

# Influence of climbing style on physiological responses during indoor rock climbing on routes with the same difficulty

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**Abstract** The objectives of this study were to (1) continuously assess oxygen uptake and heart rate; (2) quantify the extent to which maximal whole-body cardiorespiratory capacity is utilized during climbing on four routes with the same difficulty but different steepness and/or displacement. Fifteen expert climbers underwent a maximal graded exercise test (MT), on a treadmill, in order to assess their maximal physiological capacity. After MT, four sport routes, equal in difficulty rating but different in steepness and/or displacement, were climbed. Oxygen uptake and heart rate were continuously measured. Respiratory exchange ratio (RER) was calculated. Blood lactate concentration and rating of perceived exertion (RPE) were taken before and directly after climbing. Data were expressed as peak values (HR<sub>peak</sub>, VO<sub>2peak</sub> and RER<sub>peak</sub>) and as averages over the entire climb (HR<sub>avg</sub>, VO<sub>2avg</sub> and RER<sub>avg</sub>). During climbing, higher HR<sub>peak</sub> and HR<sub>avg</sub> were found in routes with a vertical upward displacement in comparison to traversing routes with a horizontal displacement. The average absolute and relative oxygen uptake was significantly lower in the traversing route in comparison with the three other routes. The traverse is done at a lower percent of the running maximum. Comparing four routes with the same difficulty but different steepness and/or displacement shows that (1) routes with an upward displacement causes the highest peak and average heart rate; (2) routes with a vertical displacement

on overhanging wall is physiologically the most demanding; (3) the traverse is physiologically the less demanding.

**Keywords** Steepness · Displacement · Heart rate · Oxygen uptake · Treadmill

## Introduction

Rock climbing is a sport with a rapid growth in popularity over the last decades both as a recreational physical activity and as an international competitive sport (Mermier et al. 1997; Morgan 1998; Sheel 2004). Sport climbing is the branch of climbing in which the element of danger is reduced by pre-placing protection points in the rock or indoor wall. Because the danger element is largely removed, the physical difficulty can be high, which allows a wide range of climbing styles and intensities.

The recent surge of interest in rock climbing has generated questions regarding how to maximize climbing performance through the design of specific physical training and conditioning plans (Watts et al. 2000). Knowledge of the metabolic and cardiovascular responses in rock climbing is useful to prescribe exercise, give guidelines and evaluate training methods. Energy expenditure rate is of value in the design of climbing-specific physical training programs and for establishing training volumes. The contribution of the physiological components may vary as the nature and difficulty of climbing changes. There are multiple elements, which play a role in the difficulty of a climbing route such as the size of hand and foot holds, distance between holds, the steepness of the terrain and the displacement (Sheel 2004).

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Previous studies (Mermier et al. 1997; Watts and Drobish 1998; Sheel et al. 2003) in indoor rock climbing investigated the effect of an increasing difficulty on physiological responses. Mermier et al. (1997) and Watts and Drobish (1998) combined a higher difficulty of climbing with climbing on steeper, more overhanging terrain. Watts and Drobish (1998) worked with a fixed route, set at different angles of steepness. Mermier et al. (1997) increased the difficulty by setting climbs on walls with steeper angles and with smaller and fewer handholds and footholds. Their results showed that while the heart rate increased with climbing angle (increasing difficulty),  $\text{VO}_2$  did not vary significantly. Sheel et al. (2003) used two climbing routes that were rated as “harder” or “easier” based on the climbers’ previous best climb. The angle of the wall was consistent for each climb; only the positioning and size of the holds altered the difficulty of the climb. Sheel et al. (2003) showed that heart rate and oxygen consumption were significantly higher during harder climbing, compared to easier climbing. However, these three authors concluded that climbing seems to cause a disproportional rise in heart rate compared with oxygen consumption and that the traditional HR– $\text{VO}_2$  relationship should not be used in the analysis of this sport or for prescribing exercise intensity for climbing activities.

