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ORIGINAL ARTICLE

Energy system contributions in indoor rock climbing

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Abstract The present study cross-sectionally investigated the influence of training status, route difficulty and upper body aerobic and anaerobic performance of climbers on the energetics of indoor rock climbing. Six elite climbers (EC) and seven recreational climbers (RC) were submitted to the following laboratory tests: (a) anthropometry, (b) upper body aerobic power, and (c) upper body Wingate test. On another occasion, EC subjects climbed an easy, a moderate, and a difficult route, whereas RC subjects climbed only the easy route. The fractions of the aerobic (W_{AER}), anaerobic alactic (W_{PCR}) and anaerobic lactic ($W_{[La^-]}$) systems were calculated based on oxygen uptake, the fast component of excess post-exercise oxygen uptake, and changes in net blood lactate, respectively. On the easy route, the metabolic cost was significantly lower in EC [40.3 (6.5) kJ] than in RC [60.1 (8.8) kJ] ($P < 0.05$). The respective contributions of the W_{AER}, W_{PCR}, and $W_{[La^-]}$ systems in EC were: easy route = 41.5 (8.1), 41.1 (11.4) and 17.4% (5.4), moderate route = 45.8 (8.4), 34.6 (7.1) and 21.9% (6.3), and difficult route = 41.9 (7.4), 35.8 (6.7) and 22.3% (7.2). The contributions of the W_{AER}, W_{PCR}, and $W_{[La^-]}$ systems in RC subjects climbing an easy route were 39.7 (5.0), 34.0 (5.8), and 26.3% (3.8), respectively. These results indicate that the main energy systems required during indoor rock climbing are the aerobic and anaerobic alactic systems. In addition, climbing economy seems to be more important for the performance of these athletes than improved energy metabolism.

Keywords Oxygen consumption · Blood lactate · Oxygen debt · Energy sources · Training status

Introduction

Indoor rock climbing has become an option of physical–technical training for climbers, but its popularity has also shown a marked increase over the last decade as a recreation and a competitive sport. According to the Union Internationale d'Associations d'Alpinisme (UIAA, International Council for Competition Climbing), more than 45 countries currently participate regularly in the official schedule of international indoor rock climbing competitions. During these competitions, climbers should reach the highest point of a route created on artificial walls without any previous attempt and without visualization of the performance of their respective opponents. The difficulty of climbing routes can be classified based on various rating systems, with the Yosemite decimal system (YDS) being the most widely used (Watts 2004). The YDS consists of an increasing decimal scale ranging from 5.0 (easy) to 5.15 (very difficult), with intermediate levels between 5.10 and 5.15 being subdivided by the letters a, b, c, and d.

Since in indoor rock climbing competitions the danger is reduced by pre-placing protection points on the indoor wall, the physical and technical difficulties imposed by the

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routes can be potentiated (de Geus et al. 2006). In this respect, some studies have analyzed the relationship between anthropometric (Grant et al. 2001; Watts et al. 1993), biomechanical (Bourdin et al. 1998; Quaine et al. 1997) and physiological (Mermier et al. 2000) variables and climbing performance. In summary, these athletes have been shown to have a short stature, low percent body fat, high upper body power, and moderate to high aerobic power (Watts 2004).

From a physiological standpoint, knowledge about the metabolic and cardiovascular responses of rock climbers has been suggested to be important for the structuring and monitoring of training programs (de Geus et al. 2006). However, the results of studies analyzing the contribution of energy metabolism during indoor rock climbing are discordant. Based on the percent maximal oxygen uptake ($\dot{V}O_2\text{max}$) values required during climbs of difficult routes, Billat et al. (1995) and Sheel et al. (2003) proposed a predominance of the anaerobic or aerobic system during climbing, respectively. Part of the difference between these two studies might be due to the fact that $\dot{V}O_2\text{max}$ was measured on a treadmill (Billat et al. 1995) or cycle ergometer (Sheel et al. 2003). Furthermore, in addition to the fact that this sport is characterized by short bouts of high-intensity exercise intercalated with periods of rest whose extent cannot be standardized, Mermier et al. (2000) demonstrated that the contribution of the upper body is more important for climbing performance than that of the lower body.

