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Heart Rate Variability Profile Changes Associated with Specialist Police Selection Activities: A Case Study

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ABSTRACT

BACKGROUND: Police Tactical Groups (PTGs) are specialist police units tasked with rigorous physical and psychosocial duties. Consequently, selection courses (SCs) for service in these units must also be rigorous. Given the intensity of SCs, holistic monitoring for potential overstress may be beneficial. Heart Rate Variability (HRV) is one holistic stress measure that can be obtained in austere environments. OBJECTIVE: The purpose of this study was to profile HRV during a PTG SC. Six (n=6) qualified male police officers attempted a 36-hour PTG selection course held at an Australian state facility. METHODS: HRV was obtained from Equivital™ EQ02+ LifeMonitor bioharnesses. The selection course consisted of physically demanding events with minimal sleep (approx. 45 mins). Only one candidate completed the full selection course; whose results are reported here. RESULTS: A visual time-series of 384 consecutive 5-min HRV analyses was generated. Contextual analysis was applied to appreciate HRV changes between SC serials. HRV decline occurred during the planning of a navigation exercise and a pack march. Increases in HRV were observed throughout the pack march exercise and rest period. CONCLUSIONS: This case study demonstrates the potential utility for selection personnel to obtain additional insight into candidate responses to various occupational challenges throughout an SC. Information provided by HRV monitoring may support leadership decisions when evaluating personnel holistically. For example, the ability to continue occupational task execution even while experiencing potential overstress (as measured by HRV) and after food and sleep deprivation is desirable. HRV may potentially inform stakeholders regarding overstress in PTG candidates.

KEYWORDS

biomarkers; data visualization; stress; fatigue; risk management; exercise; occupational health

1. INTRODUCTION

In Australia, Police Tactical Groups (PTG) are specialist units within State services tasked with a wide scope of duties that include search and rescue, counterterrorism, explosive ordnance disposal, high risk warrant service, response to active shooters, and illicit material transport interdiction (1). Because of the breadth and intensity of occupational tasks, the selection courses (SCs) that screen individuals for service in PTG units must be commensurately rigorous. These SCs integrate as many relevant occupationally derived challenges as possible to rapidly ensure selected personnel can be prepared for the realities of PTG service (2, 3). While necessarily physically demanding, other key competencies, such as the ability to perform effectively under states of intense pressure or fear and perform despite sleep or food deprivation, possibly in combination with extreme climate exposure (e.g., heat and humidity), are also evaluated (1, 4). Because these qualities are not necessarily exclusive to domains of physical performance or fitness, consideration of metrics sensitive to psychosocial influences may provide additional value to selection staff interested in holistic assessment of candidates (5, 6). Heart Rate Variability (HRV), the computational analysis of moment-to-moment changes in heart activity imposed primarily by autonomic nervous system (ANS) activity, has been demonstrated as a useful technology in the assessment of tactical personnel for assessing cognitive load and demand faced in high-stress environments (7-10). Wearable technologies have allowed for high-fidelity electrocardiogram (ECG) monitoring of ambulatory personnel in a wide variety of occupational contexts, including tactical environments (6, 11). Further, the provision of an objective holistic monitoring framework, potentially including HRV, may reduce bias in the selection of candidates. Some of these devices, such as the Equivital system utilized in this study, also demonstrate adequate comparability to the 'gold standard' Holter monitor for ECG, achieving low (<20%) to medium artefact percentages (<50%) (12).

The purpose of this case study was to illustrate the psychophysiological data (HRV) of a PTG SC candidate obtained from the aforementioned 2-Lead ECG wearable device. This case study includes consideration of the detailed HRV interpretation of the only individual (out of 18 candidates) to

successfully complete a PTG selection course from two common HRV indices. Further consideration is given to the process by which personnel supporting tactical units with HRV analysis may transform data into approachable and actionable information for decision makers.

