

Title

The effect of potential fall distance on hormonal response in rock climbing

Running head

Hormone response during climbing

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Abstract

The aim of this study was to examine the effect of alterations in potential lead fall distance on the hormonal responses of rock climbers. Nine advanced female climbers completed two routes whilst clipping all (PRO-all) or half (PRO-½) of the fixed points of protection. Venous blood samples were analysed for total catecholamines, noradrenaline, adrenaline, dopamine, lactate, cortisol and serotonin. Differences between the two conditions pre, immediately post and 15 minutes post climbing were assessed using a 2x3 repeated measures ANOVA. All hormones and blood lactate concentrations increased significantly ($p < 0.05$) immediately post climb, except for cortisol. Peak cortisol concentrations did not occur until 15 min post ascent. Further, significant interactions between climbing and clipping conditions were found for total catecholamines (890% of basal concentration in PRO-½ vs. 568% in PRO-all), noradrenaline (794% vs. 532%) and dopamine (500% vs. 210%). There were no significant interactions for adrenaline (1920% vs 1045%), serotonin (150% vs 127%), or lactate (329% vs 279%). The study showed a greater catecholamine response with an increase in potential lead fall distance. The most pronounced increases seen in catecholamine concentration were reported for dopamine and noradrenaline.

Key words

Catecholamines; Cortisol; Serotonin; Stress; Anxiety

Introduction

Lead climbing not only requires considerable physical skill, but also mental resilience. Both sport and traditional disciplines of the sport require participants to ascend routes protected either by periodically spaced pre-installed bolts, or intermittent hand placed protection. In the event of a fall,

the climber will travel some distance before being arrested by a trailing rope, attached to the points of protection, held by the belayer. The length of the fall depends on the distance between the climber and the last piece of protection and the amount of rope in the system. Differences in the method of protecting sport and traditional climbs have consequences for the potential for injury. Whilst sport climbing is more likely to result in chronic overuse injuries of the upper extremities (Backe et al. 2009), traditional climbing is more likely to result in injuries arising because of a fall (Schöffl et al. 2010). The injury risk is still considered lower than traditional sports such as football; however, fatalities can, and do, occur (Schussman et al. 1990). Consequently, the potential for taking falls, and an associated fear of injury, is often a source of anxiety for climbers (MacLeod 2010). High levels of anxiety can have a detrimental effect on climbing performance (Hardy & Hutchinson 2007; Pijpers et al. 2003).

Elevated concentrations of the stress hormone cortisol have been reported in lower grade climbers when leading (risk of a short fall) in comparison to climbing with a top-rope (no risk of fall) (Dickson et al. 2012; Hodgson et al. 2009); however, these differences were not apparent with intermediate, advanced and elite climbers (Dickson, Fryer 2012; Draper et al. 2012; Fryer et al. 2013). Further, in novice climbers an increase in height above the ground has been shown to be a potent stressor, associated with an increase in state anxiety and a change in climber's movement behaviour (Nieuwenhuys et al. 2008; Pijpers, Oudejans 2003).

It is conceivable that experienced climbers are habituated to the negative effects associated with fall potential when lead climbing. However, it is also possible that cortisol alone is not a suitable marker for the assessment of mental stress, particularly as the relationship between cortisol and subjective anxiety (cognitive and somatic anxiety and self-confidence) has been found to vary by around 21-25% (Draper, Dickson 2012). Catecholamines, which are mediating hormones to physical, environmental and behavioural stressors (Zouhal et al. 2008), may serve as a more sensitive means of quantifying psychological stress in climbers. An early study by Williams et al. (1978) found high catecholamine concentration, in response to a physically easy but mentally hard outdoor climbs, in inexperienced climbers.

From the current literature, it appears that unknown routes, involving high levels of effort, at height, are the main sources of anxiety for indoor sport climbers. However, the effect of the potential for a fall on the hormonal response is not well understood, either because of the unsuitability of cortisol or because the challenges used have not been significant enough to elicit a response. The aim of this study was to examine the effects of different potential fall distances on hormonal responses in rock climbing.

