often be modulated under stress [2]. Previous research has described changes in HRV in personnel undergoing marksmanship tasks that lacked a physically demanding component [23]. The results reported here support the premise that HR alone is likely insufficiently sensitive to provide detail regarding the association between aerobic fitness and performance during vital law enforcement tasks that incorporate physical stressors and cognitive load in austere or otherwise challenging conditions. Indeed, some previous research describes strong relationships between heart rate and marksmanship performance [40,58], while other studies do not [59]. HRV analysis may be key to reconciling these differences in the literature, though further investigation is warranted.

This study supports the premise that enhanced fitness may benefit SWAT personnel [60,61]. In terms of practical application, performance on the obstacle course, and thereby proficiency with respect to short-duration, high-intensity tasks, influences HRV changes from the baseline during primarily cognitive/fine motor tasks with high emotional stakes, but without a high physical workload (HR was only 87 bpm on average following qualification) and is therefore a more effective metric for calibrating demands experienced by SWAT personnel. While it cannot be inferred from these present results alone, it may be possible that enhancing short-duration, high-intensity performance may be a strategy to support autonomic regulation during stress exposures, and thereby enhance firearms proficiency [62]. Example activities may include training procedures similar to those of this study, in which an anaerobic activity is combined with an occupationally relevant task that requires fine motor control for successful execution [63]. Other potential scenarios may include simulated casualty evacuations, forced entry tool practice, or other physical and occupational tasks that rely on strength and power [64,65].

Further research in SWAT units specifically, but law enforcement generally, is necessary. The results reported here are largely preliminary, and, as such, are not without limitations. Chiefly, a number of variables that may influence HRV could not be accounted for in this study. These factors include withheld anthropometrics and basic medical data, as well as sleep status, dietary intake, and hydration, as it was intended to be a purely observational analysis. Indeed, highly controlled data collection would be of limited use to the organisation whose personnel must operate in uncontrolled conditions, and if HRV did not demonstrate utility outside of the laboratory, it would not viably serve the organisation. While these results do appear promising, the overall conclusions drawn must be conservative.

5. Conclusions

This study explored heart rate (HR) and heart rate variability (HRV) in SWAT personnel across different stages of their training. Significant changes in HRV were observed between the baseline and post-training, indicating that HRV can be utilized to detect physiological changes associated with intense physical exertion and stress. These findings suggest that HRV, especially time and non-linear domain measures like SDNN and SD1, could be useful in evaluating the readiness of SWAT personnel and their stress adaptation capacities, even in small cohorts. Moreover, personnel with faster obstacle course completion times tended to sustain higher HRV, highlighting the importance of anaerobic fitness in tactical settings. This study is not without limitations, however, such as the small sample size and uncontrolled variables like sleep and diet, which should be considered in further research in this area. Despite these limitations, the results point towards the potential utility of HRV analysis in law enforcement training, particularly when combined with high-intensity physical tasks that mimic real-world conditions. Law enforcement trainers may benefit from this research; incorporating HRV as opposed to HR alone may prove to enhance training practices by providing additional information regarding relationships between occupational fitness and performance, while also enhancing performance stratification efforts.

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