The effect of potential fall distance on hormonal response in rock 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 while clipping all (PRO-all) or half (PRO-½) of the fixed points of protection. Venous blood samples were analysed for total catecholamines, noradrenaline (norepinephrine), adrenaline (epinephrine), dopamine, lactate, cortisol and serotonin. Differences between the two conditions pre, immediately post and 15 min post climbing were assessed using a 2 × 3 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.

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 by either 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. While sport climbing is more likely to result in chronic overuse injuries of the upper extremities (Backe, Ericson, Janson, & Timpka, 2009), traditional climbing is more likely to result in injuries arising because of a fall (Schoffl, Morrison, Schwarz, Schoffl, & Kupper, 2010). The injury risk is still considered lower than traditional sports such as football; however, fatalities can, and do, occur (Schussman, Lutz, Shaw, & Bohnn, 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, Oudejans, Holsheimer, & Bakker, 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, Fryer, Blackwell, Draper, & Stoner, 2012; Hodgson et al., 2009); however, these differences were not apparent with intermediate, advanced or elite climbers (Dickson et al., 2012; Draper et al., 2012; Fryer, Dickson, Draper, Blackwell, & Hillier, 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, Pijpers, Oudejans, & Bakker, 2008; Pijpers et al., 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 et al., 2012). Catecholamines, which are mediating hormones to physical, environmental and behavioural stressors (Zouhal, Jacob, Delamarche, & Gratas-Delamarche, 2008), may serve as a more sensitive means of quantifying psychological stress in climbers. An early study by Williams, Taggart, and Carruthers (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

Participants

Nine advanced female climbers (mean age 28.7 years, \( s = 3.8 \); 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 – without 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, 2016). 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.

Experimental settings

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-½). Climbers attended two sessions, 4 days apart, abstained from any strenuous physical activities for 24 h and food and caffeine 2 h prior to the measurements.

The session started with an hour of calm sitting during which 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 antecubital vein and the participants were randomly assigned to their first climbing condition. The climbers completed a standardised warm-up consisting of 5 min of aerobic exercises, 5 min 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 20 min was provided.

The tested routes were climbed in OS style. Immediately (within 1 min) 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 third blood sample was drawn 15 min post climb. The total time of the ascent and heart rate (HR; Polar RS 400, Finland) were recorded.

Route setting

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, with two conditions. The 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 and 1.4 metres. For the condition PRO-½, the distance between each point of protection was increased. Climbers had to clip the second, third, fifth, and then every second point of protection until the top of the route, with 2.4–2.8 metres between each quickdraw. The pairs of routes were of identical style, difficulty and inclination, ranging from slightly overhanging (−3° from vertical; 5c+) to very overhanging (−23°; 7a+). The routes were set by the same professional route setter with an optimal clipping position with the quickdraws at head height. The same person, known to all participants, belayed all ascents.

Hormonal responses

Venous blood was drawn by venipuncture into polypropylene tubes coated with ethylenediaminetetraacetic acid. Plasma was obtained by the centrifugation of blood samples (15 min, 3000× g, 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 (epinephrine), noradrenaline (norepinephrine), dopamine, serotonin and cortisol were analysed. Lactate was measured using an Advia 1800 (Siemens, Erlangen, Germany). Serotonin, cortisol and catecholamines were analysed by Liquid chromatography (LC) and mass spectrometry (MS). LC was performed using LC system Shimadzu Prominance (Shimadzu, Czech Republic) equipped by column Atlantis dC18, 100×2.1 mm, 5 µm (Waters, Czech Republic). The detection system (MS detector QTRAP 4000; ABSciex, Czech Republic) worked in the positive ionisation mode and using selected reaction monitoring for compounds detection. Nebulisation was carried out at 500°C for serotonin, 450°C for cortisol and 600°C for catecholamines, the ionspray voltage was set at 5000 V for serotonin, catecholamines and 5500 V for cortisol.

Statistical analysis

Descriptive statistics (mean, \( s \)) were calculated for all anthropometric characteristics and physiological responses. Normal distribution was assessed with a Shapiro-Wilk’s test. To assess differences between the conditions with PRO-all and PRO-½ for total time, the 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 (2×3) was performed with two within-subject factors (PRO-all × PRO-½; pre x immediately post × 15 min post measurement). If significant main effects were observed with ANOVA, Duncan’s multiple range post-hoc tests were applied to examine specific pairwise differences between clipping conditions at different time points and effect of climbing and rest on hormonal response within a clipping condition. Statistical significance was set to \( P \leq 0.05 \). Partial omega squared (\( \omega^2 \)) 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 SPPS for Windows (Version, 22, Chicago, IL, USA).

Results

Perceived exertion, HR and total time of ascent were similar for both conditions (Table 1). However, during PRO-½ three climbers fell a short distance before the top of the route. Their results were also included in the analysis. On average, the PRO-½ ascents were significantly slower than the PRO-all ascents.

Effect of clipping condition

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 ($P = 0.016$, $\omega_p^2 = 0.437$) (Figure 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 plasma lactate ($P = 0.065$, $\omega_p^2 = 0.254$). Pairwise comparisons between clipping condition showed no differences for all hormones and plasma lactate prior to climbing and 15 min post-climbing. However, immediately after climbing, climbers had greater response ($P < 0.05$) for noradrenaline and dopamine to PRO-½ (Figure 1).