Methods

Nine advanced female climbers (mean age 28.7 yrs, $s = 3.8$; body mass 54.8 kg, $s = 4.7$; height 162.7 cm, $s = 4.4$) volunteered to take part in the study. Climbing ability ranged from 6b to 7c red-point (RP- with prior practice) and 6a to 7a+ on-sight (OS- without a fall or previous practice) on the French scale. Grades for sport climbing were determined using a previously validated self-report technique (Draper et al. 2011; Draper et al. 2015). Participants completed written informed consent and medical health questionnaires prior to taking part in the study. Approval for the study was granted by the University's Ethics Committee and conformed to the principles of the declaration of Helsinki.

To assess the effect of an increase in fall potential on hormonal response, a within-subject experimental design, with participants' ascending routes in a randomly assigned order was completed. The two conditions were *clipping all* fixed protection (PRO-all) and *clipping half* of the fixed protection (PRO- $\frac{1}{2}$). Climbers attended two sessions, four days apart, abstained from any strenuous physical activities for 24 hours and food and caffeine two hours prior to the measurements.

The session started with an hour of calm sitting, during which time the climbers completed health history and climbing experience questionnaires and pre-climbing heart rate was recorded. At the end of this initial rest phase, a venous blood sample was taken from the antebachial vein and the participants were randomly assigned to their first climbing condition. The climbers completed a standardised warm-up consisting of five minutes of aerobic exercises, five minutes mobilising/stretching exercises and two ascents of routes of their choice, at least two grades below the designated test route. The same warm-up was completed during the second session. After the warm-up, a recovery period of twenty minutes was provided.

The tested routes were climbed in OS style. Immediately (within one minute) after either reaching the top of the route or falling, the second venous blood sample was taken. At the same time as the post-exercise blood sample the climbers were asked to assess the subjective difficulty of the ascent on Borg scale of perceived exertion (RPE). Finally, the 3rd blood sample was drawn 15 minutes post climb. The total time of the ascent and heart rate (HR; Polar RS 400, Finland) were recorded.

Four pairs of routes of a similar style were constructed on a 21-metre high indoor climbing wall, and ranged in difficulty from French 5c+ to 7a. For each of the participants, a pair of routes one grade below the self-reported maximum OS grade was identified. Both routes were climbed in an OS style. The first condition, PRO-all, represented a classic indoor sport climbing protocol, with the climber required to clip all fixed protection points on the route (16-18 quickdraws). The distance between each of the quickdraws varied between 1.2 - 1.4 metres. For the second condition, PRO-1/2, the distance between each point of protection was increased. Climbers had to clip the 2nd, 3rd, 5th, and then every 2nd point of protection until the top of the route, with 2.4 – 2.8 meters between each quickdraw. The same person, known to all participants, belayed all ascents.

Venous blood was drawn by venipuncture into polypropylene tubes coated with EDTA. Plasma was obtained by the centrifugation of blood samples (15 min, 3000xg, 20°C). Plasma was frozen at -80°C and was thawed only once prior to performing the assays. From the plasma concentrations of lactate, adrenaline, noradrenaline, dopamine, serotonin and cortisol were analysed. Lactate was measured using an Advia 1800 (Siemens, Erlangen, Germany). Serotonin, cortisol and catecholamine were analysed by Liquid chromatography (LC) and mass spectrometry (MS). Liquid chromatography was performed using LC system Shimadzu Prominence (Shimadzu, Czech Republic) equipped by column Atlantis dC18, 100 x 2.1 mm, 5 µm (Waters, Czech Republic). The detection system (MS detector QTRAP 4000; ABSciex, Czech Republic) worked in the positive ionization mode and using selected reaction monitoring for compounds detection. Nebulization was carried out at 500°C for serotonin, 450°C for cortisol and 600°C for catecholamine, the ionspray voltage was set at 5000 V for serotonin, catecholamine and 5500 V for cortisol.

Descriptive statistics (mean, *s*) were calculated for all anthropometric characteristics and physiological responses. Normal distribution was assessed with a Kolmogorov–Smirnov’s test. To

assess differences between the conditions with PRO-all and PRO-1/2 for total time, speed of climbing, HR and RPE, paired *t*-tests were used. To compare hormone concentration between the two climbing conditions, a repeated analysis of variance (2x3) was performed with two within-subject factors (sport x traditional route; pre x immediately post x 15 min post measurement). Statistical significance was set to $p \leq 0.05$. Partial omega squared (ω_p^2) was computed to estimate the effect size. The relationship between climbing ability, locomotion speed and hormones response was verified by Pearson product moment correlation. All calculations were completed in Microsoft Excel and IBM SPSS for Windows (Version, 22, Chicago, Il., USA).

