Heart Rate Variability Recordings are a Valid Non-Invasive Tool for Evaluating Soldiers’ Stress

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Abstract
The purpose of the present study was to investigate physiological responses and to evaluate heart rate variability as a non-invasive stress indicator during a 72-hour military field training (MFT). Ten healthy male soldiers (age 20 ± 1 yr.) participated in MFT. They slept approximately 2 h/day and ate only army field rations. During MFT, the soldiers’ mean ±SD energy expenditure was 4646 ± 674, energy intake 2200 ± 326, and energy deficit (ED) 2405 ± 890 kcal·day−1. Throughout the entire training period, serum total testosterone (TES) reduced from 19.0 ± 3.0 to 12.6 ± 6.2 nmol·l−1 (p<0.001). Mean HR during the entire MFT was 85 ± 6 bpm. RMSSD, which reflects cardiac vagal activity, decreased from 54 ± 19 to 42 ± 12 ms (p<0.05). No changes (p>0.05) were observed in HF and LF power, but changes in HF power correlated with baseline serum TES (r=-0.72, p<0.05). Based on the present findings, working for 72 h at a relatively low level of cardiovascular strain with ED and sleep deprivation can individually modify hormonal responses in association with cardiac vagal outflow. This suggests that HRV can be used as a non-invasive tool to measure stress in soldiers during MFT.

Keywords
Hormone; Physiological stress; Military field training; Stress

Introduction
Modern military operations are still very physically demanding for soldiers. Although soldiers’ equipment has developed, the increased load of combat gear has resulted in greater physiological strain on individual soldiers [1]. To a dismounted infantry squad, this is a relevant part of daily life, as foot patrolling requires soldiers to carry all of their mission equipment and food in their backpacks. Investigation of the operational environment and physical loading affecting soldiers requires consideration of the multistressor environment [2,3].

Military operational stress generally consists of sustained physical and mental exertion combined with sleep and energy deprivation [3-5]. This has been shown to induce disturbances in hormonal sympathovagal balance, as indicated by increased susceptibility to infections, diminished physical and cognitive performance capabilities and longer recovery times [5-7]. Intense military field exercises have been reported to induce decreases in basal concentrations of circulating testosterone (TES) and free testosterone (TESfree) [8]. In military circumstances, dehydration is also a common phenomenon [9] leading to weakened physical performance [10]. In addition, soldiers often suffer sleep and caloric deprivations during military field exercises. These factors have also been shown to decrease physical performance [11-14].

Often it is quite difficult to measure a level of physiological strain. Therefore, new methods which are easy to use and to evaluate objectively overtraining or stress reactions during military service are warranted. Heart rate variability (HRV) is a relatively new method used to study physiological strain and body homeostasis via autonomic nervous system (ANS) activity [15]. In a military environment, it has been shown to be a practical tool for screening initial fatigue [5]. In particular, RMSSD (the square root of the mean of the squares of differences between adjacent R-R intervals) is the most frequently used time domain method in HRV analysis, and has been shown to reflect vagus-mediated HRV. Power spectral densities have been used to study cardiac vagal activity (HF, 0.15-0.40 Hz), sympathetic and vagal outflow (LF, 0.04-0.15 Hz), and sympathovagal interaction (LF/HF ratio) [16,17]. Recently, it has been shown in military environment that there is a relationship between changes in cardiac vagal regulation during a long-term mentally stressful condition and the serum TES-to-cortisol ratio [18]. Later, this finding was confirmed by demonstrating that individual changes in heart rate and HRV were strongly associated both with changes in aerobic fitness and with changes in anabolic hormone concentrations during the stressful military training [19].

The purpose of the present study was to investigate further associations between HRV and anabolic hormones in a more stressful condition. Thus changes in TES, TESfree, SHGB, and sympathovagal balance were studied during a 72-hour dismounted infantry squad. The unique part of this study was to associate TES and HRV data and the serum TES-to-cortisol ratio [18]. Later, this finding was confirmed by demonstrating that individual changes in heart rate and HRV were strongly associated both with changes in aerobic fitness and with changes in anabolic hormone concentrations during the stressful military training [19].

Methods

Subjects
Ten healthy male soldiers (age 20 ± 1 yr., height 1.79 ± 0.07 m, body mass 74.5 ± 7.9 kg, body fat 12.3 ± 1.7%) participated in a 72-hour dismounted infantry squad training. They were randomly selected from a larger group of volunteers, and they were informed of all test procedures. Subjects were physically fit maximal oxygen uptake, (VO2max 55.9 ± 3.8 ml·kg−1·min−1) and provided written informed consent to participate in this study. The present study was approved by the Ethical Committee of the University of Jyväskylä.

