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Changes in Performance and Morning-Measured Responses in Sport Rock Climbers

by
Artur Magiera[1], Robert Roczniok[1], Ewa Sadowska-Krępa[1], Katarzyna Kempa[1]

The aim of this study was to determine changes in climbers' hormonal, cardiovascular, neuromuscular, sleep and fatigue status, and their relationship with performance and workloads during a sport rock climbing camp. Mean difficulty of individual leading climbing routes (mean Difficulty) was calculated for six male, intermediate level sport rock climbers participating in a 2-week camp in Orpierre. Additionally, each morning climbers were tested for: cortisol (d-Cortisol) and testosterone (d-Testosterone) concentrations, testosterone/cortisol ratio (T/C), heart rate and heart rate variability in supine (d-L-HR, d-L-SD1, d-L-SD2) and standing positions (d-S-HR, d-S-SD1, d-S-SD2), difference in S-HR and L-HR (HR-S-L), maximal voluntary hand grip strength (MVC), sleep duration (Sleep) and the self-perception of fatigue (M-Fatigue). Only M-Fatigue and d-Testosterone did not change significantly during the camp. Changes in other variables were large and significant, especially in the second week of the camp when the mean Difficulty was > 70%. The greatest changes were noted on the last day, when T/C, HR-S-L, and Sleep decreased and d-Cortisol, d-L-HR, and d-SD1 increased. The monitoring of the uncoupling of neuromuscular, hormonal, and cardiovascular markers can be instrumental in determining the level of athletes' morning fatigue and readiness during a climbing camp. An increase in d-Cortisol and a decrease in T/C and HR-S-L are relevant indicators of overreaching in sport climbers.

Key words: *sport climbing, workload, hormonal markers, heart rate variability, maximal voluntary contraction.*

Introduction

Sport climbing is different from other rock climbing styles in that it relies on permanent protections such as bolts fixed to the rock. This relatively safe environment allows climbers to concentrate on athletic and gymnastic movements (Giles et al., 2006). A tangible proof that this sport discipline is gaining in popularity, not only as recreational and active sport tourism, but also as a competitive sport, is its official admittance to the Tokyo Olympic Games in 2020 (IFSC, 2016).

Sport climbing performance has a complex structure and equally depends on the climber's physical, technical and mental characteristics (Magiera et al., 2013). Neither strength nor endurance alone is sufficient to be successful in this sport. For an athlete to cope with its changing demands, an extensive combination of motor abilities, technical skills and highly mobile metabolic processes is necessary (Michailov, 2014). The physiological response to this relatively short but intensive physical activity consists of submaximal cardiac output, a high to maximal heart rate, and moderate to large increases in peripheral resistance (Delise et al., 2005).

A climber`s potential performance known as climbing readiness varies in time. The prevalent theory of training and adaptation is based on the Fitness-Fatigue paradigm (Chiu and Barnes, 2003; Zatsiorski and Kraemer, 2006) stating that the athlete`s readiness can be measured with the primary after-effects of training: fitness and fatigue. Physical fitness is a slow-changing motor component that remains

[1] - *Institute of Sport Sciences, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland.*

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relatively stable over several hours or even days, but fatigue or psychological overstress can quickly change a climber`s disposition toward leading a climbing route. Strategies maximizing fitness and minimizing fatigue have the greatest potential to optimize athlete`s readiness (Zatsiorski and Kraemer, 2006). The Fitness-Fatigue paradigm differentiates between the impact of various stressors that induce different neuromuscular and metabolic stress responses (Chiu and Barnes, 2003).

The knowledge of the metabolic and cardiovascular responses in sport climbing has been suggested as important for structuring and monitoring training. The morning monitoring of athlete's readiness is well-covered in studies on numerous sport disciplines (Chatard et al., 2002; Cormack et al., 2008; McNamara et al., 2013), but physical activity as diverse as sport climbing is scarcely discussed. This study was undertaken to determine changes in climbers' morning hormonal, cardiovascular, neuromuscular, sleep and fatigue status, and their relationship with performance and workloads during a sport rock climbing camp.

Methods

Participants

The study included six male sport rock climbers (age 26 ± 2.58 years, body height 1.77 ± 0.05 m, body mass 76.8 ± 6.83 kg, body fat 12.9 ± 3.65%, $VO_{2\ max\text{-}arm}$ 43 ± 8.43 ml/min/kg) assessed during a 14-day climbing camp in Orpierre in the south of France (84 - number of morning measurements). All participants were at an intermediate performance level (6a - 7a OS) and had short climbing experience (1-3 years). They were thoroughly informed on the procedures, aims and risks of the study, and signed informed consent forms. The study was performed in accordance with the Declaration of Helsinki and was approved by the Institutional Ethics Committee (No. 10/2014).