Results

Perceived exertion, HR and total time of ascent were similar for both conditions (Table I). However, during PRO-1/2 three climbers fell a short distance before the top of the route. Their results were also included in the analysis. On average, the PRO-1/2 ascents were significantly slower than the PRO-all ascents.

Table I Mean \pm *s* rate of perceived exertion (RPE), time of ascent, speed of climbing and peak heart rate (HR_{peak}) during the climb clipping all protection (PRO-all) and clipping half protection (PRO-1/2).

	<i>RPE (6-20)</i>	<i>Time of ascent (min:sec)</i>	<i>Speed (m.min⁻¹)</i>	<i>HR_{peak} (beats.min⁻¹)</i>
PRO-all	17 \pm 1	6:06 \pm 2:17	4.1 \pm 1.5	182 \pm 8
PRO-1/2	17 \pm 2	6:40 \pm 2:25	3.5 \pm 1.2*	179 \pm 15

* significant differences at $p < 0.05$

All hormones and blood lactate concentrations increased significantly immediately after climbing, except for cortisol (Fig. I). There was a significant main effect of climbing on total catecholamine response ($p = 0.001$, $\omega_p^2 = 0.666$), plasma lactate ($p < 0.001$, $\omega_p^2 = 0.864$), adrenaline ($p = 0.010$, $\omega_p^2 = 0.491$), noradrenaline $p = 0.001$, $\omega_p^2 = 0.704$), serotonin ($p = 0.009$, $\omega_p^2 = 0.499$), and dopamine ($p = 0.001$, $\omega_p^2 = 0.695$), however the main effect of climbing was not significant for cortisol immediately after climbing ($p = 0.260$, $\omega_p^2 = 0.043$), but was significant after 15 minutes of rest ($p = 0.017$, $\omega_p^2 =$

0.427). Catecholamines returned to basal concentration after 15 minutes of rest, whilst plasma lactate remained elevated.