2. METHODS

This study was conducted at a State PTG facility in Australia in Autumn of 2022. Environmental temperatures ranged from 24.2 – 34.4°C and the relative humidity ranged from 60 – 75%. An initial cohort of 18 personnel were inducted into a one-day physical training selection process. This one-day course was primarily a screening for physical fitness and capacity. Attrition was high, resulting in only six of those 18 progressing to participate in an additional two-day selection course. All personnel eligible for the two-day selection course were eligible for participation in this study and were successfully recruited. There were no exclusion criteria. The two-day course consisted of multiple physical training and physically demanding activities, as well as essential specialist police task training and assessment. Activities included variations of circuit training, orienteering, firearms manipulation, threat de-escalation, load carriage, and casualty evacuation. Further details of the SC serials can be found in Table 1. The timing of changes in serials was documented to the nearest tenth of a second, then rounded to the nearest whole minute utilizing an Apple watch (Apple, California, USA) and paired smartphone (iPhone 13, Apple, California, USA). Only one candidate, the present reported case, completed the entirety of the two-day selection course and was approved to proceed to the next stage of selection. The ECG data presented in this report began at approximately 0700 and ended at the completion of the selection event at approximately 1530 the next day. All candidates were involved in training activities from approximately 0600 the first day and continuously through the night into the final day of selection. The missing data period from approximately 0600 to approximately 0700 was due to signal noise; this section was discarded to improve fidelity of the HRV measurements.

85

86 *2.1 Subjects*

87 Candidates were briefed first by the research team and then again by the assessment staff regarding the
88 voluntary nature of participation; candidates were informed that participation was for the benefit of
89 their organization, and that no compensation was to be provided for participation. Further, no penalties
90 or influence on the outcome of their selection would be imparted by the decision to participate in this
91 research. All procedures were conducted in accord with the Declaration of Helsinki of 1964 and its later
92 amendments (13). Candidates provided their informed written consent, and the PTG unit provided
93 permission for publication of this work. The research protocol was approved by the Bond University
94 Human Research Ethics Committee (BS02165 amendment 1). Individual anthropometric data are not
95 available as per a privacy agreement with the host organization. However, the summarized data for all
96 six candidates enrolled in the study can be found in Table 2. This table includes anthropometric data
97 that could be provided, load carriage data, and aerobic fitness data. The aerobic fitness data (multistage
98 fitness test; MSFT) was obtained during the 1-day selection assessment. For this study, height was self-
99 reported; self-reported anthropometrics have been found to be reliable in research in previous
100 literature in law enforcement populations (14). All anthropometric values for the present reported case
101 fall within the described ranges found in Table 2 to provide context.

102

103 *2.2 Procedures*

104 All candidates were supplied Equivital™ EQ02+ LifeMonitor (Equivital, Hidalgo, UK) wearable monitoring
105 harnesses to capture ECG data throughout the selection course. Each harness was individually fitted to
106 the level of each candidate's xiphoid process. This fitment ensured ECG contact points were secured to
107 the candidate in the correct position. Physiological measures were observed through accompanying
108 software (EQ View Pro, Hidalgo, UK and LabChart 8 Pro, ADInstruments, Sydney, Australia). Data were

obtained from the harness after the conclusion of the SC. HRV measurements were considered 'short-term' in this investigation, utilizing 5-minute traces analysed every 5-minutes for the duration of the course. This process allowed for the greatest possible resolution (i.e., the most detail on changes from series to serial) without sacrificing validity. While shorter (as low as 30s) HRV measurements have been utilized in previous research, the traditional 5-min window was utilized for this study given the austere conditions in which data was collected and potential for signal artifacts (12, 15). The wearable device utilized in this study correlates well with the 'gold standard' Holter ECG, but only when artifact levels are low (<20%) (12). Therefore, additional signal length to reduce the likelihood of excessive artifact presence was opted for *a priori*. While many HRV metrics are reported in the literature, this investigation primarily considered the time-domain metrics of pRR15 (percentage of adjacent R-R intervals varying by at 15ms) and root-mean square of successive differences (RMSSD). Time domain metrics are easily approachable by end-users, such as an on-site exercise physiologists or strength and conditioning professionals, as well as the candidate assessment team.

