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Research article

Effect of an on-sight lead on the physiological and psychological responses to rock climbing

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Abstract
Rock climbing is a multi-discipline activity that encompasses forms such as bouldering, top roping and lead climbing on natural and artificial climbing surfaces. A major focus of research has been explanation of physiological functioning. More recent research indicates that anxiety levels are elevated for less experienced climbers and in response to lead climbing ascents. Research regarding the demands of rock climbing has placed a lesser focus on the interaction of psychological and physiological factors. The objective of this study was to examine the effects of an on-sight lead climb on the physiological and psychological demands of the climb in comparison with a subsequent lead climb. Ten intermediate level climbers volunteered to complete the two climbing trials, on-sight lead climb (OSLC) and second lead climb (LC2). Climb time, lactate concentrations (baseline, pre climb, post climb and 15 min post climb), heart rate (1 min pre climb, peak HR, 1 min post climb and average climb across the duration of the climb), oxygen consumption, pre climb anxiety (CSAI-2R) were assessed for each climber for both trials. Results indicated that there were significant differences in self reported pre climb somatic and cognitive anxiety ($t_{(9)}$ = 2.79, p = 0.01, $t_{(9)}$ = 1.94, p = 0.043), climb time ($t_{(9)}$ = 3.07, p = 0.0052) and post climb lactate concentrations between the climbs ($t_{(9)}$ = 2.58, p = 0.015). These results indicate that psychological as well as physiological stress impact upon the response to rock climbing. The higher anxiety levels associated with an OSLC are likely to have influenced the physiological responses for the intermediate climbers in this study. Future studies should take into account the type of climbing, experience of climbers and the number of ascents as well as taking into account the interaction between physiological and psychological factors in response to rock climbing.

Key words: Rock climbing, on-sight lead, lactate concentration, oxygen consumption.

Introduction

As an increasingly popular adventure sport, there has been a growing research interest regarding the physiological demands of rock climbing. The period from 1990 to 2006 saw a 37,514 person increase in membership of the British Mountaineering Council (BMC - the National Governing Body for rock climbing in the UK). There are now over 63,000 UK members of the BMC and more than 150,000 active climbers in the UK alone (BMC, 2004; 2006).

Rock climbing is a multi-discipline sport encompassing a wide variety of climbing styles. Traditional climbing involves ascents of single pitch (one run-out of rope to the top of the climb) and multi-pitch (ascents of longer routes over one rope length in height requiring the ability to construct multiple belays during ascent) routes placing protection into natural features in the rock. During sport climbing, single or multi-pitch ascent the climber clips the rope to bolts that have been pre-drilled in the rock surface. Traditional climbing places an emphasis on both the technical competence of the climber and their ability to protect their ascent using the gear they carry. In sport climbing the greater focus is upon the technical moves to make an ascent and the technically hardest routes tend to be climbed in this style. Traditional and sport multi-pitch routes require one climber to lead each pitch (climbing with a rope attached placing protection during the ascent) with a second climber following up the route and removing the leader's gear ready for the next pitch. Single pitch routes can be lead climbed (LC) or top roped (TRC). In TRC an anchor is placed at the top of the climb through which the rope runs between the belayer and climber to protect against a fall. In this style of climbing the climber is well protected and has a minimal risk of a ground fall.

In the past research has placed a lesser emphasis on the style of climbing (Sheel, 2004; Watts, 2004). In addition, to date only two studies appear to have been completed on natural rock, with the remaining research being conducted on artificial climbing walls or motorised and non-motorised climbing treadwalls (Booth et al., 1999; Mermier et al., 1997; Watts and Drobish, 1998). The majority of research projects have utilised bouldering or TRC systems rather than LC perhaps due to the lower risk of a ground fall (Booth et al., 1999; Draper et al., 2006a; Draper et al., 2006b; Gerbert and Werner, 2000; Mermier et al., 1997; Mermier et al., 2000; Sheel et al., 2003; Watts et al., 2000).