In order to maximize the climbing performance and to prescribe training programmes, the physiological demand of climbing should be well known. As a consequence, the physiological nature of climbing and different climbing styles should be studied on different routes, during a whole climb and not only at the end of a route. As mentioned above, not only the steepness but also the displacement will have an influence during climbing. Vertical and overhanging walls represent two specific situations, associated with specific postural constraints (Noé et al. 2001).

The objective in this study was to assess if climbing routes, different in steepness and/or displacement, but not in difficulty, would affect the physiological responses. In the light of this objective the same expert climbers all climbed routes with the same difficulty rating, but different in steepness and/or displacement. We hypothesized that climbing a ‘*traverse*’ is physiologically less demanding and that climbing would require utilization of a significant fraction of maximal values obtained during a graded exercise test to exhaustion on treadmill.

## Materials and methods

Fifteen male ( $21.4 \pm 4.3$  years) sport climbers with the ability to regularly climb without preview (on sight, a-vue)

with the range of 7b–8a, according to the French grading system, volunteered to participate in the study. Climbers who had no competitive climbing experience in the last year prior to the start of the study and/or who were not able to regularly climb a 7b without preview were excluded from the study. All participants read and signed an informed consent statement, prior to the start of the study. The study protocol was approved by the ethical committee of the Vrije Universiteit Brussel. The physical characteristics and climbing level of the participants are listed in Tables 1 and 2, respectively.

Prior to participation, all participants underwent a medical examination in the medical department of our laboratory. Body weight and body composition were assessed with a Tanita Body Composition Analyser (TBF 300, Japan). During the same day a maximal exercise test was performed on a treadmill (Woodway® GmbH, Ergo ELG 55, Weil am Rhein, Germany) in order to measure their maximal physiological performance.

At least 1 week after the maximal exercise test in the laboratory, the climbers had to come twice to the

**Table 1** Characteristics and baseline data of the 15 subjects

Age (years)	21.4 ± 4.3
Height (cm)	176.1 ± 4.2
Weight (kg)	64.1 ± 7.9
BMI	20.7 ± 2.1
Fat%	6.7 ± 2.4
Fat mass (kg)	4.5 ± 1.9
Free fat mass (kg)	60.8 ± 4.9
Experience (years)	9.4 ± 3.6
Training (h week <sup>-1</sup> )	13 ± 4

Values are means ± SD

**Table 2** Climbing level of the participants for indoor and outdoor (rock), ‘on sight’ (a-vue) and ‘redpoint’ (après travail) in overhanging and vertical walls, according to the French quoting system

	Modus	Median
Indoor		
On sight		
Overhanging wall	7c (33%)	7c
Vertical wall	7b (47%)	7b
Redpoint		
Overhanging wall	8a (40%)	8a
Vertical wall	7c (40%)	7c
Outdoor		
On sight		
Overhanging wall	7b, 7b +, 8a (27%)	7b +
Vertical wall	7b (40%)	7b +
Redpoint		
Overhanging wall	8a (46%)	8a
Vertical wall	8a (33%)	8a

climbing gym, with at least 1 week in between. On each day the climbers had to climb two different routes. Between the two climbs, they had to rest 30 min, in order to let their heart rate return to resting heart rate. Subjects were asked not to be involved in any physical activity the day prior to the testing days.

#### Maximal exercise test

Maximal physical performance was determined by a maximal graded exercise test on a treadmill with a starting speed of 5.4 km h<sup>-1</sup>. The running speed was increased every 3 min by 1.8 km h<sup>-1</sup>. The participants were encouraged to exert themselves until volitional exhaustion. The decision to stop was based on signals of extreme fatigue and was confirmed by a heart rate that approximated the theoretical maximal heart rate (220–age).