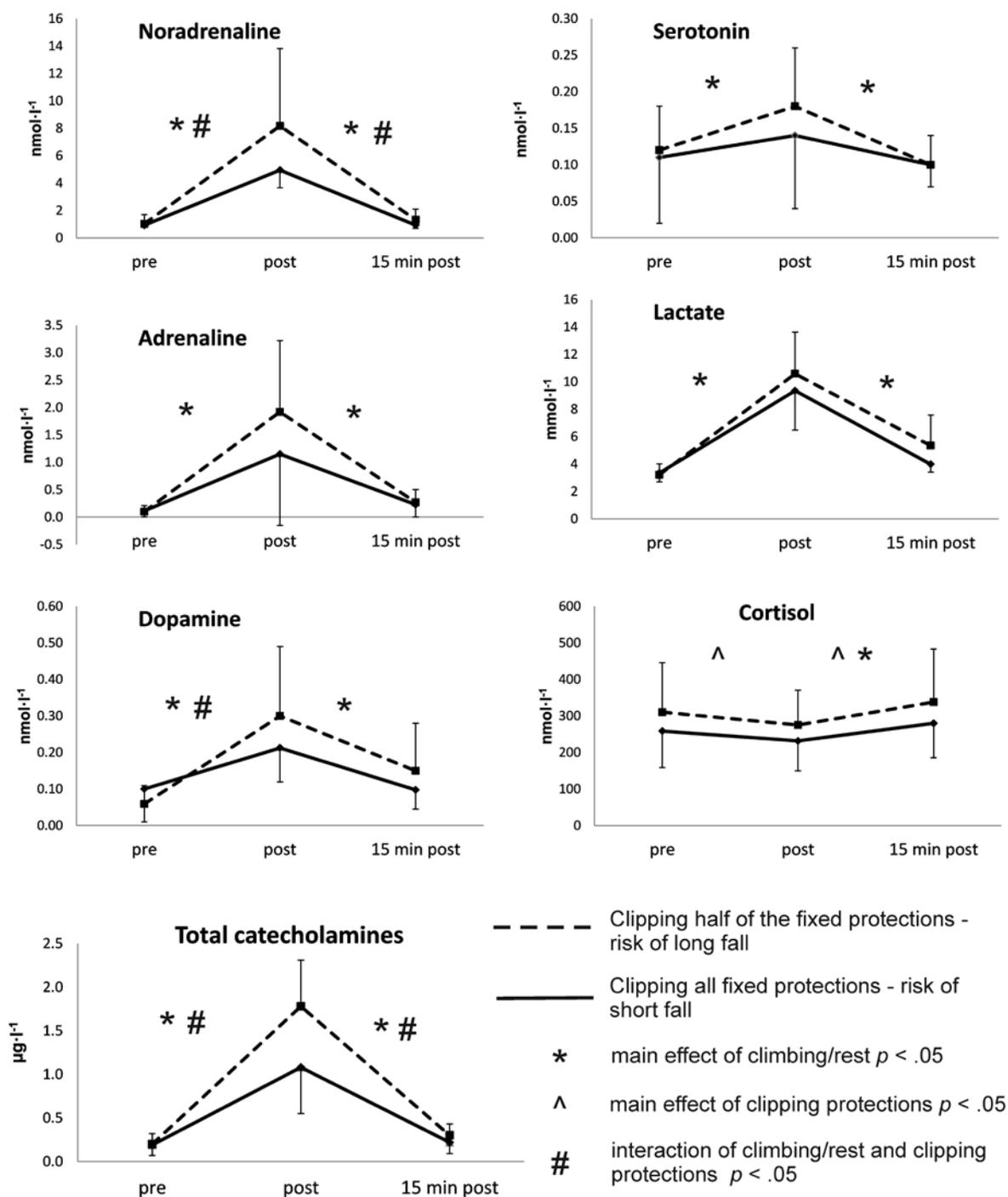


Fig. I Catecholamine, cortisol, serotonin, and plasma lactate concentration before, immediately post and 15 min after climbing with clipping security rope in all protections and half of the protections.

Further, a significant interaction between the climbing and the means of protecting the climb was found for total catecholamines ($p = 0.041$, $\omega_p^2 = 0.319$), noradrenaline ($p = 0.045$, $\omega_p^2 = 0.305$) and dopamine ($p = 0.016$, $\omega_p^2 = 0.437$) (Fig. 1). There was no significant interaction for adrenaline ($p = 0.235$, $\omega_p^2 = 0.059$), serotonin ($p = 0.219$, $\omega_p^2 = 0.069$), or lactate ($p = 0.065$, $\omega_p^2 = 0.254$), (Fig. 1). Climbers had greater noradrenaline and dopamine response to PRO-1/2.

Interestingly, a significant relationship was also found between climbing ability, speed of ascent and hormone responses (Table II). Plasma lactate was positively associated with climbing ability RP ($R^2 = 0.23$), speed of ascent ($R^2 = 0.45$), adrenaline ($R^2 = 0.43$), noradrenaline ($R^2 = 0.32$), dopamine ($R^2 = 0.43$) and serotonin ($R^2 = 0.21$). Moreover, adrenaline was positively related to noradrenaline ($R^2 = 0.57$), dopamine ($R^2 = 0.53$) and serotonin ($R^2 = 0.36$). Noradrenaline also showed a moderate relationship to serotonin ($R^2 = 0.27$) and close relationship to dopamine ($R^2 = 0.64$). Cortisol was only related to the speed of ascent ($R^2 = 0.45$).