Researchers have speculated about the relative contribution of aerobic and anaerobic metabolism to the total energy requirements for rock climbing. Booth et al. (1999) suggested a higher relative aerobic contribution than researchers such as Billat et al. (1995) and Mermier et al. (2000). For climbing oxygen consumption (VO_2) values of between 20 – 25 $mL\cdot kg^{-1}\cdot min^{-1}$ have been reported (Billat et al., 1995; Draper et al., 2008b; Mermier et al., 1997; Watts et al., 2000). The similar VO_2 levels identified for a number of different studies led Watts et al. (2004) to speculate about the existence of a VO_2 plateau for climbs lasting between 80 – 100 s. Above this plateau additional energy requirements during climbing appear to be supplied by anaerobic mechanisms.

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There appears, however, to be common agreement regarding the existence of disproportionate rise in heart rate (HR) relative to VO_2 when comparing treadmill running with climbing (Billat et al., 1995; Booth et al., 1999; Draper et al., 2008b; Mermier et al., 1997; Sheel et al., 2003; Watts et al., 2000). The reported values for VO_2 during climbing represented 43-45 % of each participant's VO_{2max} (Billat et al., 1995; Draper et al., 2008b; Mermier et al., 1997; Watts et al., 2000). During climbing the mean HR for the reported VO_2 values represented about 80 % of HR_{max} (Billat et al., 1995; Draper et al., 2008b; Mermier et al., 1997; Watts et al., 2000). The disproportionate rise in HR has been suggested to relate to factors such as the relatively high loading on the upper body muscles, the intermittent isometric contractions associated with gripping or elevated anxiety levels related to a fear of falling.

Reviews regarding the physiology of rock climbing have indicated the need for researchers to take into account the style of climbing when making comparisons between studies. (Sheel, 2004; Watts, 2004). Research by Draper et al. (2008a; 2008b) revealed differences in the physiological and psychological responses to differing forms of climbing. The findings of these studies indicated that climb time, post-climb lactate concentrations, peak HR, average HR and self-reported anxiety (CSAI-2R) were significantly higher for lead climbing (LC) than for top-roping (TRC). In agreement with these findings, Hardy and Hutchinson (2007) identified significantly elevated anxiety levels for lead climbing when compared with top-rope climbing. Further to this, research by Janot et al. (2000) found pre climb HR and climbing HR were significantly elevated for beginner climbers when compared with more experienced climbers. The HR differences in this study being attributed to increased anxiety levels in the beginner climbers. It is now widely accepted that the threat of physical harm leads to higher levels of anxiety and these are manifest through physiological and psychological measures (Chapman et al., 1997; Hardy and Hutchinson, 2007; Morris et al., 1981; Terry and Slade 1995).

The inherent threat of physical harm in climbing means the stress associated with rock climbing is related to the interaction of physiological and psychological factors as dictated by the form of climbing undertaken and experience of the climber. The importance of anxiety management has been consistently identified by writers in the field and more recently researchers have investigated the dual stresses associated with climbing performance (Draper et al. 2008a; Goddard and Neumann, 1993; Hardy and Hutchinson, 2007; Hörst, 2003). For rock climbers the purest style of ascent is a lead climb with no prior practice, referred to as an on-sight lead climb (OSLC). Research suggests that the experience of climbers and the form of ascent have an effect on the anxiety levels of climbers. To date the influence of prior practice on the response to climbing has not been reported. The objective of this study was to examine the physiological and psychological responses to an OSLC in comparison to a subsequent LC.

Methods

Participants

Ten male intermediate level rock climbers volunteered to take part in this study. The mean ± SD age was 20.3 ± 1.05 yr, height 1.77 ± 0.07 m, mass 69.96 ± 6.05 kg, bodyfat 9.61 ± 2.92 %, maximal oxygen uptake (VO_{2max}) 57.96 ± 6.08 $mL \cdot kg^{-1} \cdot min^{-1}$, heart rate maximum ($HR_{max}$) 195 ± 8 $bts \cdot min^{-1}$. The climbers had approximately three years climbing experience, training two – three times per week and a highest technical grade on a traditional (placing gear in natural rock) lead climb of 4b or 4c (British technical grade). A comparison of technical grading systems commonly used in rock climbing can be seen in Table 1. The climbers in the study had experience on at least three types of natural rock, as well frequent use of artificial climbing walls. The participants were fully acquainted with the nature of the study prior to giving written informed consent to participate and completing a health history questionnaire. Ethical approval for the study was obtained from the University of Chichester ethics committee.