Research design

The study was intended to describe changes in the performance, workload and morning endocrine responses of participants induced by a 14-day climbing camp. On a climbing day, the study participants would spend approx. 6 hours in the rock climbing area trying to complete 5 climbing routes. All routes were attempted on-sight (OS), i.e. with no beta or prior knowledge of the route. After a failed attempt a climber could continue the climb. From the second day of the camp in Orpierre, participants' hormonal, cardiovascular, neuromuscular, sleep and fatigue variables were evaluated every morning. Two weeks before the trip, participants were briefed on the orthostatic test and saliva sampling, and practised climbing on an artificial climbing wall. Baseline HR, HRV, hormonal and fatigue levels were collected in a rested state 3 days before the trip to France (Pre-Phase). Based on the analysed data, the camp days were divided into Phase I (first week) and Phase II (second week).

Performance and workload data

The performance and workload control indicators related to sport climbing are difficult to estimate because of the complexity and variety of climbing conditions (Michailov, 2014). In this study, the grade of a climbing route was converted to a decimal scale and is presented as a percentage of a climber's maximum OS level. Each day climbers attempted 5 routes of gradually changing difficulty in an ascending and then descending manner. The mean difficulty of the five routes is presented as the mean Difficulty and the previous day's performance is denoted as the climbing day's workload (mean Difficulty-1d).

Measurement and analysis of HR and HRV

HR and HRV were measured in all participants each morning after they woke up and emptied their urinary bladders. The Polar V800 heart rate monitor was used for this purpose. The measurements were taken during a 6-min orthostatic test in a supine position followed by 5 min of standing. HRV was measured and analysed as recommended by the Task Force of The European Society of Cardiology (1996). Artefacts were detected and corrected using Kubios-HRV 2.2 software (Department of Physics, University of Kuopio 2008). Two 3-min segments with the lowest number of artefacts were selected from 6- and 5-min recordings; the number of artefacts per participant was <1%. HRV indexes were represented on the Poincaré plot, where standard descriptors 1 (SD1) and 2 (SD2) denote fast beat-to-beat variability in the R-R intervals and longer-term variability, respectively. SD1 mainly reflects the parasympathetic input to the heart, while SD2 reflects both sympathetic and parasympathetic input to the heart. Mean supine (L-HR, L-SD1, L-SD2) and standing (S-HR, S-SD1, S-SD2) values recorded at each phase of the study and differences between those values registered at the camp days and baseline (d-L-HR, d-S-HR, d-L-SD1, d-S-SD1, d-L-SD2, d-S-SD2) were analysed. The difference between standing versus supine HR (HR-S-L) was also calculated.

Salivary cortisol and testosterone concentrations

Saliva samples were taken from the study participants between 8:00 and 10:00 a.m. under fasting conditions, about 30 minutes after they woke up. Mean levels of cortisol and testosterone concentrations (C, T) and their ratios (T/C) were determined for each phase of research. Differences between baseline measurements and measurements made on camp days (d-Cortisol, d-Testosterone) were analysed. Saliva was collected using special saliva sampling devices (Sali-Tubes 100 SLV-4158; DRG Instruments GmbH, Germany) and stored at -20^{o}C until further assay. Salivary cortisol and testosterone concentrations were determined with the Elisa Kit (respectively SLV-290 and SLV 3013 DRG Instruments GmbH, Germany).

Other morning measurements

The maximal voluntary contraction (MVC) of the forearm musculature was tested using the digital hand grip dynamometer (DHD-3 Saehan 2012) with G-STAR Grip Strength Testing and Research Software. Sleep duration (Sleep) was determined objectively by actigraphy (Polar V800) and then analysed on the Polar Flow website. The study participants were asked to self-assess their morning fatigue on a 10-point Linkert Scale (M-Fatigue), as well as other psychological symptoms of overtraining such as reduced motivation, irritability, depressed mood, inattention, sleepiness (Bompa and Haff, 2009; Meeysen et al., 2013).

Statistical Analysis

To determine differences between the 3 phases of the study and between particular camp days, the Friedman`s ANOVA test with post-hoc tests (Average rank and Sum of rank) was performed. The level of statistical significance was set at $p < 0.05$. The results are expressed as means ± standard deviations, as well as percentage change (%) including 90% confidence intervals (CI). Effect sizes (ES) were calculated using Cohen *d* and were interpreted in terms of the criteria proposed by Rhea (2004). Since the study participants had training experience from 1 to 3 years, they were assumed to be recreationally trained; hence, effect sizes were interpreted as follows: large >1.5, moderate – 0.80 to 1.50, small – 0.35 to 0.80, and trivial – <0.35. In interpreting the magnitude of correlations between variables the following criteria were applied: <0.10 trivial, 0.10 - 0.30 small, 0.30 - 0.50 moderate, 0.50 - 0.70 large, 0.70 - 0.90 very large, and 0.90 - 1.00 almost perfect (Hopkins, 2000). The data analysis tool was STATISTICA 13.0 (StatSoft Poland).