2.3 Analyses

As the current report is of only a single longitudinal case, descriptive statistics only regarding HR, pRR15, and RMSSD values throughout the event were generated; no inferential analyses were appropriate. Both HR and HRV were assessed every five minutes yielding 384 consecutive short-term HR/HRV values. These values were plotted by time, generating a visual HR and HRV time-series. Contextual analysis was applied to the time-series. Specifically, the selection course events and subjectively observed disposition of the candidate were documented periodically throughout the duration of the course by the lead author. Focus was given to key points in the recording timeline that might provide additional insight and information regarding the interpretation of individual HRV data. The contextual analysis process began by visually identifying deviations in the expected oscillating HRV pattern without information on which

serials were conducted at those time points to minimize bias in the analysis. Large magnitude fluctuations in HRV potentially signal overstress or excessive exertion if no commensurate increase in HR is seen, as occurs with exercise (6). Next, these anomalous HRV regions were compared against the SC serial and subjective observations of the candidate, as well as the assessment staff opinion of the candidate at the time of the disruption in HRV. Finally, any training activities or subjective observations not yet considered were included and the final visual HRV description was generated. The composite of these three steps is presented in both Figures 1 and 2, and again, further detail of the individual serials can be found in Table 1.

3. RESULTS

Figures 1 and 2 illustrate the finalized graphical descriptions of the fluctuations in HR and HRV throughout the entirety of the selection course. Table 1 contains the details of each selection course serial, the start time of the serial, and the mean and standard deviation of pRR15 and RMSSD for that event. Regarding HR (Figure 1), while some fluctuation is noted, values generally ranged between 70 beats per minute (bpm) and 150 bpm, or the equivalent of moderately intense exercise and rest (16). Specific details can be found in Figure 1. Regarding HRV, an initial decrease and low trough in values is noted at approximately 0938 through 1023 (lowest mean RMSSD; written examinations; 30.99±22.50). During this time, the candidate was travelling to, planning, and then commenced a land navigation field exercise (Figure 1, shaded region 1). A second decrease and trough is noted from approximately 1842 – 1912 hours. The candidate was again preparing for and initiating activity, at this point a sustained pack march (Figure 1, shaded region 2, RMSSD = 91.36±42.66). The change in RMSSD and pRR15 values throughout the day were of particular interest. This is because the only opportunity for rest in the 36-hour course commenced at approximately 0520 hours and lasted until approximately 0600 hours (highlighted in green on, Figures 1 and 2, shaded region 4, RMSSD = 87.45±44.78). A modest increase in

157 the percentage of pRR15 intervals and RMSSD can be seen during the rest period, along with a
158 commensurate decrease in HR. A less-lethal explosive device producing a bright flash and loud sound
159 was deployed adjacent to the candidate's sleeping area at approximately 0600 hours (Figure 2, shaded
160 region 5). A severe and immediate decrease in percentage pRR15 intervals is noted at about that time,
161 highlighted in the orange (shaded region 5, Figure 2). However, RMSSD did not also exhibit this change
162 (Figure 1). The candidate appeared to recover from this stressor and proceeded with physical training
163 activities until approximately 0800 hours, when a fear-of-heights test was conducted (Figures 1 and 2,
164 Shaded region 6). This event involved tactical police maneuvers at various heights, up to several stories
165 above ground. This again resulted in decreased HRV. The specific values of minimum and maximum
166 percentage of pRR15 intervals, along with other descriptive statistics, can be found in Table 3.
167
168 4. DISCUSSION
169 The aim of this case study was to illustrate the outcome of HRV monitoring during PTG selection. PTGs
170 select for personnel that are highly physically competent, but also resilient to cognitive and emotional
171 stressors, sleep and food deprivation. Further, PTGs also aim to select those who work effectively as a
172 team in austere conditions. Based on the results described in this study, HRV monitoring may support
173 PTG selection by providing objective information on overstress and adaptation to an otherwise
174 subjective process.
175
176 In general, lower percentage of pRR15 and lower RMSSD both indicate less variation in heart rate for the
177 assessed time window, and therefore decreased adaptive external and internal environmental
178 responses. This may in turn signal excessive psychophysiological stress (17). Overall, the HRV profile
179 indicates potential overstress periods, but also the ability to recover or continue functioning despite
180 potential exhaustion. The candidate was able to proceed through each selection serial without