TABLE 1. A comparison of international climbing grades. UIAA is the Union Internationale des Associations d'Alpinisme. In the UK traditional (where gear is placed during the ascent) routes receive two grades, a number grade for the hardest technical move on the route and an adjectival grade describing the overall feel of the climb including the amount of gear that can be placed on route.

UIAA	USA	UK	Sport Grade
I	5.1	Moderate	1
II	5.2	Moderate	2
III	5.3	Difficult	2+
IV	5.4	Very Difficult	3-
IV+	5.5	Hard Very Difficult	3
V-	5.6	Severe	3+
V	5.7	3c/4a	4
V+	5.8	4b VS	4+
VI-	5.9	4c	5
VI	5.10a	5a HVS	5+
VI+	5.10b	5b E1	6a
VII-	5.10c	5c E2	6a+
VII	5.10d	5c	6b
VII+	5.11a	5c	6b+
VII+	5.11b	6a E3	6c
VIII-	5.11c	6a	6c+
VIII	5.11d	6b E5	7a
VIII+	5.12a	6b	7a+
IX-	5.12b	6b E6	7b
IX-	5.12c	6c	7b+
IX	5.12d	6c	7c
IX+	5.13a	6c E7	7c+
X-	5.13b	7a	8a
X-	5.13c	7a E8	8a+
X	5.13d	7a	8b
X+	5.14a	7a	8b+
XI-	5.14b	7b E9	8c
XI	5.14c	7b	8c+
XI+	5.15a	7b	9a+

Experimental Overview

The participants completed two climbing trials, an (OSLC) and a second lead climb (LC2). Each participant completed familiarisation climbs on a different route wearing the HR monitor and portable gas exchange analyser to be used in the data collection. For the OSLC climbers arrived at the wall having completed a warm-up, but with no prior knowledge of the route to be climbed. Only when the climbers were ready to make the lead climb (LC) was the route revealed and explained to each participant. The participants then had time to study the route prior to commencing their ascent.

The climbers were asked to refrain from exercise the day before testing and to avoid eating within 2 h of testing. A minimum of two days was given between each trial. The results of paired samples t-tests revealed that there were no significant differences for temperature, relative humidity and wind speed across the two climbs. The means and SD across trials were: temperature 16.33 ± 2.05 ºC, atmospheric pressure 762.24 ± 8.13 mmHg, relative humidity 68.75 ± 10.38 % and wind speed 3.47 ± 2.51 kmh. Participants completed the same warm-up protocol prior to each trial which involved five min of light jogging, mobilising exercises, natural feature familiarisation and a lower grade practice climb. After a shake-out and mental preparation the participants completed each trial without weighting the rope (Goddard and Neumann, 1993; Hörst, 2003). Each climbing trial was conducted with the climber wearing a HR monitor and portable pulmonary gas exchange analyser.

Capillary blood samples for lactate analysis were taken in the laboratory before the start of climbing (baseline), after the warm-up (pre climb), post climb and 15 min post climb, following the method described by Draper et al. (2008a). Each participant completed the Revised Competitive State Anxiety Inventory-2 (CSAI-2R) questionnaire after their pre-climb capillary blood sample was collected (Cox et al., 2003). To enable a fuller evaluation of the oxygen consumption and HR data during climb at least two days prior to the climbing trials each participant completed a treadmill VO_{2max} test using the athlete led protocol (ALP) as described by Draper and Hodgson (2008). In this protocol the treadmill speed is increased by 1 kmh during each min of the test, from a starting speed of 6-8 kmh until the athlete points up with their finger. From this point the load is increased by 1 % rises in gradient each min until the participant reached volitional exhaustion. The tests were completed on a Pulsar® treadmill (h/p/ Cosmos®, Nussdorf-Traunstein, Germany) with Douglas bag pulmonary gas sampling. The HR_{max} and VO_{2max} were recorded for each participant. Bodyfat measurements were assessed using a Tanita BC-418MA segmental composition analyser (Tanita Corporation, Tokyo, Japan).