Results

Performance Data

Of the 14 camp days 10 were climbing days and 4 were rest days. Over the 10 climbing days, a climber led 50 ±1 climbing routes. Their peak readiness fell on days 11 and 13, when they climbed the hardest routes on-sight.

The climbing route difficulty was increased each day. In Phase I, changes in the mean Difficulty (from 50 to 64%) were small or moderate and statistically non-significant ($\chi^2 = 9.43$, $p = 0.051$). In Phase II, with climbers performing close to their maximal performance difficulty (between 60 and 87%), changes in this variable became significant ($\chi^2 = 19.06$, $p = 0.001$).

Morning Measures

Mean and standard deviations of the morning readings of air temperature, humidity and atmospheric pressure were 22.67 ± 3.02^{o}C, 66.29 ± 18.31%, 925 ± 5.10 hPa, respectively.

In Table 1, changes in all variables in the Pre-Phase (3 days), Phase I (7 days) and Phase II (7 days) are shown. More significant differences between baseline values and values recorded in the field were noted in Phase I (L-HR, L-SD1, cortisol, testosterone).

Based on data related to climbers' performance and physiological responses, the climbing days can be divided into two phases. As can be seen in Figure 1, HR-S-L differentiated between climbers in Phase I, yet in Phase II it was identical for all of them (the direction of changes was only positive or negative). The same pattern was followed by individual changes in d-S-SD1, MVC and Sleep, but not by hormonal variables.

Heart Rate and Heart Rate Variability

Figures 2a and 2b show the results of the orthostatic test. Of all HRV indexes, the greatest changes were noted in d-S-SD1. Above-baseline levels of S-SD1 (23 ± 6.86 ms) were recorded on days 1, 12, 14. Large differences were only recorded in Phase II (Phase II: $\chi^2 = 23.07$, $p = 0.001$ and Phase I: $\chi^2 = 11.00$, $p = 0.09$).

HR-S-L varied most considering all HR and HRV indexes. In Phase I, changes in HR-S-L ($\chi^2 = 0.86$, $p = 0.99$) were not noted, however, in Phase II moderate and large differences were observed between the group's high values on days 9 and 11 (about 31 beats/min) and low values on days 12 and 14 (about 15 beats/min) ($\chi^2 = 25.5$, $p = 0.001$). d-L-HR varied significantly in both Phase I ($\chi^2 = 13.86$, $p = 0.03$) and Phase II ($\chi^2 = 16.86$, $p = 0.01$), whereas d-S-HR showed significant variations only in Phase II (Phase II: $\chi^2 = 23.57$, $p = 0.001$ and Phase I: $\chi^2 = 4.29$, $p = 0.64$), becoming the main cause of changes in the levels of HR-S-L.

Table 1

Changes in cardiovascular (L-HR, L-SD1, L-SD2, S-HR, S-SD1, S-SD2, HR-S-L), hormonal (cortisol, testosterone, T/C ratio), neuromuscular (MVC) variables, sleep and perception of fatigue (M-Fatigue) as noted in Pre-Phase and Phases I and II.

n = 101	L-HR	L-SD1	L-SD2	S-HR	S-SD1	S-SD2	HR-S-L	C	T	T/C	M-Fatigue	MVC	Sleep
Pre Phase	54 ± 2.54	72± 27.60	95 ±34.10	80± 5.93	23± 6.86	80± 23.63	26± 6.79	7.99± 1.20	73.51± 21.08	9.17± 2.14	4.00± 2.0		
Phase I	61 ± 4.95* 2.76# large	53± 9.45* -0.69# small	82 ±9.90 -0.38# small	85± 5.38 0.84# mod.	19± 2.89 -0.58# small	64± 13.65 -0.68# small	25± 3.53 -0.15# trivial	6.58± 1.24* -1.18# mod.	49± 9.26* -1.16# mod.	7.73± 1.15 -0.67# small	4.50± 1.5 0.25# trivial	0.72± 0.04	7:30± 1:10
Phase II	57 ± 3.57 1.18# mod.	58± 11.26 -0.51# small	82 ±23.98 -0.38# small	82± 4.59 0.34# trivial	20± 4.15 -0.44# small	66± 14.94 -0.59# small	24± 3.92 -0.29# trivial	6.80± 1.24* -0.99# mod.	57± 14.74 -0.78# small	8.79± 2.24 -0.18# trivial	4.00± 1.00 0.00# trivial	0.70± 0.03* -0.5^ small	7:29± 1:10 -0.01^ trivial
Friedman's ANOVA	7.00 *p*=0.03	7.00 *p*=0.03	2.33 *p*=0.31	4.33 *p*=0.12	2.33 *p*=0.31	4.33 *p*=0.12	1.33 *p*=0.51	9.00 *p*=0.01	8.33 *p*=0.02	4.00 *p*=0.14	0.40 *p*=0.82	6.00 *p*=0.01	0.67 *p*=0.71

** statistically significant changes between Phase I or II and Pre-Phase*
for MVC and Sleep changes between Phases I and II; (p < 0.05)
^ effect sizes and their magnitude (trivial, small, moderate, large) – changes between Phases I and II.
 # effect sizes and their magnitude – changes between Phase I or II and Pre-Phase.