succumbing to fear or exhaustion. Important to note when reviewing these findings is the potential pitfall in HRV interpretation of viewing values dichotomously; that is, the implication that a result is either 'high' or 'low' and therefore either 'good' or 'bad' (18). The reality that is visually demonstrated by this case is that HRV is necessarily oscillatory (19, 20). Indeed, this case potentially agrees with the 'U-shape' distribution of illness risk for HRV values described in the psychiatric literature (21). Essentially, prolonged values at either extreme of any HRV metric are potential indications of failure to adapt and respond dynamically to external and internal environments. This is especially true if those environments are subject to abrupt and frequent change (6, 21), such as tactical police selection. Indeed, the objective is to expose personnel to as many varieties and intensities of stressors as can be permitted within the bounds of safety. A portion of the load carriage activity, spanning much of the evening on Day One (approximately 5 hours from 1900 – 0000, shaded region 3), is a prime example. An interpretation of pRR15 or RMSSD values without sufficient nuance would lead to the conclusion that the candidate was in optimal health and performance status during this window – pRR15 values remain between 70 and 90% during this time (RMSSD = 242.21±17.49). However, the reality is that the candidate was undergoing a highly rigorous task, initiated with minimal rest, minimal calorie intake, and the added psychological stress of an unknown end point for the task. Therefore, this potentially excessive variability may best be viewed in the context of research on both cognitive load and progressive exercise testing. These findings generally report overactivity of the parasympathetic nervous system during periods of heightened exertion, which would be consistent with highly elevated pRR15 values (22, 23). This finding from the present data is further supported by the HR data, in which the HR is not elevated, but rather depressed during this time window, when an elevated HR would be expected. Depressed HR during exertional tasks potentially also signals exhaustion (Figure 1) (24). Therefore, the end-user should interpret this section carefully and with understanding of the relevant context. If this individual was indeed reaching exhaustion, the extent to which it manifested externally was limited. As such, the

objective HRV data coordinated with subjective observation indicate a strong capacity to suppress discomfort and achieve the occupational aim, a highly desirable quality in PTG personnel.

The particularly depressed HRV values during the preparatory phases of the land navigation field exercise (Figures 1 and 2, shaded region 1) and pack march (Figures 1 and 2, shaded region 2) are also of interest as little physical activity was occurring, supported by both the HR data and observation of the candidates. Therefore, anticipatory stress may have contributed to the decrease in values. Additionally, the trough noted during fear of heights training (approximately 08:10-08:45 on Day Two) indicates that despite the other rigorous and challenging events conducted later that day, the candidate's strongest psychophysiological response as measured by pRR15, and perhaps period of greatest sympathetic activity, was during the fear-of-heights test (Figure 2, shaded region 6). However, again, the candidate was subjectively not demonstrating any externally visible signs of distress. The value of the objective HRV measurement that does indicate high stress further supports this candidate as an individual that is able to overcome the 'fight or flight' response and continue functioning. Other notable examples of high stress events that did not elicit such strong responses as measured by HRV include threat de-escalation simulations (approximately 11:05-11:10, Figure 2, shaded region 7) and tactical police scenario maneuvers (15:21-15:35, Figure 2, shaded region 8), indicating that potentially no excessive stress response occurred despite the intention of the instructing staff to do so. This feedback may also be beneficial for the design of future selection courses. The possible exception to this conclusion can be found at the period highlighted in orange from approximately 18:42 through to approximately 19:12 on the initial day of the selection course. This period was the only point of the entire selection course where the participant dropped to near zero pRR15 (min value 0.71%) and may be as a result of combined fatigue from earlier events during the first training day and the above-mentioned anticipatory

stress surrounding the load carriage event (18:50-23:23 on Day One) which was known to have a high attrition rate.

4.1 Limitations

The data captured for this case study were not without noise. While the recording windows were sufficiently long enough to eliminate the effects of ectopic and erroneous potential R-R intervals, the potential for confounding cannot be ignored. The region with the most noise was the discarded section of data from 0600-0700 on Day One, which may have provided additional information on this candidate's response to heavy exercise before fatigue onset occurred. Future studies may consider real-time monitoring to intervene when excessive noise events occur. Additionally, the serials were not of equal length, and therefore the mean and standard deviation values of pRR15 and RMSSD are difficult to compare. Finally, the collection of baseline data before the beginning of the SC in a controlled environment (such as an air-conditioned indoor space), and of the candidate's recovery following the SC, would provide further value and context.