Procedures

The climb

The 9.38 m high climb (Figure 1), with a technical grade of 5b, was constructed by an experienced route setter on an outdoor artificial wall (Off the Wall, Kendal, UK). The route was designed to minimise the number of Entre-prise® bolt-on holds (Entre-prise, Kelbrook, UK) and maximise the use of the natural features in the wall. Climbers were able to use the natural features on the wall and bolt-on holds for hands and feet during the ascent.

Blood analysis

Arterialised capillary blood samples were collected from the little finger of each climber to minimise the impact on grip during the climb. Prior to blood collection the little finger of each participant was prepared using a non-alcohol mediwipe. Capillary blood samples (100 µL) were collected from the finger using a lithium-heparin CB300LH Microvettes® (Sarstedt Aktiengesellschaft & Co., Nümbrecht, Germany). To avoid the risk of 'milking' the finger and possibility of lysing red blood cells during the sampling procedure 1.6 mm (puncture depth) Haemolance Plus Max Flow lances (Hemocue® Ltd., Dronfield, UK) were used for all samples drawn during the study. The samples were kept on ice before lactate analysis within 15 min of collection. The lactate analyses were conducted using a YSI 2300 Stat Plus (Yellow Springs Instruments, Ohio, USA). The YSI 2300 was calibrated and checked against standard solutions prior to use. The YSI 2300 used a 25µl blood sample that was haemolysed (YSI 1515 Lysing Agent) and stabilised (YSI 2357 Buffer).

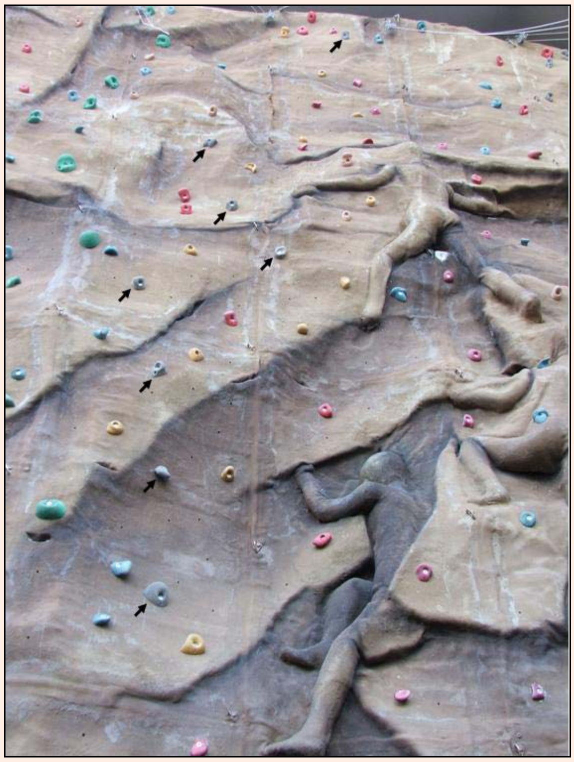

Figure 1. The route for the climb and the angle of the wall (90° from horizontal). Climbers followed the arrowed holds and features for hands and feet during ascent of the climb. The number of bolt-on holds (arrowed) was kept to a minimum to ensure the climb was as close to climbing on natural rock as can be achieved on an artificial wall.

Oxygen consumption, heart rate and CSAI-2R

For each trial the climbers wore a Cosmed K4b^2 portable pulmonary gas exchange analyser (Cosmed, Rome, Italy) and Polar PE 3000 HR monitor (Polar Electro Oy, Kempele, Finland) to record oxygen consumption (VO_2), HR and climb time. The K4b^2 was room air, gas, turbine and delay calibrated between participants. Total climb time, HR one min pre climb, peak HR, mean HR and HR one min post climb were recorded for each trial. The CSAI-2R

Table 2. Means (± SD) for climb time, mean VO_2 and average HR for the two lead climbs.