Table 2

Correlations between climbing workloads (mean Difficulty-1d) and Morning Measurements (HR and HRV indexes, hormones, MVC, Sleep, M-Fatigue) in all three periods

	P	d-L-HR	d-L-SD1	d-L-SD2	d-S-HR	d-S-SD1	d-S-SD2	HR-S-L	d-Cortisol	d-Testosterone	T/C	MVC	Sleep	M-Fatigue
mean Difficulty-1d	I+II	-0.08	-0.12	-0.03	-0.35#	0.35	0.23	-0.53^	0.47#	-0.09	-0.28*	-0.61^	-0.44#	0.05
	I	0.12	-0.28	-0.26	0.18	-0.06	-0.07	-0.11	0.47#	-0.20	-0.25	-0.51^	-0.46#	0.18
	II	0.01	-0.01	0.21	-0.59^	0.46#	0.29	-0.84!	0.46#	-0.23	-0.46#	-0.46#	-0.52^	-0.21

*P- period (I+II = 10 climbing days (n=59), I – Phase I, II – Phase II), Statistically significant correlations ($p < 0.05$): *- small, # - moderate, ^ - large, !- very large*

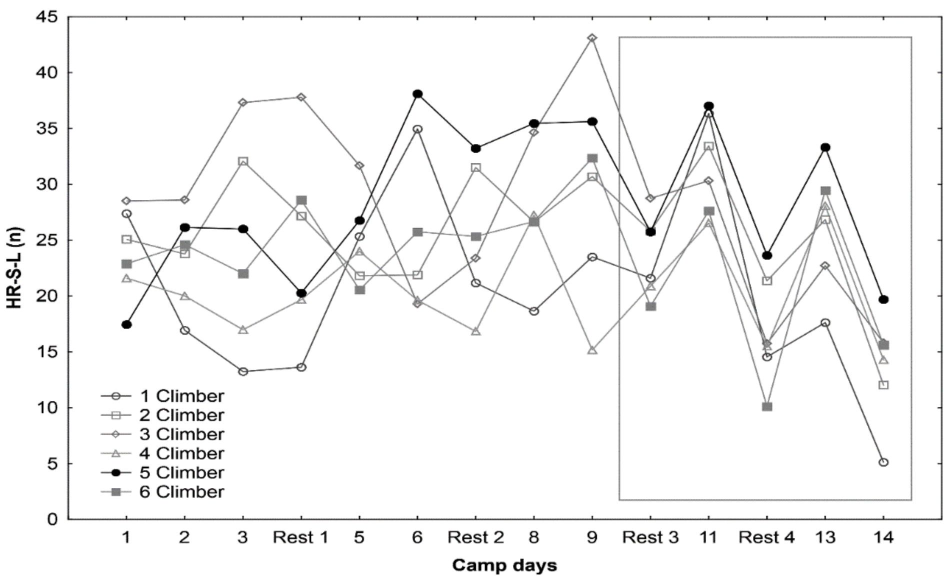

Figure 1

Individual changes in HR-S-L on the orthostatic test

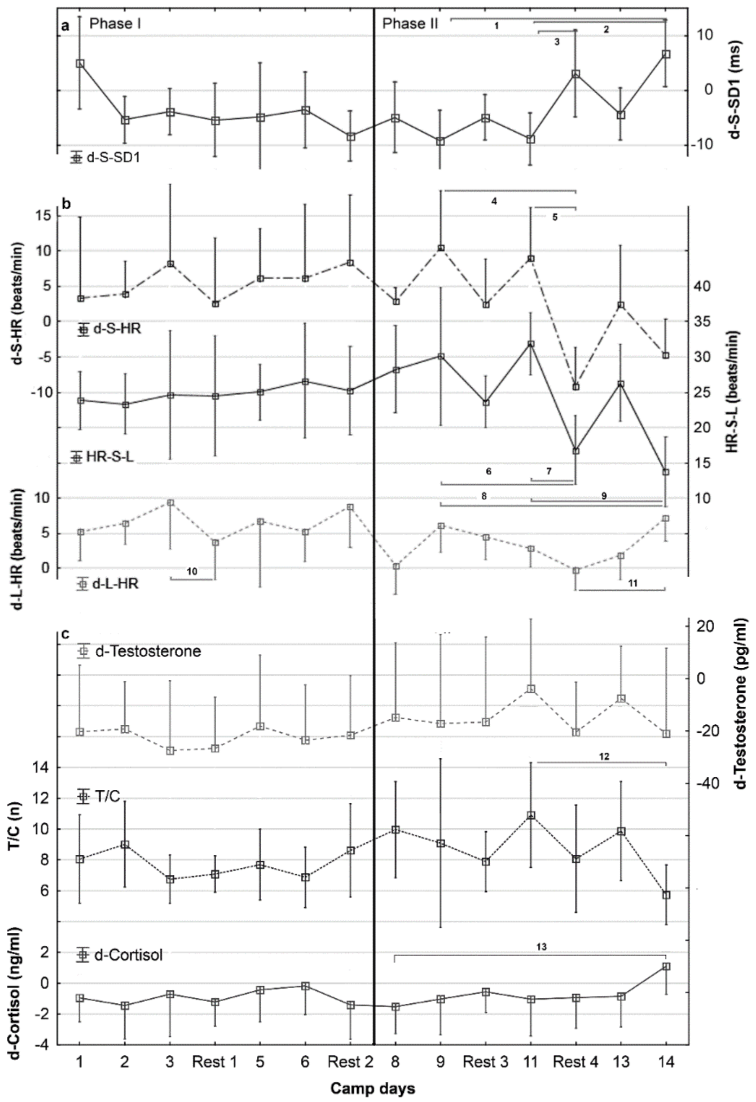

Figure 2

Changes in a) vagal cardiac activity (d-S-SD1), b) heart rate (d-L-HR, d-S-HR, HR-S-L), and c) hormonal concentrations (d-Cortisol, d-Testosterone, T/C) in Phases I and II

Statistically significant changes:

1 - d-S-SD1- large (136%, 90% CI = 57 - 214, $p < 0.05$, ES = 2.74)