Oxygen uptake ( $\dot{V}O_2$ ), carbon dioxide production ( $\dot{V}CO_2$ ) and minute ventilation ( $\dot{V}E$ ) were measured throughout the test using a portable cardiopulmonary indirect breath-by-breath calorimetry system (MetaMax<sup>®</sup> 3B, Cortex Biophysik, Germany). The MetaMax<sup>®</sup> was fixed onto a chest harness worn by the participant. A flexible facemask (Cortex Adult Face Mask) covered the subject's mouth and nose. Before each test, gas and volume calibration took place with a 3 l syringe, according to the manufacturer's guidelines. The oxygen analyser was calibrated with known gas mixtures of 18% O<sub>2</sub> and 5% CO<sub>2</sub>. The room air calibration was automatically run before each test to update the CO<sub>2</sub> analyser baseline and the O<sub>2</sub> analyser gain so that they coincided with atmospheric values. Data were averaged using a moving average over seven breaths (Robergs and Burnett 2003).  $\dot{V}O_{2peak}$  was defined as the highest  $\dot{V}O_2$  attained during MT over a time interval of 30 s (Wasserman et al. 1999). Respiratory exchange ratio (RER) was calculated by dividing the measured CO<sub>2</sub> by the measured O<sub>2</sub>. Heart rate was recorded through the MetaMax<sup>®</sup> via a Polar<sup>®</sup> X-Trainer Plus (Polar Electro OY, Kempele, Finland) measurement system. Maximal heart rate (HRmax) was defined as the highest heart rate attained during the test. In order to measure the lactate concentration

blood samples (20  $\mu$ l) were drawn from an arterialized ear lobe, before the start of the maximal exercise test and at the point of exhaustion. Lactate concentrations were determined enzymatically (EKF, BIOSEN 5030, Magdeburg, Germany). Participants were also requested to state their rate of perceived exertion (RPE) according to Borg scale (Borg 1962) of 6–20 before and at the end of the test.

#### Climbing test

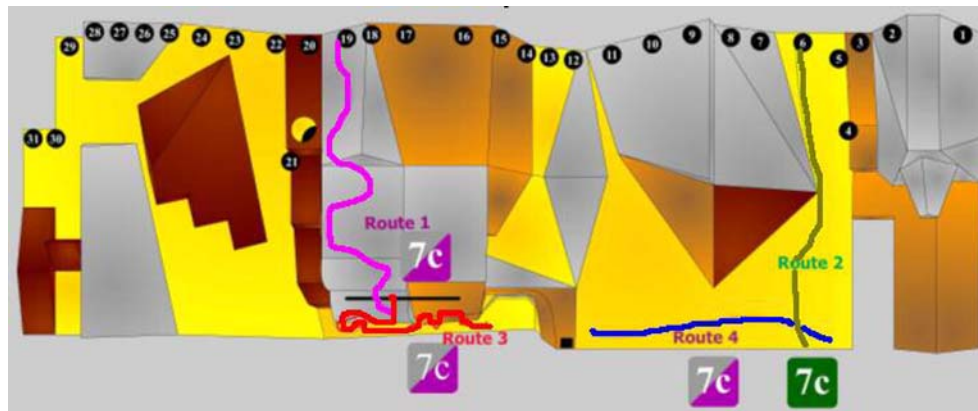
Climbing tests consisted of four sport routes carried out on two separate occasions (two routes per test day) on an artificial wall in a climbing gym, with at least one rest week between the first and second test day. The order of the routes was randomly attributed. Prior to the testing days subjects were asked to 'work out the moves' on the testing routes. Four tries per route were granted.

The four testing routes were equal in difficulty rating (7c) but different in steepness and/or displacement. A professional route builder constructed the testing routes. Every route had, from the start to the end, the same difficulty, meaning that easy resting spots or boulder passages were minimized. Six independent climbers who did not participate in the study assessed the difficulty of the routes. The evaluation procedure was carried out so that the six climbers did not influence each other. If necessary, the route was changed to obtain four routes with the same difficulty rate. Route OR was a climbing route with a vertical displacement on an overhanging wall. Route VR had a vertical displacement on a vertical wall. Route OT was an almost horizontal overhanging roof with horizontal displacement (roof). Route VT had a vertical displacement on a vertical wall (traverse). The characteristics and schematic overview of the four routes are listed in Table 3 and Fig. 1, respectively. Arrangements were made with the climbing gym staff to refrain from moving any holds on the four routes until the end of the study.