5. CONCLUSIONS

This case study demonstrates the potential utility for selection personnel to obtain additional insight from HRV data into candidate responses to various occupationally relevant challenges throughout a selection course. This information may support leadership decisions when evaluating personnel holistically for service in extremely demanding professions such as PTG units. The ability for personnel to recover quickly with limited rest, continue performing even under potential overstress (such as when afraid of heights) and continue to display adaptive response after food and sleep deprivation are valuable traits in specialist police. Provision of visual aids for the interpretation of HRV data may also be useful for stakeholders using HRV data for decision making. While additional studies are needed that

assess multiple cohorts of personnel, both successful and unsuccessful, the consideration for HRV as an element in the personnel selection matrix to assess the overall suitability of a candidate for service in PTG units is warranted.

ETHICAL APPROVAL

The study was conducted in accordance with the Declaration of Helsinki and approved by the Bond University Human Research Ethics Committee (BUHREC) (Protocol 2019-022 amnd 2).

INFORMED CONSENT

Written informed consent was obtained from all participants involved in the study.

CONFLICT OF INTEREST STATEMENT

The authors report there are no competing interests to declare.

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DATA AVAILABILITY STATEMENT

Requests for data can be made to the corresponding author but will only be provided once approval has been granted by the law enforcement agency involved in this study.

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337 Table 1. Description of Selection Course Serials, Start Time, and RMSSD descriptive data

Serial	Description	Start Time (Duration)	Mean HR (bpm)	pRR15 (%)	RMSSD (mean ± SD, ms)
Briefings and equipment issue	Candidates were briefed on expectations and role of the PTG. Standardized equipment was provided and any individual items were inspected for approval.	0705 (1:50)	103±12	27.28±11.12	44.7±38.9
Written examination	Multimodal assessment of land navigation (orienteering) principles.	0850 (0:25)	94±3	28.85±5.34	30.99±22.50
Administration	Mobilization, review and further explanation of expectations for the land navigation exercise.	0930 (0:35)	104±14	30.71±10.42	91.36±42.66
Land Navigation Preparation	Candidates were provided time to plan their routes and mark their maps before embarking.	1005 (0:20)	116±13	18.44±4.68	166.88±58.56
Land Navigation Exercise	Orienteering assessment of navigation over various terrain using only a supplied map, compass, and grease pencil.	1018 (5:00)	117±13	28.99±11.67	91.34±49.70
Administration	Mobilization, hands-on assessment and written safety/proficiency check.	1547 (2:50)	92±5	38.06±16.26	138.56±131.82
Load Carriage/Pack March	Various load carriage and transportation of stores at self-selected pace. Candidates proceeded for undisclosed time/distance.	1850 (10:30)	112±16	39.67±30.21	144.22±98.56
Rest	Candidates were permitted to eat, sleep and change clothing/equipment as needed.	0520 (Day 2) (0:40)	78±8	52.31±9.18	87.45±44.78
Less-lethal device deployment	Less than lethal device that produces bright	0606 (Day 2)	109±3	25.53±13.26	140.41±44.28

	light and sound was activated adjacent to the sleeping area.				
Physical Training	Circuit training consisting of various weightlifting, calisthenics, and plyometric activities.	0626 (Day 2) (1:35)	115±7	50.31±15.94	247.56±85.99
Fear of heights evaluation	Perform various activities at various heights, up to several stories above ground.	0800 (Day 2) (1:20)	121±11	33.51±17.56	195.07±79.74
Physical Training	Candidates engaged in additional physical challenges.	0922 (Day 2) (1:40)	119±10	52.16±23.22	248.15±81.84
Threat de-escalation simulation	Candidates were given an operational scenario.	1105 (Day 2) (0:10)	111±2	36.82±0.70	95.12±1.08
Tactical police occupational scenario	Candidates were tasked with scouting a region on foot.	1246 (Day 2) (1:40)	100±9	38.99±13.90	125.32±52.67
Tactical police occupational scenario	Candidates were given an operational scenario.	1521 (Day 2) (0:20	128±16	44.07±22.10	242.12±49.84

Legend: HR: Heart rate, bpm: beats per minute, pRR15: percentage of R to R intervals varying by at least 15ms, RMSSD: root-mean square of successive differences, SD: standard deviation.