2 - d-S-SD1 - large (110%, 90% CI = 83 - 136, $p < 0.05$, ES = 4.81)
3 - d-S-SD1 - large (89%, 90% CI = 59 - 119, $p < 0.05$, ES = 3.71)
4- d-S-HR- large (-21%, 90% CI = -13 to -29, $p < 0.05$, ES = -1.66)
5 - d-S-HR - large (-20%, 90% CI = -17 to -24, $p < 0.05$, ES = -3.11)
6 - HR-S-L- moderate (-39%, 90% CI = -18 to -60, $p < 0.05$, ES = -1.37)
7 - HR-S-L - large (-48%, 90% CI = -38 to -57, $p < 0.05$, ES = -3.40)
8 - HR-S-L - large (-51%, 90% CI = -30 to -71, $p < 0.05$, ES = -1.68)
9 - HR-S-L - large (-56%, 90% CI = -42 to -69, $p < 0.05$, ES = -4.09)
10 - d-L-HR - small (-9%, 90% CI = -3 to -14, $p < 0.05$, ES = -0.76)
11 - d-L-HR - large (14%, 90% CI = 6 to -22, $p < 0.05$, ES = 2.52)
12 - T/C - large (-42%, 90% CI = -21 to -64, $p < 0.05$, ES = -1.52)
13 - d-Cortisol - moderate (136%, 90% CI = 76 - 195, $p < 0.05$, ES = 1.49)

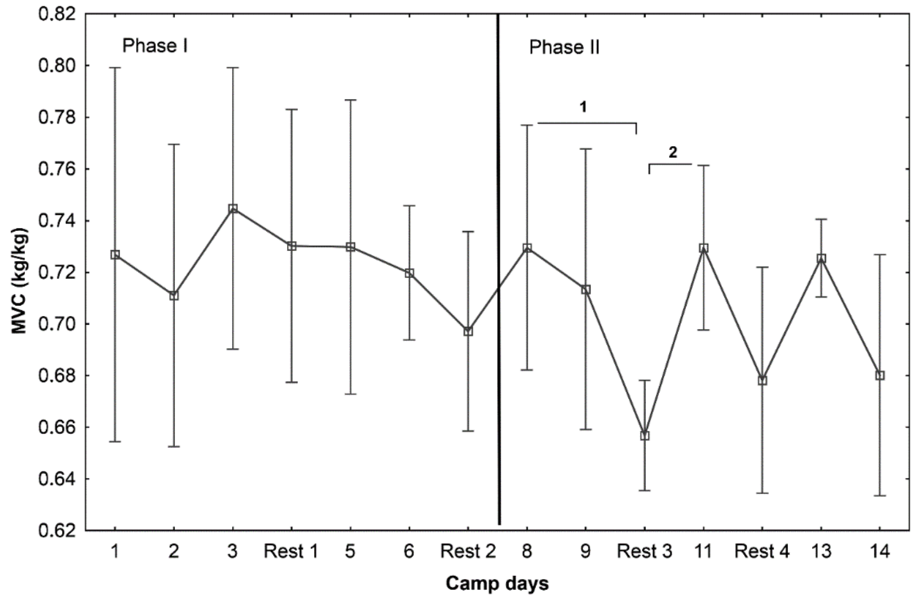

Figure 3

Changes in relative maximal hand grip strength (MVC) in Phases I and II
Statistically significant changes: 1- large (-10%, 90% CI = -6 to -14, p < 0.05, ES = -1.53)
2- large (11%, 90% CI = 7 - 15, p < 0.05, ES = 3.40)