However, in other sports (i.e., running), the technical level may influence energy demand, with beginners presenting a lower movement economy than elite athletes (Saunders et al. 2004). To our knowledge, no study has analyzed the energy demand of elite and recreational climbers on indoor rock climbing routes with different levels of difficulty. Thus, based on measurements that permit the assessment of the contributions of the aerobic and anaerobic metabolism (Beneke et al. 2004, 2002; di Prampero and Ferreti 1999), the present study cross-sectionally investigated the effects of training status on the energy profile of subjects climbing an easy (5.10a YDS), moderate (5.11b YDS) and difficult route (5.12b YDS). In addition, it was determined whether the aerobic and anaerobic components measured during arm-crank exercise are associated with the energy metabolism required during climbing. Assuming that intensity exercise and training status may influence energy system interaction (Gastin 2001), we hypothesized that elite rock climbers would have a lower energy expenditure compared to the recreational rock climbers during the easy route. Additionally, the energy expenditure and the anaerobic contribution would be higher according to the route level climbed by the elite group.

Methods

Subjects

Thirteen climbers [elite (EC) = 6; recreational (RC) = 7], who had been practicing indoor rock climbing for at least 1 year, voluntarily participated in the study. All subjects were nonsmokers and none of them received any pharmacological treatments or had any type of neuromuscular disorder or cardiovascular, respiratory or circulatory dysfunction. EC and RC consisted of subjects able to climb difficult (higher than 5.12d YDS) and easy routes (up to 5.11c YDS), respectively. In addition, all EC subjects occupied places within the first ten positions of the National Ranking of Indoor Rock Climbing. The experimental protocol was approved by the Ethics Research Committee of the School of Physical Education and Sport of the University of São Paulo.

Experimental design

The experiment was carried out in three sessions at minimum intervals of 48 h and maximum intervals of one week. On their first visit to the laboratory, the subjects were submitted to anthropometric measurements, followed by the counterbalanced application of a maximal incremental exercise test for the measurement of peak oxygen uptake ($\dot{V}O_{2\,\text{peak}-\text{arm}}$) and the Wingate anaerobic test. Both tests were adapted to the upper body and the time interval between tests was at least 2 h. In the subsequent session, the subjects familiarized themselves with the climbing routes in a gym specializing in indoor rock climbing. In the last session, EC subjects climbed three routes with different levels of difficulty (easy, moderate and difficult), whereas RC subjects climbed only one (easy) route for the determination of metabolic profile. The order of the routes in EC was counterbalanced. All tests were performed at the same time of day at a similar ambient temperature (20–24°C) and at least 2 h after the last meal of the subjects. In addition, the participants were asked not to practice any exhaustive exercise during the 24 h preceding the sessions.

Anthropometry

All anthropometric measurements were made according to the procedures described by Norton and Olds (1996). Subjects were weighed using an electronic scale to the nearest 0.1 kg (Filizola, model ID 1500, São Paulo, Brazil). Height was measured with a stadiometer to the nearest 0.1 cm. Arm span was measured in the standing position with the arms abducted horizontally at the height of the shoulders. Skinfold thickness was measured at nine sites (triceps, biceps, suprailiac, abdominal, chest, subscapula, midaxilla, thigh and calf) with a Harpenden caliper (West Sussex, UK) to the nearest 0.2 mm. Body density was predicted using the generalized equation of Jackson and Pollock (1985) and body fat was estimated using the equation of Brozek et al. (1963).

Upper body tests

The maximal incremental exercise test was carried out on a mechanically braked cycle ergometer (Monark, 828E, Stockholm, Sweden) adapted to the upper body. After a 3 min warm-up using only the inertial resistance of the equipment, the subjects exercised at a cranking frequency of 90 rpm (Cateye, Osaka, Japan) with an increment of 23 W per stage until exhaustion.

Throughout the test, oxygen uptake ($\dot{V}O_2$) was measured breath-by-breath with the telemetric system of a portable gas analyzer (K4b^2, Cosmed, Rome, Italy). Before each test, the gas analyzer was calibrated according to manufacturer specifications (K4b^2 instruction manual). Heart rate was measured during the test with a heart rate monitor (Polar Vantage NV, Polar Electro Oy, Kempele, Finland) coupled to the gas analyzer. In addition, the highest mechanical power generated during this test was expressed in a relative fashion (W kg^{-1}) to represent the maximum upper body aerobic power (UB$_{\text{aerobic-power}}$) of the climbers.

