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ORIGINAL ARTICLE

Physiological responses in rock climbing with repeated ascents over a 10-week period

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Abstract The purpose was to analyze the physiological responses and energy expenditure during repeated ascents of the same climbing route over a 10-week period. Nine climbers completed nine ascents of a specific route spaced 1 week apart. Expired air was analyzed continuously during each ascent, and time of ascent was recorded to the nearest second. Energy expenditure during climbing (EE_{CLM}), and during climbing +10 min recovery (EE_{TOT}) was calculated by the Weir and Zuntz equations. Differences among ascents 1, 4, 6 and 9 were analyzed by repeated measures ANOVA. Climbing time was longer for ascent 1 compared with ascents 4, 6 and 9 ($P < 0.001$). Differences were found for EE_{CLM} (kcal; $P < 0.001$), between ascent 1 versus 6 and 9 and ascent 4 versus 9, using both Zuntz and Weir equations. Also, differences were observed in EE for recovery ($P < 0.05$) and EE_{TOT} ($P < 0.05$) using both equations. Repeated ascents of a climbing route decreased the climbing time and absolute energy expenditure during climbing. Initially, the decrease in climbing energy expenditure is accompanied by an increase in energy expenditure during recovery; however, by the ninth ascent, the total energy expenditure of the task is lower than for ascent 1.

Keywords Rock climbers · Repeat ascents · Energy expenditure · Exercise economy

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Introduction

Sport climbing is being increasingly practiced either as a training mode for rock climbing or as a recreational activity (Watts 2004). It can be performed either indoors on artificial climbing structures or outdoors on real rock. Indoor sport climbing is characterized by movements on variable terrain fitted with artificial hand and foot holds (Booth et al. 1999). The development of indoor climbing structures has made the activity of rock climbing available to a wide audience and promoted climbing as a competitive activity (Watts et al. 2008). Research on sport climbing has also increased recently with a main focus on physiological responses during climbing (Booth et al. 1999; Mermier et al. 1997; Sheel et al. 2003; Watts et al. 1996, 2000; Watts and Drobish 1998) and anthropometric and physiological characteristics of the climbers (Bertuzzi et al. 2007; Cutts and Bollen 1993; Grant et al. 1996; Mermier et al. 2000; Watts et al. 1993, 2006). These investigations help to better design climbing-specific training programs.

Oxygen uptake (VO_2) and heart rate (HR) have been the physiological responses most studied in both indoor and outdoor climbing (Bertuzzi et al. 2007; Billat et al. 1995; Booth et al. 1999; de Geus et al. 2006; Espana-Romero et al. 2009b; Mermier et al. 1997; Sheel et al. 2003; Watts et al. 2000; Watts and Drobish 1998). From these studies, it appears that VO_2 during climbing ranges between 20.0 and

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44.0 ml min^{-1} kg^{-1}, from the easiest routes to the most difficult routes (Espana-Romero et al. 2009a). Also, climbing seems to cause a disproportionate rise in HR compared with VO_2, probably caused by the repetitive isometric contraction of the forearm musculature (Billat et al. 1995; de Geus et al. 2006; Sheel et al. 2003; Watts and Drobish 1998). Energy expenditure rate (EE) is also of value in the design of climbing training programs and for establishing training volumes (de Geus et al. 2006). However, this parameter has been reported in fewer climbing studies (Mermier et al. 1997; Watts and Drobish 1998), and observed values of EE during climbing fall within a narrow range of 9.3 to 12.6 kcal min^{-1}. Most of the above-mentioned studies have analyzed the physiological responses during a single-ascent route, while studies examining the effect of repeated ascents of a climbing route are scarce. Whether physiological responses vary when performing the same route several times is still unknown. Furthermore, whether a climber becomes more economical relative to energy expenditure with repeated ascents of the same route has not been studied. The main objective of this study was to analyze the physiological responses and energy expenditure during repeated ascents of the same climbing route over a 10-week period in a sample of experienced rock climbers. We have studied this from an applied perspective, involving a typical climbing situation and under normal training conditions usually employed by climbers.

Methods

Participants

A sample of nine experienced rock climbers (8 male, 1 female; age range 22–58 years), all of them currently active in rock climbing but not engaged in a specific periodized training program, volunteered to participate in the study. The mean self-reported ability ranged from 5.11a to 5.12b on the Yosemite Decimal System (YDS) scale (from 6c to 7b+ on the French grading system). In brief, the YDS is based on a decimal scale ranging from 5.0 (very easy) to 5.15 (extremely difficult). The routes of ≥5.10 are further subdivided into a, b, c, d according to ascending difficulty. Currently, the YDS scale extends into the 5.15 range for worldwide climbing routes (Laurent 2010).