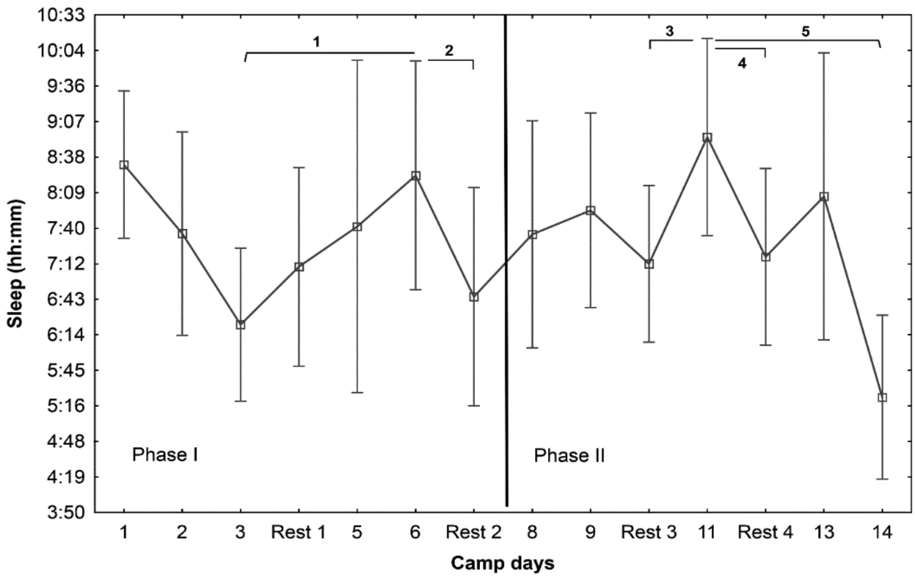

Figure 4

Changes in sleep duration (Sleep) in Phases I and II
Statistically significant changes:
1- large (32%, 90% CI = 19 - 44, p < 0.05, ES = 1.95)
2- moderate (-20%, 90% CI = -12 to -27, p < 0.05, ES = -1.06)
3- large (24%, 90% CI = 16 - 32, p < 0.05, ES = 1.62)
4- moderate (-18%, 90% CI = -15 to -22, p < 0.05, ES = -1.22)
5- large (-38%, 90% CI = -25 to -51, p < 0.05, ES = -2.64)

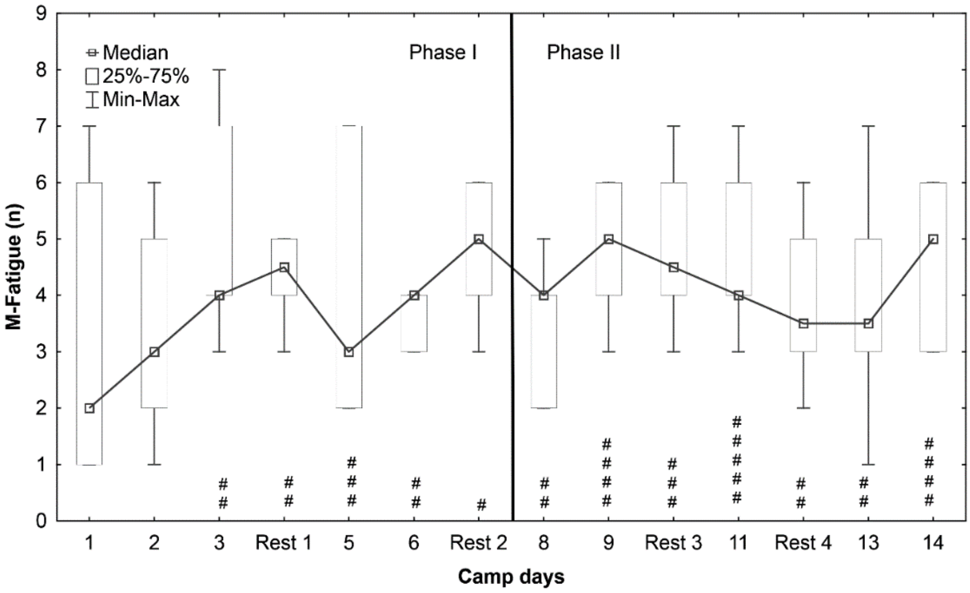

Figure 5

Changes in self-perceived morning fatigue (M-Fatigue) in Phases I and II
 # number of subjective symptoms of overtraining

Hormonal Measures

A moderate increase in d-Cortisol was noted between days 8 and 14 in Phase II (χ^2 = 14.71, p = 0.02). In Phase I neither d-Cortisol (χ^2 = 7.90, p = 0.25) nor T/C ratio (χ^2 = 7.25, p = 0.30) changed significantly, and d-Testosterone did not show significant variations throughout the camp period (Phase I: χ^2 = 2.36, p = 0.88 and Phase II: χ^2 = 6.82, p = 0.34). T/C varied in II Phase (χ^2 = 12.36, p = 0.045), decreasing markedly between days 11 and 14 (Figure 2c).