The Wingate anaerobic test was performed as described by Inbar and Bar-Or (1986), against a resistance of 0.05 kp kg^{-1} body weight. The external power output was measured every 1 s by a software (Wingate Test, Cefise, São Paulo, Brazil) and peak power (PP), mean power (MP) and fatigue index (FI) were calculated (Bar-Or 1987).

Climbing trials

An experienced route setter created the climbing routes and determined their respective ratings, which were subsequently confirmed by three experienced climbers who did not participate in the study. The easy route was rated as 5.10a (YDS) and possessed an angle of approximately 90°. The moderate route was characterized by an overhanging (angle of approximately 120°) and was rated as 5.11b (YDS). The difficult route was rated as 5.12b (YDS) and possessed an angle (approximately 110°) intermediate between the two other routes. Irrespective of the angles, the routes were created on a 10-m high wall and included a mean of 25 movements. Before the climbs, the subjects were asked to perform a warm-up (approximately 5 min) which consisted of stretching and climbing an easy horizontal route. The subjects were asked to climb at their own pace so that the physiological responses in a true climbing situation could be quantified. The total climbing time (T_{TOT}) was measured with a manual chronometer (Casio HS 50W, Tokyo, Japan) from the time the two feet left the ground until reaching the last hold of the route. Recovery time between routes was 10 min or until $\dot{V}O_2$ and HR returned to pre-climbing values. In all climbs, safety was guaranteed with a 10.5-mm thick static rope fed through the ring bolt at the top of the wall and then attached to the waist harness of the climbers. However, the subjects were not allowed to support themselves on any part of the security system to help climbing.

Before, during and after climbing, $\dot{V}O_2$ was measured continuously adopting the same procedures used in the maximal incremental exercise test. Oxygen uptake at rest ($\dot{V}O_{2\,\text{rest}}$) used for the calculation of the aerobic and anaerobic alactic system contributions (see below) was defined as the arithmetic mean of the last 20 s of $\dot{V}O_2$ measured with the subjects sitting for 5 min. The arithmetic mean of $\dot{V}O_2$ obtained over the last 20 s of each route was defined as peak oxygen uptake during climbing ($\dot{V}O_{2\,\text{peak-climbing}}$). In addition, $\dot{V}O_{2\,\text{peak-climbing}}$ was expressed as percentage in relation to $\dot{V}O_{2\,\text{peak-arm}}[\%\dot{V}O_{2\,\text{climbing-arm}} = (\dot{V}O_{2\,\text{peak-climbing}} \times 100)/\dot{V}O_{2\,\text{peak-arm}}]$. Heart rate was measured during climbs with a heart rate monitor coupled to the gas analyzer. Peak heart rate during climbing (HR$_{\text{peak-climbing}}$) was defined as the highest heart rate obtained at the end of each route. Blood samples (25 µl) were collected from the ear lobe at rest and in the first, second and third minute post-climbing for the determination of lactate concentration. The difference between the highest post-climbing ([La$^-$]$_{\text{peak}}$) and pre-climbing lactate concentration was expressed as a delta value ([La$^-$]net). Lactate concentrations were determined with an automatic blood lactate analyzer (Yellow Springs 1500 Sport, Ohio, USA).

Calculations

Net aerobic energy (W_{AER}) was estimated by subtracting $\dot{V}O_{2\,\text{rest}}$ from the $\dot{V}O_2$ area integrated over time during climbing by the trapezoidal method. The contribution of the anaerobic alactic system (W_{PCR}) was considered to be the fast component of excess post-exercise oxygen consumption (Beneke et al. 2002, 2004). In the present study, we fitted the kinetics of post-climbing oxygen consumption to a bi- and monoexponential model and observed that the slow component of the biexponential model was negligible. Thus, the post-climbing breath-to-breath $\dot{V}O_2$ data were fitted to a monoexponential model (Eq. 1) (Origin 6.0, Microcal, Massachusetts, USA) and W$_{\text{PCR}}$ was obtained by integration of the exponential part (Eq. 2).

$$\dot{V}O_{2(t)} = \dot{V}O_{2\text{baseline}} + A\left[e^{-(t/\tau)}\right] \quad (1)$$

$$W_{\text{PCR}} = A\,\tau \quad (2)$$

where $\dot{V}O_{2(t)}$ is oxygen uptake at time t, $\dot{V}O_{2\text{baseline}}$ is oxygen uptake at baseline, A is the amplitude, and τ is a time constant.