	On-sight Lead Climb	2nd Lead Climb
Climb time (s) *	213 (46)	199 (33)
Mean VO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$)	26.54 (2.46)	25.98 (2.48)
Average HR ($bts \cdot min^{-1}$)	161 (6)	159 (6)
CSAI-2R		
Somatic Anxiety (Pts) *	17.7 (7.0)	14.3 (5.7)
Cognitive Anxiety (Pts) *	22.6 (5.9)	19.0 (8.3)
Self Confidence (Pts)	26.6 (5.5)	26.2 (5.2)

* indicated significant ($p < 0.05$) differences between trials.

questionnaire as revised by Cox et al. (2003) was completed by each climber prior to both climbs to provide an insight into the levels of state anxiety for each lead climb.

Statistical analysis

After checking for normality of distribution of the descriptive data, using the Kolmogorov-Smirnov test, means and standard deviations were calculated for self reported anxiety levels (CSAI-2R), lactate concentrations, oxygen consumption during climb, HR data and climb time. Paired samples t-tests were calculated for each variable to identify statistical differences between the climbs with a one-tailed alpha level of $p < 0.05$ used to determine significance. The analyses were calculated using the SPSS 12.0.1 for Windows and Microsoft excel software packages.

Results

The Kolomogorov-Smirnov test results indicated normality of distribution for all variables within the study. Descriptive data for climb time, VO_2, average (across the length of the climb) HR and CSAI-2R are displayed in Table 2. The results for mean VO_2, and average HR were very similar, with differences of less than 1 $mL \cdot kg^{-1} \cdot min^{-1}$ and 2 $bts \cdot min^{-1}$, despite the 32 s mean difference in climb time for the two climbs. Results indicated that the OSLC took longer to complete for all ten participants in the study. Paired samples t-tests for each of these variables indicated there were non-significant differences between the climbs for mean $VO_2$and average HR across the climb. There was, however, a significant difference between the climb times ($t_{(9)} = 3.07$, $p = 0.0052$).

As can be seen in Table 2, there was a decrease in mean pre-climb somatic and cognitive anxiety reported by the participants for LC2 when compared with the OSLC. The mean scores for self-confidence were similar, with a small (0.4 pt) difference reported between the two climbs. The results of three paired samples t-tests indicated that there was a significant difference between mean self-reported scores for somatic anxiety ($t_{(9)} = 2.79$, $p = 0.01$) and cognitive anxiety ($t_{(9)} = 1.94$, $p = 0.043$), while there was a non-significant difference for self-confidence.

Figure 2 provides the mean lactate concentration results for the two lead climbs. There were non-significant differences between the lactate concentrations for the baseline and pre climb assays. Post climb the mean lactate concentration was significantly higher for the OSLC than for LC2 ($t_{(9)} = 2.58$, $p = 0.015$). Fifteen min post climb the mean lactate concentrations had dropped by over 2.0 $mmol \cdot l^{-1}$ and there was only a 0.05 $mmol \cdot l^{-1}$ non-significant difference between the climbs.

The mean HR data for one min pre climb, peak HR and one min post climb are shown in Figure 3. The HR