On the day of testing all subjects reported to the climbing gym with their own climbing harness, shoes and chalk bag and refrained from exercising at least 12 h before testing, and eating at least 2 h before testing. We

**Table 3** Characteristics of the four sport routes

Route	Difficulty rating	Gradient	Length (m)	Number of moves	Course
OR: vertical displacement on overhanging wall	7c	120°–135°	17	33	↑
VR: vertical displacement on vertical wall	7c	90°	15.5	26	↑
OT: horizontal displacement on horizontal overhanging roof	7c	135°–180°	16	26	→
VT: vertical displacement on vertical wall (traverse)	7c	90°	13	29	→



**Fig. 1** Schematic course of the four climbing routes on a three dimensional sketch of the climbing gym

did not dictate the speed at which climbers had to complete the routes as we wished to quantify the physiological response to climbing in a “field” setting. Climbers were encouraged to climb continuously and pauses for rest were not to last longer than 5 s and only used in order to put chalk on their hands. They all followed the same warm up with 10 min rest between the three warm up routes (rating: 6a, 6b+, 7a). They had to rest 30 min between the last warm up route (7a) and the first testing route and another 30 min between the first and the second testing route. The time spent on each testing route was measured from the moment the subject had the first grip in his hand until he finished the route. If a fall occurred during climbing, the subject was instructed to immediately remount the climbing wall and continue climbing. Top ropes were used for safety reasons; however, subjects climbed without aid from any rope tension and resting on the rope was not allowed. Only two falls were allowed per testing route. If a third fall occurred, then the test was immediately terminated and the subject had to try later on after a rest period of 30 min.

Resting heart rate was determined when arriving in the climbing gym. Heart rate and gas exchange were continuously measured with the same equipment as used during the maximal exercise test. Volume and gas calibration were conducted in the same way as described above. Before each individual test, an ambient air measurement was performed according to the manufacturer’s prescriptions. Before averaging, data were inspected for non-physiological values that can occur with breath-by-breath data collection. Data collection and averaging started when the subject left the ground and ended when the end of the route was reached. By dividing  $VO_{2peak}$  by the  $VO_2$  measured during the climbing tests, the relative oxygen consumption (% $VO_2$ ) was calculated. The same method was used for calculating the %HR, %RER, %Lct and %RPE (Spelman et al. 1993). Five blood samples were

taken in the ear lobe in order to determine the blood lactate concentration. The first one was taken before warming up and the other four before and directly after the two testing routes, as soon as the climber reached the ground. Blood samples were stored in a cooling box and analysed the same day and with the same equipment. RPE was asked before and after each testing route.

#### Statistical analysis

Data analysis was carried out using the Statistical Package for the Social Sciences (SPSS, 13.0, Inc., Chicago, IL, USA).

The one-sample Kolmogorov–Smirnov goodness of fit test was used to test whether the outcome variables had a normal distribution. Results showed that the distribution was normal. The values were averaged among the subjects to obtain group means ( $\pm$  SD). Repeated measures ANOVA for parametric data was used to test for differences between climbing routes. When significant  $F$  ratios were found ( $P < 0.05$ ), paired sample  $t$  tests with Bonferroni correction were carried out to indicate between which routes differences existed. For the RPE a Friedman test for non-parametric data was used to test for differences between the four climbing routes.

To calculate the relative intensity, a percent difference was calculated between the individual values measured during their maximal exercise test and the peak values and mean values measured during the climbing.

#### Results

The results of the maximal exercise test on the treadmill are presented in Table 4.

**Table 4** Results of the maximal exercise test on treadmill

HRmax (beats min <sup>-1</sup> )	192 ± 13
VO <sub>2</sub> max (l min <sup>-1</sup> )	3.321 ± 0.510
VO <sub>2</sub> max kg <sup>-1</sup> (ml kg <sup>-1</sup> min <sup>-1</sup> )	52.20 ± 5.06
VE (l min <sup>-1</sup> )	123.9 ± 21.1
RERmax	1.16 ± 0.13
Lactate (mmol l <sup>-1</sup> )	10.27 ± 2.10
RPE	18 ± 1

Values are means ± SD

Table 5 shows the time, speed and the peak heart rate, oxygen uptake, RER, lactate and RPE measured during the climbing routes. The HR<sub>peak</sub> measured during VT (traverse) was significantly ( $P < 0.016$ ) lower than during OR and VR. The highest RER values measured during OT was significantly ( $P < 0.016$ ) higher than the RER values measured during VT. Lactate concentrations measured at the end of OR were significantly ( $P < 0.016$ ) higher than at the end of VT. No statistical difference could be found among the four climbing routes for the peak VO<sub>2</sub>, VO<sub>2</sub> kg<sup>-1</sup> and RPE.