To estimate anaerobic lactic energy ($W_{[\text{La}^-]}$) a value of 1 mmol l^{-1} $[\text{La}^-]_{\text{net}}$ was considered to be equivalent to 3 ml O_2 kg^{-1} body mass (di Prampero and Ferretti 1999). A caloric equivalent of 20.9 kJ l O_2^{-1} was considered for the three energy systems. Total metabolic work (W_{TOTAL}) was calculated as the sum of the three energy systems ($W_{\text{AER}} + W_{\text{PCR}} + W_{[\text{La}^-]}$). In addition, the contributions of the three energy systems were also expressed as percentage in relation to W_{TOTAL}.

Statistical analysis

All analyses were performed using the SPSS program (version 13.0, Chicago, USA). Data are reported as means and standard deviation (SD). The distribution of the data was analyzed by the Shapiro–Wilk test and the results showed a normal Gaussian distribution. EC and RC variables were compared by the unpaired t test. $\dot{V}O_{2\,\text{peak-climbing}}$ and $\dot{V}O_{2\,\text{peak-arm}}$ was compared by a paired t test. Repeated measures analysis of variance, with the factor difficulty, and Bonferroni's multiple comparisons test were used to compare EC variables between the easy, moderate and difficult routes. The percent contribution of the three energy systems was compared between groups using also repeated measures analysis of variance and Bonferroni's multiple comparisons test. Compound symmetry, or sphericity, was determined by Mauchley's test. Pearson's correlation coefficient was applied to analyze the relationship between laboratory and climbing variables, as well as the relationship between W_{TOTAL} and body mass or percent body fat of climbers of the two groups. A level of significance of 5% ($P < 0.05$) was adopted in all analyses.

Results

The mean age, climbing experience and anthropometric and physiological parameters measured in the laboratory obtained for the two groups are shown in Table 1. As previously established, the experience of EC subjects was significantly greater than that of RC subjects. The range of the climbing experience was 5.10b–5.11c and 5.12d–5.14a for RC and EC, respectively. The sum of skinfold thickness and percent body fat were lower in EC compared to RC ($P < 0.05$). In addition, PP and MP were significantly higher in EC ($P < 0.05$).

Table 1 Age, climbing experience, and anthropometric and physiological characteristics of the recreational and elite rock climbers

	Recreational group (n = 7)	Elite group (n = 6)
Age (years)	24.1 (3.0)	20.1 (4.1)
Climbing experience (years)	1.6 (0.8)	4.6 (2.6)[a]
Body mass (kg)	64.0 (7.2)	62.4 (3.3)
Height (cm)	170.0 (6.8)	173.3 (4.2)
Arm span (cm)	173.3 (10.6)	176.8 (2.3)
Σ skinfold thickness (mm)	91.1 (24.4)	66.3 (18.0)[a]
Body fat (%)	10.6 (3.7)	6.6 (2.3)[a]
$\dot{V}O_{2\,\text{peak-arm}}$ (ml kg^{-1} min^{-1})	35.5 (5.2)	36.5 (6.2)
$\text{UB}_{\text{aerobic power}}$ (W kg^{-1})	1.9 (0.4)	2.1 (0.3)
PP (W kg^{-1})	7.0 (0.7)	8.0 (0.5)[a]
MP (W kg^{-1})	5.3 (0.5)	6.2 (0.4)[a]
FI (%)	46.8 (10.1)	51.1 (10.3)

Data are reported as mean and SD

Σ skinfold thickness: sum of triceps, biceps, suprailiac, abdominal, chest, subscapula, midaxilla, thigh and calf skinfold thickness; $\dot{V}O_{2\,peak-arm}$: peak oxygen uptake in the upper body test; $HR_{peak\text{-}arm}$: Peak heart rate in the progressive test; $UB_{aerobic\ power}$: greatest mechanical power in the upper body test progressive test; *PP:* peak power in the upper body test Wingate test; *MP*: mean mechanical power (30 s) in the anaerobic Wingate test; *FI*: fatigue index of the upper body test Wingate test

[a] Different from recreational climbers ($P < 0.05$)