Military field training (MFT)
The day before MFT (0 day) consisted of lessons and short military drills in a garrison. MFT, which lasted 72 h, was a simulated two-
Results

Energy balance and body mass alterations

Mean EE during the 72-hour MFT was 4646 ± 674 kcal/day. Based on EE, the most physically demanding training phase was day 2 (5170 ± 603 kcal), whilst EE was lowest during the first 24 hours (4112 ± 773 kcal). On the average, the total daily energy intake (EI) was 2200 ± 326 kcal on each day of the training. However, individual variations were considerably high. Energy balance calculations (energy expenditure–energy intake) revealed that the mean energy deficit (ED) was 2405 ± 890 kcal/day, with the greatest value occurring at day 2 (2978 ± 1270 kcal/day), when EE was also highest.

Before MFT, the mean body mass of the subjects was 74.5 ± 7.9 kg, which decreased to 72.3 ± 7.8 kg (p<0.001) after the training. Thus, mean body mass decreased by 2.2 ± 0.8 kg (2.9 ± 1.0%, p<0.001). Plasma volume decreased by -4.1% (p<0.01), -3.2% (p<0.05), and -4.3% (p<0.01) in three consecutive days, respectively.

Testosterone Responses

The hormonal responses to MFT are shown in Figure 1. Mean serum TES (p<0.01) and TES\textsubscript{free} (p<0.01-0.05) decreased after 48 and 72 hours of MFT. During the entire MFT, mean TES reduced by 34% from 19.0 ± 3.0 to 12.6 ± 6.2 nmol·l\textsuperscript{-1} (p<0.008) and TES\textsubscript{free} by 31% from 56.0 ± 19.2 to 38.9 ± 21.8 pmol·l\textsuperscript{-1} (p<0.04).

Heart rate (HR) and heart rate variability (HRV)

The mean HR during MFT was 85 ± 6 bpm, and the mean HR relative to the maximal individual level (%HR max) was 44 ± 4%. The highest HR values were measured on the second day, when the mean daily HR increased from 76 ± 9 to 90 ± 6 bpm (p<0.01), and %HR max from 40 ± 5 to 46 ± 4% (p<0.01). Ambulatory measurements of HRV revealed no significant changes in HF power (6.93 ± 0.50 at day 0, 6.51 ± 0.82 day 1, 6.62 ± 0.87 day 2, and 6.33 ± 0.50 ln ms\textsuperscript{2} at day 3). The situation was the same for LF power, while the RMSSD values decreased from 54 ± 19 to 39 ± 12 ms (p<0.05) by the second day of MFT, and remained at 42 ± 12 ms (p<0.05) on the third day. Throughout the entire MFT, the average value of RMSSD decreased from 54 ± 19 to 43 ± 11 ms (p<0.05). In spite of insignificant changes in HF power, individual changes were related to the baseline serum TES concentrations (r=-0.72, p<0.05) (Figure 2).

Discussion

The present results clearly demonstrate that even a relatively low level of cardiovascular strain in a military environment, involving
several stressors, can modify hormonal functions. In addition, it seems that prolonged military operational stress activates the autonomic nervous system, and that the cardiac vagal activity cannot be fully activated without sufficient sleep. However, high interindividual variability is evident in HRV data. Individual changes in HF power induced by MFT were strongly associated with baseline serum TES concentrations in this study. This finding may indicate an association between cardiac vagal activity and TES concentration. In other words, HF power seems to reflect altered regulation of both neural and hormonal mechanisms. Thus, due to the fact that the measurement of HRV is a non-invasive and reliable method, it can be utilized to determine individually suitable physical loads in military environment.

According to Friedl et al. [2], in prolonged military training, soldiers’ body weight decreased by 7.8% and TES by 74%, compared to 2.8% and 34% in the present study. A noteworthy finding in that study was the immediate endocrinologic response to restoration of the energy balance. This kind of severe energy deficit also negatively affects physical and psychological performance [7] as well as resistance against diseases and infections [6]. The present results also indicate slight dehydration of the subjects. Mean daily water intake (2.9 ± 0.8 l) did not correspond to the calculated water requirement, the minimum being 4.6 l according to EE (1ml/kcal). The decreased plasma volume supports this interpretation.

This study also indicates that physically fit soldiers are capable of training well with a 2400 kcal/day energy deficit in dismounted infantry squad training is related to ED and sleep deprivation. Thus, working for 72 h at a relatively low cardiovascular strain level in a multistressor environment can modify cardiac vagal outflow, which may reflect individual adaptations of the autonomic nervous system to the exercise task. Interestingly, these changes seem to be associated with changes in serum TES levels. This suggests that HRV can be used as a non-invasive tool to measure stress in soldiers during MFT.

In conclusion, 72-hours of military operational stress due to dismounted infantry squad training is related to ED and sleep deprivation. Thus, working for 72 h at a relatively low cardiovascular strain level in a multistressor environment can modify cardiac vagal outflow, which may reflect individual adaptations of the autonomic nervous system to the exercise task. Interestingly, these changes seem to be associated with changes in serum TES levels. This suggests that HRV can be used as a non-invasive tool to measure stress in soldiers during MFT.

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