Climbers spent significantly ( $P < 0.016$ ) more time on route VR in comparison with route OR and VT and climbed significantly ( $P < 0.016$ ) faster in routes OR

and OT in comparison with routes VR and VT. The climbers indicated to be equally fatigued after having climbed the four routes.

The average heart rate, oxygen uptake, RER and energy expenditure are listed in Table 6. The results indicate that the HR<sub>avg</sub> was significantly ( $P < 0.0083$ ) higher in the routes with a vertical upward displacement (OR and VR), compared to traversing routes with horizontal displacement (OT and VT). The absolute (VO<sub>2</sub>avg) and relative (VO<sub>2</sub> kg<sup>-1</sup>avg) oxygen uptake capacity for VT was significantly ( $P < 0.016$ ) lower than in the three other routes. No statistical difference could be found between the four routes for RER<sub>avg</sub> values.

The relative intensity of climbing is shown in Table 7. The average absolute and relative %VO<sub>2</sub> values measured during traverse (VT) were attained at a significantly ( $P < 0.016$ ) lower percentage of the maximal values measured during the treadmill test in comparison with the three other routes. The average %HR measured during the routes with vertical displacement (OR and VR) is a significantly ( $P < 0.0083$ ) higher percentage of the maximal values measured during the treadmill test in comparison with the routes with

**Table 5** Time, speed, peak heart rate (HR), peak oxygen consumption (VO<sub>2</sub>), lactate (Lct) and RPE values measured in the four climbing routes

Route	Time (s)	Speed (m min <sup>-1</sup> )	HR <sub>peak</sub> (beats min <sup>-1</sup> )	VO <sub>2</sub> peak (l min <sup>-1</sup> )	VO <sub>2</sub> peak (ml kg <sup>-1</sup> min <sup>-1</sup> )	RER <sub>peak</sub>	Lct (mmol l <sup>-1</sup> )	RPE
OR	189 ± 25 <sup>bb</sup>	5.5 ± 0.7	175.1 ± 13.9	2.602 ± 0.429	41.62 ± 4.19	1.15 ± 0.17	6.19 ± 1.61	16.7 ± 2.3
VR	244 ± 38	3.9 ± 0.6 <sup>a</sup>	173.8 ± 8.8	2.716 ± 0.547	44.10 ± 5.82	1.12 ± 0.13	5.95 ± 1.80	14.7 ± 2.6
OT	190 ± 68	5.6 ± 1.8	167.3 ± 9.9	2.575 ± 0.417	40.50 ± 4.36	1.12 ± 0.09	5.55 ± 1.66	15.9 ± 2.0
VT	195 ± 47 <sup>bb</sup>	4.2 ± 1.0 <sup>aa,c</sup>	164.5 ± 10.5 <sup>aa,b</sup>	2.451 ± 0.333	39.14 ± 5.38	1.01 ± 0.12 <sup>cc</sup>	4.84 ± 1.30 <sup>aa</sup>	15.0 ± 2.3
Mean	202 ± 51	4.4 ± 1.4	170.0 ± 11.7	2.576 ± 0.429	41.34 ± 4.90	1.10 ± 0.13	5.63 ± 1.59	15.5 ± 2.3

Values are means ± SD

OR vertical displacement on overhanging wall, VR vertical displacement on vertical wall, OT horizontal overhanging roof with horizontal displacement (roof), VT vertical displacement on vertical wall (traverse), Mean mean value of the four routes

<sup>a</sup>  $P < 0.0083$  vs route OR; <sup>b</sup>  $P < 0.0083$  vs route VR; <sup>c</sup>  $P < 0.0083$  vs route OT; <sup>d</sup>  $P < 0.0083$  vs route VT