Visually, the $\dot{V}O_2$ response of the two groups did not reach a steady state during all climbs. A representative example of a typical $\dot{V}O_2$ response of climbers on the easy, moderate and difficult routes is shown in Fig. 1. $\dot{V}O_{2\,\text{peak-arm}}$ of both groups were not statistically different from $\dot{V}O_{2\,\text{peak-climbing}}$ in all routes ($P > 0.05$). In general, the relative (Fig. 2) and absolute (Table 2) contributions of the aerobic and anaerobic alactic systems in the two groups were significantly higher ($P < 0.05$) than the contribution of the glycolytic system in all situations. In addition, on the easy route the anaerobic lactic system showed a significantly greater percent contribution in RC than in EC ($P < 0.05$). $\text{HR}_{\text{peak-climbing}}$, $[\text{La}^-]_{\text{peak}}$ and W_{TOTAL} were significantly higher in RC compared to EC on the easy route ($P < 0.05$). Additionally, $\text{HR}_{\text{peak-climbing}}$ of EC subjects during the easy route was significantly lower than that observed for the other routes ($P < 0.05$).

Significant correlations were only observed between W_{TOTAL} and body mass in EC subjects on the moderate route ($r = 0.82$; $P = 0.047$) and in RC subjects on the easy route ($r = 0.80$; $P = 0.043$). $\dot{V}O_{2\,\text{peak-arm}}$ showed no significant correlation with percent contribution of the aerobic or anaerobic alactic system in EC or RC. Similarly, PP and MP were not significantly correlated with the percent contribution of the anaerobic alactic or lactic system in EC or RC. Finally, no significant correlations between

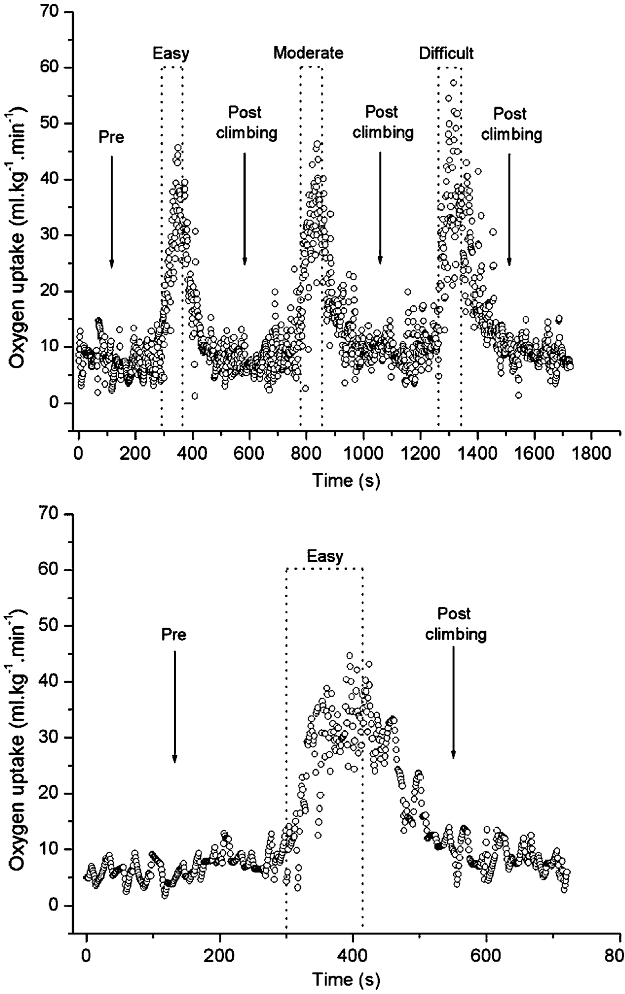

Fig. 1 Representative example of the oxygen uptake responses of a typical elite (*upper panel*) and recreational (*lower panel*) rock climber before (*pre*), during and after (*post*) climbing of the easy, moderate and difficult routes

$\dot{V}O_{2\,\mathrm{peak-arm}}$ and $\dot{V}O_{2\,\mathrm{peak-climbing}}$ were observed for EC or RC subjects.

Discussion

To our knowledge, this is the first study characterizing the energy profile of elite and recreational climbers based on the measurement of aerobic and anaerobic metabolism during climbs of routes with different levels of difficulty. The main findings of this investigation were: (a) the aerobic and anaerobic alactic systems are the main energy systems required during indoor rock climbing, and (b) training status, route difficulty and upper body power do not directly influence the contributions of the energy systems.