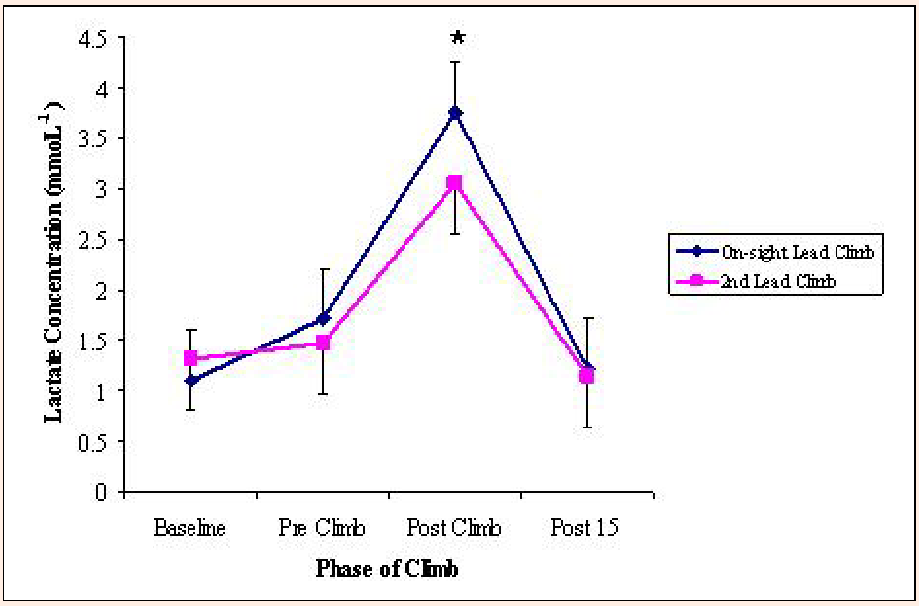

Figure 2. Capillary blood lactate concentrations for each the two lead climbs. *p = 0.015.

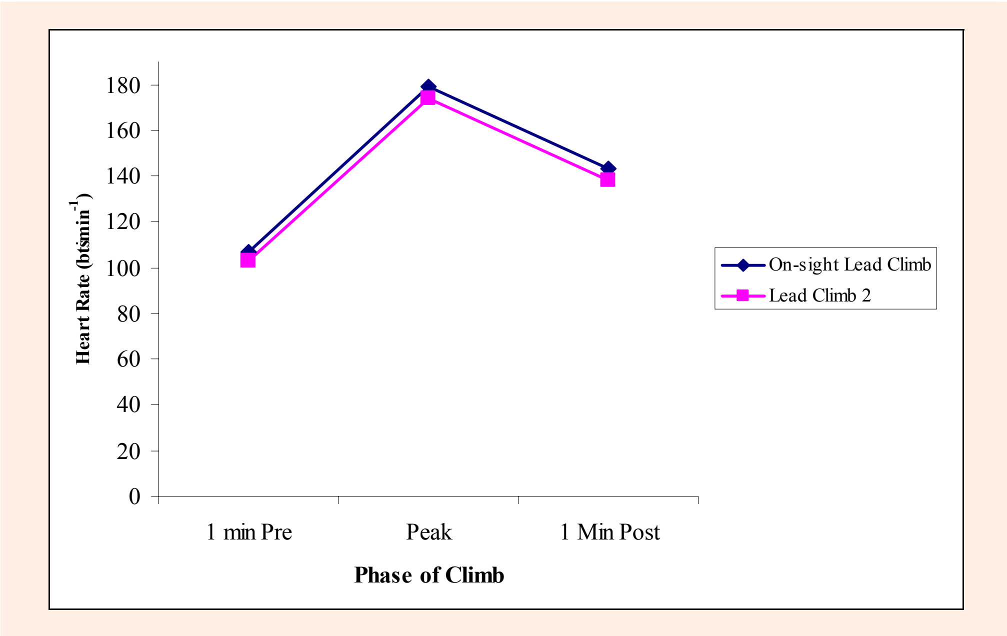

Figure 3. Mean HR for one minute pre climb, peak HR on the climb and one minute post climb for the OSLC and LC2.

for each of these variables follows a very similar pattern for both climbs. There was a maximum of a 6 bts·min^{-1} difference between the two lead climbs with HR for OSLC being higher at each time point. There appears to be a similar HR response to the OSLC and LC2 as the results of the paired samples t-tests for each time point indicated that the differences in HR between the climbs were non-significant.

Discussion

The focus of this study was an investigation of the effects of prior knowledge of a climb upon the physiological and psychological responses pre, during and post performance. The results indicate that mean climb time, VO_2, and average HR were higher for the OSLC (Table 1). The mean climb time for LC2 were very similar to those reported by Draper et al. (2008b) which were on the same height of climb (9.38 m). The mean climb time for the OSLC was significantly slower ($p = 0.0052$) and this can be most likely attributed to the additional time required for route planning during a first ascent. The mean VO_2 of approximately 25 mL·kg^{-1}·min^{-1} for the two conditions in this study was similar to that obtained in previous research and may indicate that the oxygen consumption plateau suggested by Watts (2004) for climbs between 80 – 100 s may extend to climbs of up to 240 seconds or more.