<sup>aa</sup>  $P < 0.016$  vs route OR; <sup>bb</sup>  $P < 0.016$  vs route VR; <sup>cc</sup>  $P < 0.016$  vs route OT; <sup>dd</sup>  $P < 0.016$  vs route VT

**Table 6** Average heart rate (HR), oxygen consumption (VO<sub>2</sub>) and respiratory exchange ratio (RER) values measured in the four climbing routes

Route	HR <sub>avg</sub> (beats min <sup>-1</sup> )	VO <sub>2</sub> avg (l min <sup>-1</sup> )	VO <sub>2</sub> kg <sup>-1</sup> avg (ml kg <sup>-1</sup> min <sup>-1</sup> )	RER <sub>avg</sub>
OR	168.7 ± 8.0	2.24 ± 0.38	35.9 ± 3.2	1.11 ± 0.12
VR	167.5 ± 9.5	2.19 ± 0.40	35.9 ± 3.6	1.05 ± 0.10
OT	160.3 ± 8.8 <sup>aa,b</sup>	2.18 ± 0.35	34.9 ± 3.1	1.02 ± 0.08
VT	161.8 ± 8.4 <sup>aa,b</sup>	1.98 ± 0.28 <sup>ga,bb,cc</sup>	32.0 ± 3.8 <sup>aa,bb,cc</sup>	1.00 ± 0.07
Mean	164.6 ± 8.7	2.14 ± 0.36	34.7 ± 3.4	1.04 ± 0.10

Values are means ± SD

OR vertical displacement on overhanging wall, VR vertical displacement on vertical wall, OT horizontal overhanging roof with horizontal displacement (roof), VT vertical displacement on vertical wall (traverse), Mean mean value of the four routes

<sup>a</sup>  $P < 0.0083$  vs route OR; <sup>b</sup>  $P < 0.0083$  vs route VR; <sup>c</sup>  $P < 0.0083$  vs route OT; <sup>d</sup>  $P < 0.0083$  vs route VT

<sup>aa</sup>  $P < 0.016$  vs route OR; <sup>bb</sup>  $P < 0.016$  vs route VR; <sup>cc</sup>  $P < 0.016$  vs route OT; <sup>dd</sup>  $P < 0.016$  vs route VT

**Table 7** Physiological parameters expressed as percent of running maximum

	Peak						Average		
	%HR	%VO <sub>2</sub>	%VO <sub>2</sub> kg <sup>-1</sup>	%RER	%Lct	%RPE	%HR	%VO <sub>2</sub>	%VO <sub>2</sub> kg <sup>-1</sup>
OR	91.2 ± 5.5	81.4 ± 10.2	81.1 ± 9.9	98.5 ± 10.9	63.0 ± 19.1	97.0 ± 12.7	88.2 ± 7.1	70.3 ± 8.0	69.6 ± 7.3
VR	91.4 ± 9.8	84.7 ± 13.6	83.9 ± 12.4	96.8 ± 7.9	61.4 ± 21.4	87.7 ± 16.0	88.0 ± 9.4	69.1 ± 10.8	68.0 ± 10.6
OT	88.0 ± 7.4	78.0 ± 11.4	77.7 ± 11.6	97.8 ± 8.7	53.4 ± 10.4	89.2 ± 13.3	83.9 ± 7.5 <sup>a,b</sup>	67.2 ± 9.3	65.9 ± 9.9
VT	86.2 ± 7.7	75.4 ± 12.8	75.5 ± 13.1	88.5 ± 12.9	48.9 ± 13.7	87.8 ± 19.2	84.9 ± 7.6 <sup>a,b</sup>	61.5 ± 9.1 <sup>aa,bb,cc</sup>	60.8 ± 9.8 <sup>aa,bb</sup>
Mean	88.8 ± 6.3	79.3 ± 10.9	79.0 ± 10.8	94.5 ± 8.6	56.9 ± 12.0	91.0 ± 12.6	85.8 ± 7.1	66.9 ± 8.6	66.1 ± 8.7