The anthropometric data obtained for the two groups agree with other studies showing that climbers tend to present a relatively short stature, low body mass and low body fat percentage (Watts 2004; Giles et al. 2006). Although in the present study the body fat results differed significantly between groups, anthropometric variables have not always been associated with climbing performance. Grant et al. (1996) observed no significant difference in body mass, height or body fat percentage between elite climbers, recreational climbers, and control group. Similarly, Mermier et al. (2000) found that the morphological component—corresponding to height, total body mass, arm span, leg length and arm span/height ratio—accounted for only 0.3% of the total variation in climbing performance. However, the results of Mermier et al. (2000) and Grant et al. (1996) should be compared with caution since in both studies the groups consisted of climbers who presented a wide variation in skill levels (5.8–5.13d YDS and 5.10a–5.14b YDS, respectively). It is believed that a higher body fat percentage may negatively interfere with the performance of RC climbers since this tissue is not directly involved in sustaining or movement of the body during climbing (Watts 2004). Thus, it is likely that muscle demand was higher in RC climbers compared to EC climbers which, in turn, resulted in a correlation between body mass and W_{TOTAL}, in addition to the difference in W_{TOTAL} observed between groups on the easy route.

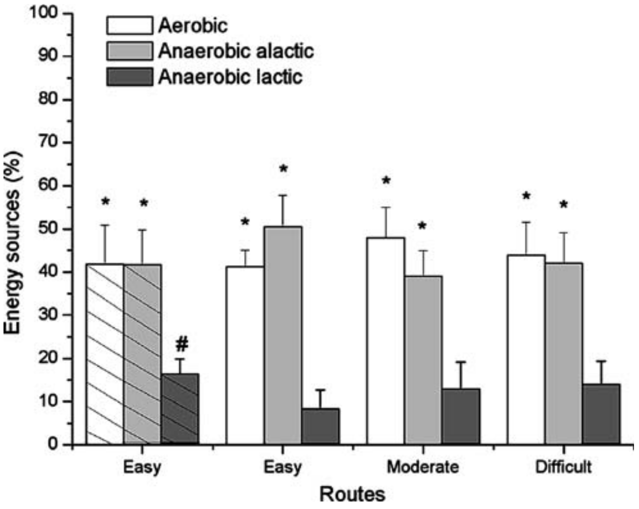

Fig. 2 Relative contributions of the energy systems during indoor rock climbing. *Bars* with and without *transverse stripes* refer to the recreational and elite groups, respectively. Values are means ± SD. *Different from the anaerobic lactic system ($P < 0.05$). #Different from the anaerobic lactic system of the elite group on the easy route ($P < 0.05$)

Some studies have measured $\dot{V}O_2$max max in climbers, which was higher than $\dot{V}O_{2\,\mathrm{peak-arm}}$ obtained for the present sample. Submitting subjects to progressive treadmill tests, de Geus et al. (2006) and Billat et al. (1995) obtained $\dot{V}O_2$max values of 52.1 ± 5.1 and 54.6 ± 5.2 ml kg^{-1} min^{-1}, respectively. In addition, $\dot{V}O_2$max measured on a cycle

Table 2 Total climbing time and metabolic responses of recreational and elite climbers on the three routes

	Recreational group (*n* = 7)	Elite group (*n* = 6)		
	Easy	Easy	Moderate	Difficult
T_{TOTAL} (s)	83.9 (20.1)	73.8 (17.6)	80.8 (14.5)	82.3 (16.4)
$\dot{V}O_{2\,\mathrm{peak-climbing}}$ (ml kg^{-1} min^{-1})	36.0 (5.5)	37.2 (7.6)	38.0 (6.3)	38.6 (5.4)
$HR_{\mathrm{peak\text{-}climbing}}$ (beats min^{-1})	171 (6)[b]	162 (8)	175 (5)[b]	181 (7)[b]
$[La^{-}]_{\mathrm{peak}}$ (mmol l^{-1})	4.4 (1.6)[b]	2.4 (0.9)	3.7 (0.8)	3.9 (1.8)
$\%\dot{V}O_{2\,\mathrm{climbing-arm}}(\%)$	104.3 (27.7)	102.2 (19.5)	106.4 (23.9)	108.1 (24.8)
$\dot{V}O_2(ml\,kg^{-1})$	30.3 (7.7)	23.0 (5.2)	30.1 (6.9)	31.3 (8.0)
$\dot{V}O_{2\,\mathrm{PCR}}(ml\,kg^{-1})$	30.1 (6.9)	27.7 (4.5)	24.5 (5.5)	30.2 (7.8)
W_{AER} (kJ)	40.9 (12.4)[a]	29.7 (6.1)[a]	39.3 (10.4)[a]	40.4 (9.8)[a]
W_{PCR} (kJ)	40.3 (11.0)[a]	35.8 (5.1)[a]	31.8 (8.1)[a]	39.1 (10.5)[a]
$W_{[\mathrm{La^-}]}$ (kJ)	15.9 (3.9)[b]	6.0 (3.4)	10.0 (3.8)	12.7 (4.8)
W_{TOTAL} (kJ)	97.1 (18.9)[b]	71.4 (9.7)	81.0 (12.9)	92.1 (15.4)

