Relationship Between Heart Rate Variability Outcomes vs. Occupational Performance, Physical Activity, and Fitness Measures in Firefighters

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Abstract

PURPOSE: The purpose of this study was to determine the relationship between heart rate variability (HRV) versus firefighter occupational performance, fitness characteristics and physical activity measures. **METHODS**: Twelve male structural firefighters (Age: 37.3±7.6 yr; Height: 183.2±7.1 cm; Body mass: 90.4±13.7 kg; Body mass index: 26.9±2.4 kg·m^{-2}) wore an accelerometer for 19.1±5.8 days to measure physical activity levels. Physical activity was also quantified by a self-reported log. HRV was determined with a portable ECG device upon waking for 20.8±4.6 days. HRV was assessed daily, upon waking, and included SDNN, RMSSD, high frequency (HF) and low frequency (LF) components. Firefighters also completed a simulated fire ground test (SFGT) as well as a battery of fitness tests including an estimate of 1-repetition maximum shoulder press, deadlift, bench press, bentover row and kettlebell swing (muscular strength) and a submaximal prediction of aerobic capacity (aerobic fitness). HRV was assessed the day of the SFGT (acute) and averaged over all days (mean HRV). Pearson Product Moment Correlation coefficients were calculated between HRV vs. performance, fitness, and physical activity variables. The level of significance was set at p < .05. **RESULTS**: SDNN values recorded the morning of the SFGT were correlated with SFGT time on 3 individual SFGT tasks (r=-.70 to -.75, p<.05) and overall SFGT time (r=-.74, p=.016). Mean HF was correlated with frequency of moderate-to-vigorous physical activity (r=.73, p=.011). Mean RMSSD and SDNN were also correlated with shoulder press strength (r=.89, p<.01; and r=.88, p<.01 respectively) and bench press strength (r=.78, p=.008; and r=.76, p=.011 respectively). **CONCLUSIONS**: Acute HRV was correlated with better occupational performance, whereas mean HRV was associated with physical activity and strength measures. These outcomes indicate that HRV parameters may reflect the physiological status of firefighters and the complex interaction between HRV, physical activity and fitness outcomes.

Introduction

Firefighting is a dangerous and physically demanding occupation, requiring high levels of fitness [1, 2]. A paradox may exist between the training stimuli required to enhance functional adaptations and the resultant fatigue that may acutely reduce work efficiency [3]. Practitioners are often left to speculate when an individual is physiologically prepared for the next training workload. Omegawave, Ltd. (Espoo, Finland), provides a non-invasive comprehensive assessment of the individual's preparedness for training loads and physiological responses to previous activity. The Omegawave system measures heart rate variability (HRV) and direct current (DC) potentials produced by the brain to assess the functional state of the cardiovascular and central nervous systems, respectively [4]. Specifically, HRV indices (low frequency: LF, high frequency; HF, & LF/HF) have been shown to be altered due to acute changes in aerobic training load and reflect the state of the autonomic nervous system[5, 6].

Omegawave is marketed as a tool that provides an indicator of stress level, resistance, adaptational changes, compensation abilities, cost of adaptation, and adaptability in general. Athlete monitoring via HRV may be an indicator of future performance. It is suggested that DC potential represents short- and long-term adaptational changes that occur in response to any stressors [4, 7]. LF is related to both sympathetic and parasympathetic modulation whereas the HF band is indicative of parasympathetic effects[8]. LF/HF power can be used as an indicator of sympathetic-parasympathetic balance [8]. Reduced HRV is associated with reduced cognitive and emotional ability [9]. Firefighting and non-occupational stressors are mentally and emotionally stressful and this cannot be overlooked as these external factors can negatively impact performance and elevate injury risk [10, 11]. It is critical to understand how training stimuli affect firefighters' readiness to perform work in an effort to maximize functional adaptations while minimizing residual fatigue. Monitoring firefighters to reduce the risk of overtraining and overexerting themselves especially on days that they work is imperative to public safety as well as their own. The purpose of this study was to determine the relationship between HRV versus firefighter occupational performance, fitness characteristics and physical activity measures.

Methods

Experimental Design

The study followed a longitudinal design during which HRV was tracked for 20.8±4.6 days and physical activity was tracked for 19.1±5.8 days. A convenience sample of 12 career structural firefighters (Age: 37.3±7.6 yr; Height: 183.2±7.1 cm; Body mass: 90.4±13.7 kg; Body mass index: 26.9±2.4 kg·m^{-2}) volunteered to participate in this study.