The mean VO_2 for climbing in this study represented 46% and 45% of treadmill VO_{2max} for the OSLC and LC2 respectively. These results are in agreement with those found by Billat et al. (1995) and Draper et al. (2008b) for artificial wall climbing. The type of climbing does appear to have had an impact upon the percentage of VO_{2max} utilised during performance. For bouldering VO_2 represented 33-38% of VO_{2max} whereas for other forms of climbing higher values of 45% have been reported during LC/TC and figures of up to 60% treadwall climbing (Billat et al., 1995; Draper et al., 2008b; Watts and Drobish, 1998).

The significant differences found for the mean scores CSAI-2R somatic and cognitive anxiety ($p = 0.01$ and $p = 0.043$ respectively) and mean lactate concentrations post climb ($p = 0.015$) are indicative of the interaction between the physical and emotional aspects within climbing. The climbers in the present study found the OSLC condition more anxiety inducing than a subsequent LC. In combination with the increased climb time the elevated anxiety levels pre-climb are the most likely explanations for the differences found in mean lactate concentrations post climb. It is of interest to note that although there was a significant difference between the mean lactate concentrations post climb for the OSLC and LC2 by the 15 min sampling the mean lactate concentrations were similar 1.20 and 1.15 mmol·L^{-1} respectively. During the time between the two post climb samples each participant returned from the climbing wall to the laboratory, a distance of 146 m. Each participant walked slowly to the laboratory and remained seated until the 15 min post climb sample was collected. The similarity in the mean 15 min post climb lactate concentrations are perhaps related to the good levels of aerobic fitness indicated through the relatively high VO_{2max} scores for the participants. The good levels of aerobic fitness may have assisted with blood lactate removal during the recovery.

Although there has been a research focus upon the physiological responses to rock climbing there has been less attention directed towards the form of climbing and the number of trials and their effect on the physiological and psychological responses to climbing. Previous studies have tended to discretely investigate psychological issues and physiological responses to rock climbing, rather than applying an inter-disciplinary approach to the study of rock climbing (Llewellyn et al., 2008; Llewellyn and Sanchez, 2008; Morrison et al., 2007). In sports where there is a threat of physical harm the influence of anxiety must also be taken into account (Chapman et al., 1997; Hardy and Hutchinson, 2007; Morris et al., 1981; Terry and Slade 1995). The results of studies by Janot et al. (2000), Hardy and Hutchinson, (2007) and Draper et al. (2008a, 2008b) provide evidence for the need of such an approach for research related to rock climbing. These studies indicate that the form of climbing, LC or TRC, and experience of the climbers had a significant effect on psychological and physiological responses to climbing. The results of the present study indicate that in a LC situation the number of practice trials also affects performance.

A useful direction for future research in the area of rock climbing would be to focus upon delineation of the interaction between physical and emotional factors and how they influence responses in different situations. Specifically, an examination of the influence of climbing experience upon the psychological and physiological responses to climbing would be of benefit for those interested in understanding performance for rock climbing. In addition, the examination of the rock type and its influence on responses to climbing could usefully become the focus of future studies. A great deal of research remains necessary to expand the climbing knowledge base to such an extent that the dynamic interplay between factors associated with rock climbing performance can be more fully understood. In adventure sports such as rock climbing an inter-disciplinary approach may provide the most beneficial way forward in understanding the factors that affect performance.

Conclusion

The results of this study suggest that the oxygen consumption plateau suggested by Watts (2004) may extend beyond 100 s and up to 240 s or more. Previous studies have indicated that there are differences in the physiological and psychological responses to different forms of rock climbing. The results of this study indicate that there are also differences over time within the same form of climbing. Prior knowledge of the route affects the physical and emotional responses to the stress of climbing. Researchers need to take into account prior practice of a route as well as the form of climbing when making comparison between studies.

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Key points

- For intermediate climbers, there are significant differences in physiological and psychological responses to on-sight lead and subsequent lead climb.
- There was an increased psychological and physiological load for leading a climb for the first time (on-sight).
- These results indicate that the type of climbing should be taken into account when interpreting results from climbing studies with intermediate or recreational climbers.

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