Data are reported as mean and SD

T_{TOTAL}: Total climbing time; $\dot{V}O_{2\,peak-climbing}$: peak oxygen uptake during climbing; $HR_{peak\text{-}climbing}$: climbing peak heart rate; $\%\dot{V}O_{2\,climbing-arm}$: peak oxygen uptake during climbing expressed as percent of peak oxygen uptake in the upper body test; $[La^{-}]_{peak}$: highest post-climbing blood lactate concentration; $\dot{V}O_2$: cumulative oxygen uptake above resting values during the routes; $\dot{V}O_{2\,PCR}$: $\dot{V}O_2$ equivalent to the fast component of excess post-exercise oxygen consumption; W_{AER}: aerobic energy corresponding to $\dot{V}O_2$; W_{PCR} : anaerobic alactic energy corresponding to $\dot{V}O_{2\,\mathrm{PCR}}$; $W_{[La^-]}$: anaerobic lactic energy corresponding to $[La^{-}]_{net}$; W_{TOTAL}: total metabolic work ($W_{\mathrm{AER}} + \dot{V}Os_{2\,\mathrm{PCR}} + W_{[\mathrm{La^-}]}$)

[a] Different from the contribution of the glycolytic system on the respective route ($P < 0.05$)

[b] Different from the easy route of the elite group ($P < 0.05$)

ergometer was 45.5 ± 6.6 ml kg^{-1} min^{-1} in the study of Sheel et al. (2003). Although the subjects of the cited studies presented an elevated climbing skill level (5.12a–5.13b YDS in most of them), extrapolations of these results regarding the adaptations promoted by regular sport climbing are limited. In principle, this is due to the fact that the ergometers used in those studies do not preferentially recruit the upper body, which has been considered to be the most important for climbing (Watts 2004; Mermier et al 2000). In contrast, our results demonstrate that even on routes with a difficulty level below the maximum skill level of the climbers, $\%\dot{V}O_{2\,\mathrm{climbing-arm}}$ exceeds $\dot{V}O_{2\,\mathrm{peak-arm}}$. It is known that oxygen uptake during predominantly aerobic physical exercise depends on the intensity and muscle mass involved in the task (Åstrand and Rodahl 1970). Thus, it is plausible to assume that the "extra" muscle mass of the upper body substantially contributed to $\dot{V}O_{2\,\mathrm{peak-climbing}}$. In this respect, it is likely that, regardless of the ergometers adopted, the procedure of establishing the contributions of the energy systems during climbing based on the determination of $\%\dot{V}O_2$max is limited. However, further studies quantifying the respective percent contributions of the upper and lower body to $\dot{V}O_{2\,\mathrm{peak-climbing}}$ are necessary.

The disproportional rise in $HR_{\mathrm{peak\text{-}climbing}}$ compared to $\dot{V}O_{2\,\mathrm{peak-climbing}}$ observed in the two groups of the present study was similar to that reported in other investigations measuring these variables during indoor rock climbing (Billat et al. 1995; Sheel et al. 2003) and on a climbing treadmill (Watts and Drobish 1998). The psychological stress, metabolic changes of the exercised muscles and arm position have been indicated as potential factors related to the disproportional response between $\dot{V}O_2$ and heart rate during indoor rock climbing (de Geus et al. 2006; Sheel et al. 2003; Mermier et al. 1997). Psychological stress was not measured in the present study but we believe that its influence was minimal because of the following three main factors: (1) the climbing experience reported by the subjects, (2) the adopted safety system, and (3) especially the previous knowledge of the routes.