Other measurements

Significant changes in MVC were noted in Phase II (χ^2 = 19.90, p = 0.003), but not in Phase I (χ^2 = 7.64, p = 0.27). In Phase II it decreased after climbing days to return to its mean values after rest days (Figure 3).

In both phases of the camp period, the duration of sleep changed significantly many times (Phase I: χ^2 = 18.57, p = 0.005 and Phase II: χ^2 = 24.57, p = 0.001). Mean sleep duration ranged from 5:24 to 8:52 hours, with climbers waking up at almost the same time (around 8:30 a.m.) (Figure 4).

As far as the self-perception of fatigue (M-Fatigue) at the beginning of the day is concerned, significant changes were not registered either in Phase I (χ^2 = 12.00, p = 0.06) or Phase II (χ^2 = 4.31, p = 0.64), but on days 9, 11 and 14 participants reported several subjective symptoms of overtraining (Figure 5).

Correlations

The correlations between climbing workloads and variables measured in the morning were analysed for the whole camp period (n = 59), as well as for Phase I (moderate climbing workload) and Phase II (large climbing workload) (Table 2). Significant correlations were established between the previous climbing day's workload (mean Difficulty-1d) and MVC, d-Cortisol, Sleep (in all 3 periods), HR-S-L, d-S-HR, T/C (Phase II and Phases I+II as a whole), d-S-SD1 (only Phase II).

Discussion

The period at the climbing camp was only 2 week long, but it can be divided into two distinct phases: climbers' adaptation to a new environment and acquisition of new behaviours (an unfamiliar rock area, sleeping in a tent, all day activity) and days of peak performance when they climbed the most difficult routes. Changes in the adaptation phase included a large and statistically significant increase in the HR measured in the supine position, a small decrease in parasympathetic activation (d-L-SD1) and a moderate decrease in cortisol and testosterone concentrations in relation to their baseline values (Pre-Phase). Many of these significant differences (excluding d-Cortisol) were not observed in Phase II.

A substantial reduction in cortisol evident at 95% of comparison points occurred in players during an Australian Rules Football season (Cormack et al., 2008). In that study, a likely cause of cortisol reduction was climbers' exposure to the natural environment that effectively reduced daily stress. The salivary cortisol levels (indicative of stress) obtained in the natural environment were significantly lower from those recorded in the urban environment (Lee, 2009).

The morning tests revealed that the previous day's climbing workload had a significant influence on climbers' physiological responses, especially on hand strength, the level of cortisol concentration and sleep duration that correlated with mean Difficulty-1d throughout the camp period. Morning fatigue caused by climbing difficulty of more than 70% (climbing workload in the peak performance period) also contributed to a large decrease in HR-S-L and T/C and it may have been responsible for a similar pattern of changes in HR-S-L, d-S-SD1, MVC and Sleep. An unexpected finding was that mean Difficulty-1d and the self-assessments of fatigue were not significantly correlated. This outcome is supported by the major finding of the study of McNamara et al. (2013) into the uncoupling of neuromuscular, endocrine, and perceptual fatigue markers in response to external loads during morning monitoring.

The relative strength of finger flexors is one of the most important factors determining performance in sport climbing (Magiera and Ryguła, 2007; Michailov, 2014; Sheel, 2004). Previous research has shown that hand grip strength significantly decreases following the performance of climbing tasks (Watts et al., 1996). In this study, a large decrease in the morning MVC after a heavy climbing day was relevant to estimate muscle fatigue. The MVC values returned to average after one day rest.

Physical exercise exceeding the intensity of 60% $VO_{2\,max}$ or lasting at least 20 - 30 minutes (Papacosta and Nassis, 2011) elicits considerable changes in salivary cortisol concentration. Cortisol is considered the main hormone responsible for catabolic processes (Papacosta and Nassis, 2011). In this study, d-Cortisol was moderately and positively correlated with mean Difficulty-1d. Fatigue induced stronger catabolic metabolism in climbers. This finding is supported by changes in the T/C ratio (testosterone/cortisol ratio), which is a measure of the anabolic/catabolic balance responses to training. A decrease in the T/C ratio greater than 30% may suggest "insufficient recovery" and the onset of non-functional overreaching which, if misdiagnosed, can develop into the overtraining syndrome (Meeusen et al., 2004). In this study, increased fatigue was accompanied by a decline in the T/C ratio, which led to the predominance of the catabolic process ($r = -0.28$, $p < 0.05$). Moreover, a large increase in cortisol concentration and a large decrease in the T/C ratio (-42%) on day 14 indicated that at the end of the camp period climbers entered a state of overreaching.