Values are means ± SD

OR vertical displacement on overhanging wall, VR vertical displacement on vertical wall, OT horizontal overhanging roof with horizontal displacement (roof), VT vertical displacement on vertical wall (traverse), Mean mean value of the four routes

<sup>a</sup>  $P < 0.05$  vs route OR; <sup>b</sup>  $P < 0.05$  vs route VR; <sup>c</sup>  $P < 0.05$  vs route OT; <sup>d</sup>  $P < 0.05$  vs route VT

<sup>aa</sup>  $P < 0.05$  vs route OR; <sup>bb</sup>  $P < 0.05$  vs route VR; <sup>cc</sup>  $P < 0.05$  vs route OT; <sup>dd</sup>  $P < 0.05$  vs route VT

horizontal displacement (OT and VT). No statistical difference could be found for the peak %VO<sub>2</sub>, %VO<sub>2</sub> kg<sup>-1</sup>, %RER and %RPE between the four routes.

## Discussion

To our knowledge, it is the first time that the physiological responses were continuously measured on four climbing routes with the same difficulty rating, but different in displacement and/or steepness.

Given the climbing level of the climbers, the number of years of climbing experience and the similarity with subjects in previous studies (Mermier et al. 1997; Watts et al. 2000; Sheel et al. 2003) we can state that this sample is a good representation of expert rock climbers. Looking at the climbers' previous best climb, we can conclude that the tests were carried out on routes that were near to their maximal performance.

The VO<sub>2peak</sub> of our sample ( $52 \pm 5$  ml kg<sup>-1</sup> min<sup>-1</sup>) is similar to values reported in previous studies, where climbers had approximately the same level (7b):  $55 \pm 5$  ml kg<sup>-1</sup> min<sup>-1</sup> (Billat et al. 1995),  $55 \pm 4$  ml kg<sup>-1</sup> min<sup>-1</sup> (Wilkins et al. 1996),  $51 \pm 7$  ml kg<sup>-1</sup> min<sup>-1</sup> (Watts and Drobish 1998).

Route ascent times of competition style routes typically range from 2 to 7 min (Watts 2004). The mean climbing time was 3 min and 22 s and the climbers spent significantly more time on the vertical route with vertical displacement (VR) in comparison with the traverse (VT) and the vertical displacement on overhanging wall (OR). We found significantly faster climbing speeds in overhanging routes (OR and OT) in comparison with the routes on vertical wall. Watts and Drobish (1998) examined the physiological responses to climbing at different angles. Because their study was carried out with a climbing treadmill on which climbing holds were not changed, difficulty increased with

steeper angles. They found that subjects climbed slower with steeper angles and therefore on walls with increasing difficulty.

In our study a significantly higher peak and average heart rate was found in routes with a vertical upward displacement (OR and VR) in comparison to traversing routes with a horizontal displacement (OT and VT), although there was no significant difference between OT and OR for the peak heart rate. This could be the result of the average movement vector for the climber's centre of mass (COM) relative to gravity. During vertical climbing, the COM is moving directly in opposition to the line of gravity, whereas during traverse climbing the COM is moving perpendicular to the line of gravity. Another explanation could be the position of the hands. Åstrand et al. (1968) had earlier found that the HR is higher in activities in which the arms perform effort above the heart. During ascending routes, it is more likely that the arms are extended above the level of the heart. Lower HR in the almost horizontal overhanging route (OT) could be a result of the horizontal position of the body (Hauber et al. 1997).

Watts and Drobish (1998) and Mermier et al. (1997) found that the highest HR value, observed during the last 20 s and final minute, respectively, increased with increasing angle and by this mean with increasing difficulty.

It seems unlikely that HR differences are due to psychological fear of heights because of the experience of the climbers, the use of safety ropes and the fact that they had worked out the routes before the test.

The values for VO<sub>2avg</sub> and VO<sub>2</sub> kg<sup>-1</sup>avg were significantly lower in the traversing route (VT) in comparison with the three other routes. We found no significant differences for VO<sub>2peak</sub> and VO<sub>2</sub> kg<sup>-1</sup>peak between the four routes. Watts and Drobish (1998), Mermier et al. (1997) and Billat et al. (1995) found a

modest increase in peak  $\dot{V}O_2$  values with increasing climbing angle and increasing difficulty. The increase was only significantly different between the easy 90° vertical wall and the difficult horizontal overhang (151°) (Mermier et al. 1997). As Watts and Drobish (1998) suggested, this could be due to the fact that the arm-specific peak  $\dot{V}O_2$  was attained, taking into consideration that the upper body is the primary contributor to work during climbing.