Physical Activity and Fitness Measures

The first two testing sessions included familiarization trials of the SFGT. Anthropometrics, aerobic endurance, and strength data were collected. Standing height was measured with a portable stadiometer (Road Rod 214 Seca, Hanover, MD, USA). Body mass was measured with an electronic scale (TBF-521, Tanita Corporation, Arlington Heights, IL, USA). Body composition was measured with a bioelectric impedance analyzer (BIA; Bodystat 1500, Ventura, CA, USA) and relative body fat was calculated using the manufacturer's prediction equation. To assess HRV, Omegawave Ltd. (Espoo, Finland) technology was used immediately upon waking. HRV outcomes used from the Omegawave device are displayed in Table 1. The Gerkin submaximal treadmill protocol was used to estimate peak oxygen consumption (VO_{2peak})[13]. Subjects completed a 5-repetition maximum (RM) test for bench press, deadlift, shoulder press, and 1-arm bent over row exercises. 1-RM was calculated using the Brzycki prediction equation [14]. Physical activity levels were measured with a triaxial accelerometer (GT3X, ActiGraph, Pensacola, FL) that was worn for four weeks as an objective measure of the intensity, duration, and frequency of the firefighters' physical activity while on- and off-duty. The accelerometer was fixed to a waistband or belt and positioned on the firefighters' right hip in the midaxillary line. Validated activity count thresholds were used to define sedentary, light, moderate, and vigorous physical activity intensities [15]. To enhance the validity of the accelerometer data, only data where the subjects wore the accelerometer for at least 10 hr·d^{-1} were used for analysis. Non-wear periods will be defined as periods of at least 20 consecutive minutes of zero activity counts. In addition, each firefighter was asked to keep a daily log to identify the general activities that were performed (e.g., work performed on-duty, resistance training, etc.). The accelerometer data were averaged across the days the monitor was worn for data analysis.

Simulated Fire Ground Test

Occupational performance was assessed using a simulated fire ground test (SFGT). The SFGT was designed in consultation with a content expert and the test-retest reliability of the SFGT was established using a series of 3 SFGT trials (ICC= .97; 2 familiarization trials and one official trial). The SFGT was performed with full personal protective equipment (NFPA, 1971; standard issued helmet, coat, pants, gloves, and boots). The total mass of the NFPA protective gear is approximately 22 kg [1]. All trials were performed using a self-contained breathing apparatus (SCBA; Scott Inc., Monroe, NC). The SFGT was composed of the following tasks performed in sequential order to simulate the order they would typically be performed on the fireground: stair climb, charged hose drag, equipment carry, ladder raise, forcible entry, search, and victim rescue. An overall SFGT time (s) and split times (s) were taken of each task with a stopwatch. During the SFGT physiological and psychological measurements were taken. Heart rate was measured via a monitor worn around the chest (Polar A1, Electro, Oy, Finland) and a receiver (ActiTrainer, Pensacola, FL, USA) worn in a neoprene sleeve around the upper arm. The average heart rate during the SFGT was calculated and used for data analysis. Blood lactate was measured at rest prior to the SFGT and 5 minutes following the SFGT. Rating of perceived exertion (RPE) was assessed immediately following the SFGT using a validated 0-11 category-ratio scale to indicate the overall feeling of fatigue from the entire test [16].

Statistical Analysis

Descriptive statistics were calculated as mean ± standard deviation and Pearson product moment correlation coefficients were calculated to determine if there were correlations between the HRV versus occupational performance, fitness characteristics, and physical activity data. The level of significance was set at p < .05.

Results

Several significant correlations between acute HRV (taken the morning of the SFGT) and SFGT performance are described in Table 2. SDNN was correlated with 3 of the individual SFGT tasks (hose drag: r = -.75; ladder raise: r = -.74; rescue task: r = -.70) as well as overall performance on SFGT (r = -.74). LFnu and HFnu were correlated to RPE following the SFGT (r = .88 & -.88, respectively). Regarding physical activity outcomes, HF was correlated to the average amount of moderate-to-vigorous physical activity (MVPA) (r = .73) as well as average vigorous minutes (r = .86), average moderate minutes (r = .63), average very vigorous minutes (r = .62) and total accelerometer activity counts (r = .70). Correlations between mean HRV indices and measures of fitness are displayed in Table 3. Mean HRV indices were correlated to measures of maximal strength. Average LF was related to bench press (r = .65) and shoulder press strength (r = .77). Average LFnu and HFnu were correlated with deadlift strength (r = -.65 & .65, respectively). Bench press strength was also correlated with average total power (r = .76), RMSSD (r = .78), SDSD (r = .78) and SDNN (r = .76). Shoulder press strength was correlated with average total power (r = .87), RMSSD (r = .89), SDSD (r = .89), LF/HF (r = .70) and SDNN (r = .88).

Table 1. Operational definitions for HRV outcomes.