Table II Relationship between climbing ability, speed of ascent and hormone responses

	<i>Speed</i>	<i>Cortisol</i>	<i>Lactate</i>	<i>Adrenaline</i>	<i>Noradrenaline</i>	<i>Dopamine</i>	<i>Serotonin</i>	<i>Catecholamines</i>
<i>Ability (RP)</i>	.403	-.066	.484*	.250	.043	.252	.488*	.113
<i>Speed</i>		.672*	.673*	.409	.247	.182	.360	.310
<i>Cortisol</i>			.377	.093	.058	.089	.016	.073
<i>Lactate</i>				.654*	.568*	.658*	.456*	.629*
<i>Adrenaline</i>					.752*	.727*	.599*	.870*
<i>Noradrenaline</i>						.800*	.523*	.979*
<i>Dopamine</i>							.344	.829*
<i>Serotonin</i>								.573*

* significant correlation at $p < 0.05$

Discussion

The aim of this study was to examine the effect of differences in potential fall distance on hormonal responses for rock climbers. The results indicate that an increase in the distance between points of protection, whilst lead climbing indoors, induces a greater catecholamine response, despite similar changes in HR and subjective measures of exertion. The most pronounced increases in

catecholamine concentration were found in dopamine and noradrenaline. The increase in adrenaline was not found to be significant due to high levels of inter-individual variability.

A greater catecholamine response (168%) in PRO- $\frac{1}{2}$ was attributed to psychological stress (fear of a long fall), as all other variables were controlled for. However, the greater catecholamine response may have been mediated by differences in ascent strategy. The PRO- $\frac{1}{2}$ condition was associated with a slower speed of locomotion, which may be explained by longer and more careful movement planning. Previously, situations with greater anxiety were found to induce longer contact times with climbing holds and more frequent exploratory movements (Pijpers et al. 2005). Further, during the PRO- $\frac{1}{2}$ ascent, moderately greater concentrations of blood lactate were found (+ 1.2 mmol·l⁻¹, $p = 0.65$, $\omega_p^2=0.26$). This may be related to increased contact times and/or greater force applied to the handholds, which has previously been reported in less experienced climbers, and may be attributed to reduced movement economy (Baláš et al. 2014; Fuss & Niegl 2008).

Noradrenaline concentrations increased from basal levels by 532% in PRO-all and 794% in PRO- $\frac{1}{2}$. The increase was similar in magnitude to the 500%-1000% increases previously reported in tasks that involve maximal and above maximal aerobic power (Zouhal, Jacob 2008). Elevated noradrenaline concentrations may not have occurred solely because of the intensity of the exercise. The nature of the intermittent isometric contractions required for climbing, which are known to elicit local ischemia of the forearms (Baláš et al. 2015), has previously been found to induce greater catecholamine response in comparison to dynamic contractions, where blood flow was not restricted (Zouhal, Jacob 2008). Moreover, other psychological factors, such as a fear of height, the on-sight nature of the route and/or stress elicited by the testing conditions, may have also increased the noradrenaline response.

Adrenaline concentrations increased from basal values by 1050% in the PRO-all and 1920% in the PRO- $\frac{1}{2}$ conditions. Although the increase in adrenaline was much greater than seen with noradrenaline, very high levels of inter-individual variability were present and consequently, there was no statistical difference between the two clipping conditions. The variation between individuals may likely be a result of each climber's unique perception of the risk associated with the two climbing conditions used. Adrenaline secretions are greater in amplitude in situations when the risk is

unexpected or non-controllable (McCarty & Gold 1996). In support of this, it is of interest to note that, while not within the aims of our study, a smaller increase in adrenaline was found for the females who regularly led routes outdoors, in comparison to those who solely climbed indoors. The authors acknowledge that the factors involved in adrenaline secretion are complex and other physiological and psychological factors may have contributed to adrenaline concentration variability. For example, a moderate to high relationship ($R^2 = 0.43$) was found between the increase in adrenaline and plasma lactate concentrations. This is in agreement with other authors, who have demonstrated that catecholamines' regulate muscular glycogenolysis and their inhibition reduces VO_{2max} , plasma glucose, plasma glycerol and blood lactate concentrations (Galbo et al. 1976).

Dopamine in the plasma is rarely analysed in sports research. The current study has found a significant association with noradrenaline, adrenaline and also plasma lactate. Dopamine concentration increased by 210% and 500% in PRO-all and PRO-1/2, respectively. When this result is considered with the change in concentration of the other catecholamines this study shows that plasma dopamine not only reflect physical stress but also stress due to the fear of falling, and therefore also psychological stress.