Lactate values appeared to be influenced by the difficulty of the climbing and the style of climbing. In our study, the lactate concentration was lower in the traversing route in comparison with the three other routes, although only significantly with OR. In the study of Watts and Drobish (1998) the blood lactate did not begin to increase until the angle became overhanging and increased slightly at each angle above 90° relative to vertical. In the study of Mermier et al. (1997) blood lactate increased with increasing angle.

When comparing the intensity of climbing with a maximal test on a treadmill, it was found that climbing a 7c route, according to the French grading system, was performed at a relative peak heart rate of 86–91% and a relative average heart rate of 84–88% of the maximal heart rate measured during the treadmill test. These results are in accordance with the findings of Billat et al. (1995). The relative average heart rate of the two upward going routes (OR and VR) was significantly higher than the relative average heart rate of the two traversing routes (OT and VT). This means the relative heart rate is dependent on the displacement and on the difficulty of the climbing (Sheel et al. 2003).

The same calculations were done for the  $\dot{V}O_2$ . In our study, the peak  $\dot{V}O_2$  was attained between 75 and 85% of running  $\dot{V}O_{2peak}$  and the average  $\dot{V}O_2$  was attained between 62 and 70% of running  $\dot{V}O_{2peak}$ . The absolute and relative average % $\dot{V}O_2$  measured during the traverse was significantly lower in comparison with the three other routes. In the study of Sheel et al. (2003) subjects climbed at 51 and 45% of cycling maximum, depending on whether they were climbing a harder or easier route, respectively. These findings indicate that indoor sport climbing requires a significant contribution of the aerobic metabolism, as previously mentioned by Sheel et al. (2003).

Climbing seems to cause a disproportionate rise in heart rate compared with  $\dot{V}O_2$ . As other authors (Billat et al. 1995; Watts and Drobish 1998; Sheel et al. 2003) had mentioned, this could be caused by the repetitive isometric contractions of the forearm musculature. These isometric contractions stimulate the metaboreflex, which in turn is responsible for the dissociation between heart rate and  $\dot{V}O_2$  (Sheel et al. 2003).

The mean lactate concentration measured directly after the climbing was only between 49 and 63% of the maximal values measured during the maximal exercise test, with the lowest values for the traverse, although there was no significant difference between the four routes.

Therefore, we can conclude that the relative intensity is influenced by the climbing style and by the difficulty of climbing and that the traverse was done at a significantly lower percent than the three other routes.

A potential problem of this study was the fact that the climbers had to carry the portable calorimetry system of weight 2.1 kg. No attempt was made to measure if the extra weight had any influence on the performance. The choice to make them carry the equipment was made in order to be able to measure the oxygen uptake capacity from the beginning of the climbs to the end.

## Conclusion

This study is unique because it is, to our knowledge, the first time that the physiological responses were measured on four climbing routes with the same difficulty rating, but different in displacement and/or steepness. On the other hand, it is only the second time that the oxygen consumption and heart rate were continuously measured during difficult rock climbing with expert climbers, which allowed us to calculate the average values over a whole route.

In summary, our results indicate that climbing on four routes with the same difficulty but different steepness and/or displacement leads to a significantly higher peak and mean heart rate in routes with an upward displacement. The route with a vertical displacement on overhanging wall was physiologically the most demanding. Heart rate, oxygen uptake, RER and lactate concentrations were significantly lower in traversing routes. These conclusions are the same when the percent difference between the values measured during a maximal test on a treadmill and the values measured during climbing was calculated. The traverse was physiologically (aerobically and anaerobically) less demanding than the other routes. Possibly this is a result of the type of muscle contraction, more demanding technique and/or better relative resting positions as a result of the vertical angle of the wall and because the body moved in a horizontal direction.

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