Variable	Abbreviation	Definition
Low frequency	(LF)	Power in low frequency range 0.04–0.15 Hz, represents sympathetic activity. [ms^2]
High frequency	(HF)	Power in high frequency range 0.15–0.4 Hz, represents parasympathetic activity. [ms^2]
Low frequency	(LFnu)	LF power in normalized units. LF/(Total Power–VLF) x 100, n.u.
High frequency	(HFnu)	HF power in normalized units.
Total Power	TP	Variance of all normal-to-normal intervals ≤0.4 Hz. This reflects the overall activity of the regulatory system.
Root of the Mean Square of the Difference of Successive Intervals	RMSSD	The square root of the sum of differences of sequential series of cardiointervals. This represents parasympathetic activity. (ms)
Standard Deviation of Successive Differences	SDSD	Standard deviation of differences between adjacent normal to normal intervals. (ms)
Ratio between Low and High Frequency Components	LF/HF	Reflects the Sympathetic-Parasympathetic Balance. Ratio LF[ms^2] /HF[ms^2]
Standard Deviation Normal to Normal	SDNN	Standard deviation of the full array of cardio intervals. Reflects the total effect of autonomic regulation.
Stress Index		Level of tension in the cardiac system in response to total stress (physical and mental). (N/7)
Fatigue		The temporary state of the cardiac system that occurs during prolonged work that leads to a decreased efficiency (N/7)
Adaptation Reserves		A measure of how long and effective the cardiac system can to adapt to external stimuli. (N/7)
Central Nervous System	CNS	Readiness of the CNS determined via interpretation of DC potential activity. This measurement is within the frequency range of 0.0-0.5 Hz and is thought to provide an overall representation of the functional state.

(Morris 2015)

Table 2. Correlation matrix between acute HRV outcomes versus SFGT performance. * p<.05

	Overall	Stair Climb	Hose Drag	Equip. Carry	Ladder	Forcible Entry	Search	Rescue	RPE	Pre Lactate	Post Lactate
SDNN	-0.74*	-0.48	-0.75*	-0.37	-0.74*	-0.52	-0.59	-0.70*	0.26	0.24	0.35
RMSSD	-0.06	-0.01	-0.28	0.30	-0.21	-0.20	-0.04	-0.11	0.01	0.52	-0.09
LF	-0.31	-0.32	-0.34	-0.15	-0.41	-0.04	-0.19	-0.28	0.53	0.41	0.15
HF	0.13	0.15	-0.12	0.48	0.01	-0.24	0.13	0.04	-0.44	0.39	-0.16
LFnu	-0.29	-0.45	-0.16	-0.54	-0.20	0.22	-0.05	-0.26	0.88*	-0.36	0.47
HFnu	0.29	0.45	0.16	0.54	0.20	-0.22	0.05	0.26	-0.88*	0.36	-0.47

Table 3. Correlation matrix between mean HRV outcomes versus fitness data. *p<.05

	VO_{2peak}	Fat Mass	Lean Mass	1RM KB swing	1RM Bench press	1RM Deadlift	1RM Row	1RM Sh. press
LF	-0.17	0.19	0.21	0.42	**0.65***	0.27	0.42	**0.77***
LFnu	-0.42	0.25	0.14	-0.15	-0.11	**-0.65***	-0.19	-0.07
HF	-0.02	0.14	0.23	0.25	0.19	0.51	0.14	0.18
HFnu	0.42	-0.25	-0.14	0.15	0.11	**0.65***	0.19	0.07
Total Power	-0.07	0.11	0.04	0.37	**0.76***	0.15	0.53	**0.87***
RMSSD	-0.06	0.10	0.04	0.37	**0.78***	0.17	0.54	**0.89***
SDSD	-0.06	0.10	0.04	0.38	**0.78***	0.18	0.55	**0.89***
LF/HF	-0.26	0.25	0.21	0.22	0.62	-0.17	0.42	**0.70***
SDNN	-0.05	0.09	0.03	0.37	**0.76***	0.15	0.52	**0.88***
CNS	0.13	0.07	0.02	0.10	-0.39	-0.20	-0.36	0.00
Stress	0.38	-0.45	-0.57	-0.28	0.05	-0.09	-0.21	0.21
Fatigue	0.28	-0.35	-0.40	-0.17	-0.05	0.04	-0.17	0.09
Adaptation	0.32	-0.38	-0.42	-0.17	0.07	0.06	-0.18	0.23

Conclusion

In conclusion, mean HRV may be a useful tool for practitioners to see long term adaptations of training as well as to monitor the possibility of overtraining. Acute HRV may be an indicator of immediate occupational readiness, in addition to it's traditional role as an indicator of adaptability to training stimuli. In a firefighter population, HRV may be used to guide timely reductions in training stress and implementation of restoration strategies to prevent detrimental occupational performance and reduce the risk of maladaptation. Acute SDNN, a reflection of overall autonomic regulation was correlated with 3 of the individual tasks as well as overall performance on the SFGT, indicating that those with greater balance in their autonomic nervous systems performed better on the SFGT that day. Acute LFnu was directly correlated to RPE during the SFGT, suggesting that increased sympathetic activation was related to the perception of a more difficult test. Regarding physical activity outcomes, mean HF – a reflection of parasympathetic activity- was correlated to the average amount of moderate to vigorous physical activity performed. This may be a training adaptation from partaking in more physical activity or may suggest that physical activity is able to moderate firefighters' overall stress. Mean strength measures were also correlated with several indices of mean HRV, including RMSSD, SDSD and SDNN, suggesting that strength (or the training for strength) is related to a healthier autonomic nervous system in this population. HRV assessment may have applications to enhance firefighter health, fitness, safety and occupational performance.

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