Table 2. Anthropometric, Load Carriage and Fitness data of Australian PTG Candidates

Value	**Body Mass (Kg)**	**Height (cm)**	**Age (Years)**	**Land Nav Equipment Mass (Kg)**	**Pack March Equipment Mass (Kg)**	**BMI**	**MSFT (Total shuttles)**
Mean	93.63	180.17	30.67	12.24	11.95	28.88	84.17
SD	8.83	5.98	2.94	0.14	1.32	2.92	7.22
Median	94.78	181.00	31.00	12.24	11.96	29.22	81.00
Range	20.50	21.08	14.00	8.00	0.20	8.47	1.9

Legend: body mass index (BMI), multistage fitness test (MSFT). Range is reported as the difference between maximum and minimum values.

345 Table 3. Descriptive Values of HRV and HR

	Recording Duration	Mean	Median	SD	Maximum	Minimum
Heart Rate (beats per minute; bpm)	32:27:56 (hr:min:sec)	109.54	109.42	14.78	146.00	69.57
pRR15 Value (Percentage)	32:27:56 (hr:min:sec)	36.04	31.78	20.71	96.83	0.71
RMSSD Value (ms)	32:27:56 (hr:min:sec)	154.53	142.88	91.17	380.98	11.78

346 *Legend: SD: standard deviation, pRR15: percentage of R to R intervals varying by at least 15ms, RMSSD:*
347 *root-mean square of successive differences*
348

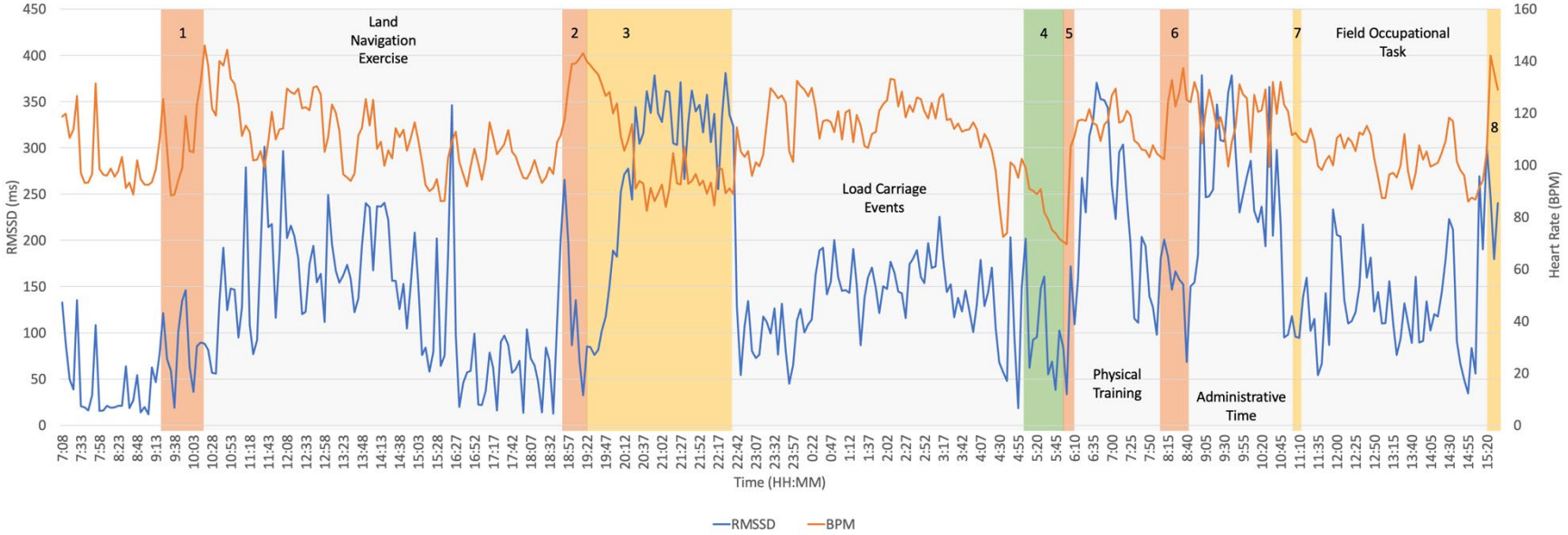

Figure 1. RMSSD HRV and HR Illustration.