Considering the difference in $[La^{-}]_{\mathrm{peak}}$ observed between the two groups on the easy route, we believe that metabolic changes in the skeletal muscles required during climbing were the main factor responsible for the rise of $HR_{\mathrm{peak\text{-}climbing}}$ in the absence of a concomitant increase of $\dot{V}O_{2\,\mathrm{peak-climbing}}$ in this situation. Peripheral adaptations promoted by high intensity interval training, including reduced lactate production and an increased buffering capacity of H^{+} ions, have been well established (Laursen and Jenkins 2002; Bishop et al. 2004). Ferguson and Brown (1997) demonstrated an enhanced vasodilatory capacity of the forearm muscles of trained climbers during sustained isometric handgrip exercise compared to the control group. Probably, these factors together may reduce both local blood pressure and cellular acidosis, events that have been intimately associated with activation of the sympathetic system (Kaufman et al. 1983).

On the other hand, with increasing difficulty of the routes climbed by EC subjects, the disproportional relationship between $\mathrm{HR}_{\text{peak-climbing}}$ and $\dot{V}\mathrm{O}_{2\,\text{peak}-\text{climbing}}$ was maintained but without the concomitant significant alteration in $[\mathrm{La}^{-}]_{\text{peak}}$. Thus, as the level of difficulty of the routes reaches the maximum skill level of elite climbers, the nonlinear relation between these two variables is mainly the result of an increase in local blood pressure promoted by isometric contractions of the active muscles and maintenance of the arms above heart level (de Geus et al. 2006). It is believed that during the static phase of sport rock climbing, subjects perform successive isometric contractions of the upper body for the control of posture, whereas the lower body is mainly required for sustaining body mass (Bourdin et al. 1998). In this respect, it is plausible to suppose that increased activation of the sympathetic nervous system with increasing route difficulty occurs in response to the mechanical obstruction of blood flow in order to maintain an adequate blood supply to the exercised muscles (Kaufman et al. 1983).

As mentioned earlier, regardless of the training status or skill level of the climbers, the aerobic and anaerobic alactic systems are the main energy systems required during indoor rock climbing. The relationship between these two bioenergy systems has been described in the studies of Margaria et al. (1933) and Piiper and Spiller (1974). More recent investigations have confirmed this interdependence (Walsh et al. 2006; McCully et al. 1994; Idström et al. 1985). Before climbing, climbers visually choose some points for short rests on the largest holds. The aim of these short rests is to dry sweat from their hands with magnesium carbonate and/or to reduce the process of fatigue of the muscles responsible for fingers flexion. Thus, the increased contribution of the oxidative system probably occurs to meet the energy demand imposed by these tasks and to help with the partial resynthesis of the high-energy phosphate stores in muscle during these nonsystematized resting periods. However, both the use of $[\mathrm{La}^{-}]$ and the fast component of excess post-exercise oxygen consumption to estimate the anaerobic systems contribution may be criticized. Gladden (2004) indicated that O_2 availability is only one of several interacting factors that cause the increase in blood lactate during exercise, whereas McMahon and Jenkins (2002) suggested that more studies are necessary to elucidate the most dominant components governing the PCr resynthesis following muscular contraction. However, the inexistence of a method universally accepted for the measurement of the anaerobic metabolism during exercise, especially in non-laboratory tests, is still an unsolved problem.

Although upper body anaerobic power differed significantly between the groups studied, this variable showed no significant correlation with the percent contributions of the energy systems during climbing. Thus, the difference in W_{TOTAL} observed may indicate that, as reported for highly trained distance runners (Saunders et al. 2004), greater climbing economy may be more important for climbing performance than improvement of the energy systems. In addition, it is attractive to suspect that climbing economy can be dependent of posture control during climbing. However, these causal relations should be seen with caution since we did not evaluate biomechanical variables indicative of posture control during climbing.

In conclusion, the results of the present study demonstrated that the main energy systems required during indoor rock climbing are the aerobic and anaerobic alactic systems. Furthermore, the contribution of these energy systems does not depend on the training status, route difficulty or upper body aerobic and anaerobic performance of the climbers. Thus, climbing economy seems to be more important for the performance of these athletes than improved energy metabolism. Finally, further studies should be performed to investigate variables that determine movement economy during indoor rock climbing.

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