The level of plasma serotonin was strongly related to all catecholamines, especially adrenaline. Serotonin concentration increased after climbing, although there were no significant differences between the clipping conditions. Fifteen minutes after climbing serotonin concentration returned to basal level. The reactive response of plasma serotonin towards psychological stress is not well documented in the literature. The role of serotonin in the CNS after prolonged exercise is attributed to feelings of tiredness and lethargy and the onset of fatigue (Meeusen et al. 2006). However, as serotonin cannot pass the brain blood barrier (except for its precursor tryptophan), the concentration in the plasma may not correspond with the concentration in the CNS. It has been proposed that decrease in plasma serotonin, after regular exercise, may be linked to changes in the brain that are similar to the effects of anti-depressants (Wipfli et al. 2011). An acute plasma serotonin increase may, on the other hand, be connected with lower brain serotonin production and the onset of central fatigue.

Finally, cortisol has seen extensive use in climbing psychophysiology related research to indicate the level of anxiety (Draper, Dickson 2012; Fryer, Dickson 2013; Hodgson, Draper 2009). Whilst

plasma cortisol concentration is in a close relationship with cognitive and somatic anxiety (Draper, Dickson 2012), it appears that this relationship is only valid in lower level and intermediate climbers and not in more advanced or elite climbers (Fryer, Dickson 2013). This study confirmed greater plasma concentration 15 minutes after climbing (Fryer, Dickson 2013). However, there were no differences between the clipping conditions and it is suggested that plasma cortisol concentrations do not indicate the level of stress related to a fear of falling. Interestingly, there were significant differences between the plasma concentrations before the two climbing trials. These differences may be explained by the design of the experiment, some climbers may have been more or less stressed during the second trial because they already knew which condition to expect. When climbing for 30 minutes, or until exhaustion, no differences in cortisol concentration in pre-, immediate post-, and 15 min post-climbing have been found in young male climbers (Sherk et al. 2011). Sherk et al. 2011) speculated that the low cortisol concentration increase were due to lower intensity of climbing in the prolonged protocol, than the intensity of actual sport climbing. It is also suggested that the psychological stress was reduced in this case, as all participants climbed repeatedly the same route, and were belayed using a top-rope (without any risk of fall).

The current study provides new insight regarding alterations in catecholamine concentrations during indoor sport climbing, and has made several advancements on previous research: 1) an increase in catecholamine concentrations has been found when climbing routes with greater distances between fixed points of protection; and 2) plasma cortisol concentrations do not appear to indicate levels of stress related to a fear of fall in climbing. However, the following limitations should be acknowledged. The study assessed only two fall situations – with a risk of short and long fall, the risk of fall was present in both conditions. The catecholamine response to PRO-all may have also been influenced by a fear of falling. Future studies could compare climbers with/without traditional route experience and/or with high/low level of anxiety to understand the role of adrenaline and serotonin in these specific conditions, as high inter-individual variability in adrenaline and serotonin response were found after climbing. High inter-individual serotonin variability may due to different follicular phase in participants, as estrogens have been shown to affect serotonergic activity (Borrow & Cameron 2014). Although not reported in the results, the follicular phase was not related with plasma

serotonin pre-test concentrations. Finally, as the research was undertaken only with female intermediate and advanced climbers, the hormonal response in males and/or other performance levels is purely speculative.

Conclusion

The study demonstrated a greater catecholamine response with a longer distance between fixed protections whilst indoor sport climbing. The most pronounced increases in catecholamine response were reported for dopamine and noradrenaline. Adrenaline increase appeared to be dependent on other personality and/or climbing experience related factors. Plasma serotonin was shown to increase after physical and mental stress and was also associated with adrenaline concentrations.

Perspectives

It was shown that climbing an unknown route induces ~ 500%-1000% increases in catecholamines. This increase corresponds to tasks that involve maximal and above maximal aerobic power, although climbing to exhaustion elicits only ~ 70-80% of VO_2 peak (Baláš et al. 2014; de Geus et al. 2006). Greater catecholamines response is likely to be influenced by psychological factors and fear from fall, as longer distance between points of protection induced greater noradrenaline and dopamine response. The role of adrenaline and serotonin seems to be related to climbing experience and personality type. Studies with participants of different anxiety and experience levels may help to further develop our understanding of endocrine responses in activities that induce high mental and physical stress.

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