Measurements of sleep duration and quality are part of the morning monitoring of athletes (Saw et al., 2015). In this study, the correlation between Sleep and mean Difficulty-1d was moderate and negative, whereas the correlation between d-Cortisol and Sleep ($r = -0.66$, $p < 0.05$) was strong and negative. Garde et al. (2012) published a review of a large number of studies, none of which provided solid evidence of sleep and cortisol being connected with each other. Nevertheless, the authors concluded that longer sleep duration was related to a more dynamic cortisol secretion, the so-called cortisol awakening response (CAR – percentage increase in cortisol secretion from awakening to 30 minutes later). In another meta-analysis, CAR positively correlated with general life stress and negatively with fatigue, burnout and exhaustion (Chida and Steptoe, 2009). In this study, CAR was not tested because cortisol was measured only once approx. 30 minutes after awakening.

HR and HRV have in recent years been

frequently used to study changes in athletes' autonomic nervous systems to gain insight into their adaptation/fatigue status. In this study, of all HR indexes HR-S-L was the most strongly (negatively) correlated with mean Difficulty-1d, especially in Phase II. This result stands in contrast to the results obtained by Bompa and Haff (2009), who showed that better fitness levels were associated with lower HR-S-L, L-HR and S-HR, and that increases in variables such as fatigue, stress, illness and overtraining raised the levels of HR-S-L and L-HR, S-HR. The results obtained in this study are supported by findings of other authors.

Firstly, there are studies that show in detail how individual spectral patterns of HRV and HR divert in "fatigue" states from a "no fatigue" condition and reveal the clustering of different types of fatigue through mathematical proximity of HR and HRV indexes. These distinct patterns encompass increases and/or decreases in the HR as well as in spectral low frequency (LF) and high frequency (HF) components of HRV (Schmitt et al., 2016).

Secondly, Meur et al. (2013) who analysed HR and HRV to detect alterations in autonomic function that might be associated with functional overreaching (FOR) in endurance athletes reported a progressive decrease in resting HR values (in supine and standing positions) and more parasympathetic modulation in the FOR group during the overload period.

Lastly, it is relevant to note that in this study the morning data were analysed on a day-to-day basis. The conclusions might be different if weekly averages (Bompa and Haff, 2009; Meur et al., 2013; Shona, 2014) or cardiovascular benefits from long-term practice of sport climbing (Gomez et al., 2017) were used. Statistically significantly different HRV times and frequency domains (RR interval, SD1, RMSSD, LF, and HF) between the sedentary individuals and indoor rock climbers indicate that the long-term practice of sport climbing stimulates parasympathetic activity (Gomez et al., 2017). Although two weeks of climbing activity are insufficient to significantly improve climbers' fitness, daily HRV changes can have influence on their readiness.

This study provides insight into the importance of the workload, fatigue and readiness variables associated with sport rock climbing, but it has several limitations that warrant discussion. Firstly, the statistical power of the analysis may be low because of the relatively small sample size; this notwithstanding, large changes in many variables were observed. Secondly, as all participants were male, intermediate-level climbers who had never climbed the limestone rocks in Western Europe before, the study results are not generalizable over more advanced, more experienced, and female climbers.

The research findings indicate that the intermediate-level, unexperienced climbers need an adaptation phase to achieve their best readiness and to be able to climb the most difficult routes on-sight. The fact that large workloads in the performance phase (> 70% mean Difficulty) induced major changes in the hormonal, cardiovascular, neuromuscular and sleep variables, but not in the perception of morning fatigue, provides a valid argument for monitoring these variables in the performance phase to control overreaching in climbers. Insufficient recovery may impair their performance as well as make them more vulnerable to injuries, a loss of concentration during belaying, etc.

Conclusions

As observed during the two weeks of the climbing camp, changes in the previous day's workload elicit large fluctuations in maximal hand grip strength, testosterone/cortisol ratio, cortisol concentration, HR and HRV indexes and the duration of sleep. An increase in d-Cortisol and a decrease in T/C and HR-S-L are relevant indicators of overreaching in sport climbers. The monitoring of the uncoupling of neuromuscular, hormonal, cardiovascular markers can reveal variations in morning fatigue and the level of readiness during the climbing camp.

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Corresponding author:

dr Artur Magiera
The Jerzy Kukuczka Academy of Physical Education in Katowice
Institute of Sport Sciences
ul. Mikolowska 72a, 40-065 Katowice, Poland
Phone: 048 -32 207 51 56
E-mail: a.magiera@awf.katowice.pl