Legend: RMSSD: root-mean square of successive differences, HRV: heart rate variability, HR: heart rate. 1. Travel to and planning of navigation exercise; 2. Pack march planning; 3. Pack march exercise; 4. Rest period; 5. Less-lethal device deployment; 6. Fear of heights evaluation; 7. Occupational Scenario; 8. Tactical Police Occupational Scenario. Events within the shaded light grey areas are described within the figure.

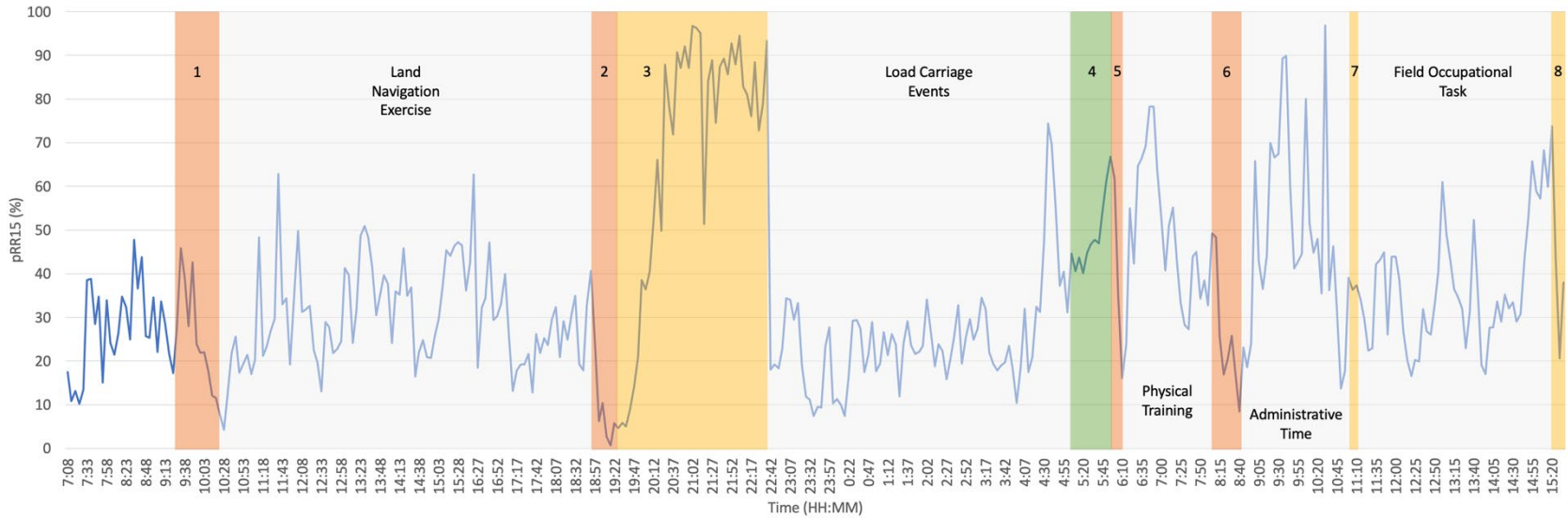

Figure 2. pRR50 HRV Illustration.

Legend: pRR15: percentage of R to R intervals varying by at least 15ms, HRV: heart rate variability. 1. Travel to and planning of navigation exercise; 2. Pack march planning; 3. Pack march exercise; 4. Rest period; 5. Less-lethal device deployment; 6. Fear of heights evaluation; 7. De-escalation simulation; 8. Tactical Police Occupational Scenario. Events within the shaded light grey areas are described within the figure.