Table 1. Mean ± 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-½).

|        | RPE (6–20) | Time of ascent (min:sec) | Speed (m · min$^{-1}$) | HR peak (beats · min$^{-1}$) |
|--------|------------|--------------------------|------------------------|-----------------------------|
| PRO-all | 17 ± 1     | 6:06 ± 2:17              | 4.1 ± 1.5              | 182 ± 8                     |
| PRO-½  | 17 ± 2     | 6:40 ± 2:25              | 3.5 ± 1.2*             | 179 ± 15                    |

* significant differences at $P < 0.05$.

Figure 1. Catecholamine, cortisol, serotonin and plasma lactate concentration before, immediately post and 15 min after climbing using all points of protection (PRO-all condition) and half the points of protection (PRO-1/2 condition).
Effect of climbing and rest

All hormones and plasma lactate concentrations increased significantly immediately after climbing, except for cortisol (Figure 1). There was a significant main effect of climbing on total catecholamine response ($R^2 = 0.001$, $\omega_p^2 = 0.666$), 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 min of rest ($P = 0.017$, $\omega_p^2 = 0.427$). Catecholamines and serotonin returned to basal concentration after 15 min of rest, while plasma lactate remained elevated. Pairwise comparisons between pre-climbing and post-climbing assays showed a concentration increase ($P < 0.05$) of noradrenaline, adrenaline, dopamine, serotonin and plasma lactate within both clipping conditions indicating the effect of climbing on hormonal response whatever the potential fall distance was (Figure 1). Pairwise concentration did not confirm a significant effect of climbing on cortisol response (Figure 1).

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

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, while 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-½ 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-½ 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 (Aras & Akalan, 2014; Pijpers, Oudejans, & Bakker, 2005). Further, during the PRO-½ 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, Panáčková, Jandová, et al., 2014; Fuss & Niegler, 2008).

Noradrenaline concentrations increased from basal levels by 532% in PRO-all and by 794% in PRO-½. The increase was similar in magnitude to the 500–1000% increases previously reported in tasks that involve maximal and above maximal aerobic power (Zouhal et al., 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 is 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 et al., 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 by 1920% in the PRO-½ 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 clipping 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 lower 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.

### Table 2. Relationship between climbing ability, speed of ascent and hormone responses.

| Ability (RP) | Speed | Cortisol | Lactate | Adrenaline | Noradrenaline | Dopamine | Serotonin | Catecholamines |
|-------------|-------|----------|---------|------------|---------------|----------|-----------|---------------|
| .403        | −.066 | .484*    | .250    | .043       | .252          | .488*    | .113      |
| .672*       | .673* | .409     | .247    | .182       | .360          | .310     |
| .377        | .093  | .058     | .089    | .016       | .073          |
| .654*       | .568* | .638*    | .456*   | .629*      | .870*         |
| .752*       | .727**| .590*    | .979*   | .573*      |
| .800*       | .344  | .829*    | .573*   |

* significant correlation at $P < 0.05$. 

Note: The table highlights the relationships between climbing ability (RP), speed, and hormone responses such as cortisol, lactate, adrenaline, noradrenaline, dopamine, serotonin, and catecholamines. The correlations indicate the significant relationships at $P < 0.05$. The asterisks (*) denote significant correlations.
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 glycolysis and their inhibition reduces $V_0_{\text{max}}$, plasma glucose, plasma glycerol and blood lactate concentrations (Galbo, Holst, Christensen, & Hilsted, 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-½, 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 central nervous system (CNS) after prolonged exercise is attributed to feelings of tiredness and lethargy and the onset of fatigue (Meeusen, Watson, Hasegawa, Roelands, & Piacentini, 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, Landers, Nagoshi, & Ringenbach, 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 physiology-related research to indicate the level of anxiety (Draper et al., 2012; Fryer et al., 2013; Hodgson et al., 2009). While plasma cortisol concentration is in a close relationship with cognitive and somatic anxiety (Draper et al., 2012), it appears that this relationship is only valid in lower level and intermediate climbers and not in more advanced or elite climbers (Fryer et al., 2013). This study confirmed greater plasma concentration 15 min after climbing (Fryer et al., 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 nearly significant differences ($P = 0.06$) 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 min, 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, Sherk, Kim, Young, & Bemben, 2011). Sherk et al. (2011) speculated that the low cortisol concentration increase was 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. Moreover, the condition with the longer fall does not represent a high risk situation; longer falls often appear when climbing outdoor. 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 be due to different follicular phase in participants, as oestrogen has 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 with only female intermediate and advanced climbers, the hormonal response of males and/or other performance levels is purely speculative.

Conclusions

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, or close to exhaustion, elicits only ~70–80% of $V_0_{\text{max}}$ peak (Baláš, Panáčková, Strejcová, et al., 2014; de Geus, O’Driscoll, & Meeusen, 2006). Higher catecholamines response is likely to be influenced by psychological factors and fear from fall as longer distance between points of protection induces greater noradrenaline and dopamine response.

Disclosure statement

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