All participants read and signed an informed consent prior to participation in the study. The study protocol was performed in accordance with the ethical standards established in the 1961 Declaration of Helsinki (as revised in Hong Kong in 1989 and in Edinburgh, Scotland, in 2000), and was approved by the Institutional Review Board of Northern Michigan University. Prior to participation in the study, participants were familiarized with the instrumentation involved and performed a brief session of practice climbing while fitted with the face mask and apparatus of the expired air analysis system used in the study.

Climbing route

A specific climbing route was designed by three experienced climber/route setters and marked on an indoor climbing structure in the University Recreation Area (NICROS ArtWall; Fig. 1). The route contained 35 modular features, or holds, which were bolted to the main climbing wall surface and were available to the participants for hand and foot support. Two additional built-in features on the wall were marked for use by hands and feet and a touch-box was marked at the top of the wall to indicate the end of the route. Climbers could also use any built-in features on the main wall for foot support, but not for hand support. Participants were required to progress along the route within these constraints, but were not required to use all of the marked hold features. No time limit was imposed to finish the route. The climbers were instructed to climb as normally as possible. The usable climbing area measured approximately 6.5 m in width by 6.8 m in height and began with a leftward traverse over vertical terrain to a final ascent over terrain that overhung by approximately 10°. Participants wore their own climbing harnesses and were protected via a safety rope managed by a trained belayer according to standard rock climbing procedures (Luebben 2004). Climbing time was recorded from the point of first hand contact with a route feature to the point when the climber made hand contact with the touch-box at the top of the route. Upon completion of the route, the climber was lowered to floor level via the belayer. The difficulty of the specific route was rated as 5.10a on the YDS scale. Each participant completed nine ascents of the test route spaced 1 week apart over a 10-week period. Climbers were allowed to continue their habitual climbing activity over the course of the study, but they were not allowed to ascend the specific test route other than during the test sessions. There were no falls experienced by any of the participants during any of the test ascents. Data of test sessions 1, 4, 6 and 9 were selected for statistical analysis. Missing data in the other test sessions did not make the use of these sessions possible.

Body composition

Anthropometric data were recorded using standardized methods according to the International Society for the Advancement of Kinanthropometry's protocol (ISAK 2001). All anthropometric measurements were conducted by the same trained anthropometrist, certificated by the

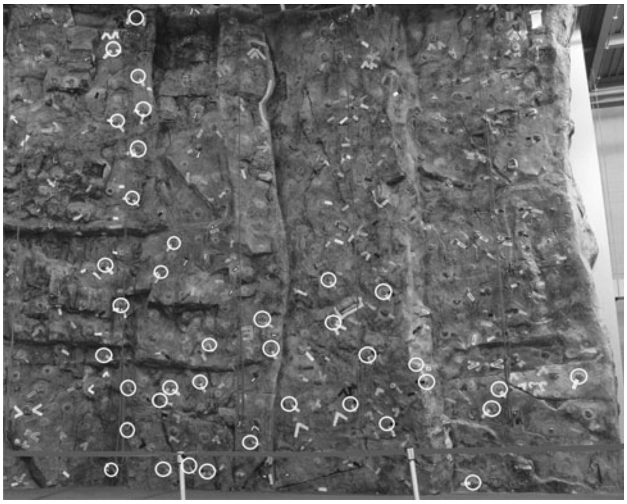

Fig. 1 Specific climbing route design. *Circles* indicate marked features available for support by hands and/or feet. Subjects could also use natural built-in features of the wall for feet only. Approximate width and height of the climbing route area were 6.5 and 6.8 m, respectively. Subjects moved from right to left, and then upward along the marked route

ISAK. Body weight was measured by using an electronic scale (Tanita Digital Scale BWB-800A Class III; Tanita Corp., Japan; accurate to within 0.1 kg). Height was measured with a Seca stadiometer to the nearest 0.5 cm. The participant was instructed to take and hold a full breath. Stretched height with the head at the Frankfort plane was recorded.

Skin fold thickness was measured on the right side of the body to the nearest 1 mm with a calibrated Lange calliper at the following sites: triceps, a vertical fold halfway between the acromion process and the superior head of the radius, in the posterior aspect of the arm; biceps, at the same level as the triceps skin fold and directly above the center of the cubital fossa; subscapular, 20 mm below the inferior angle of the scapula and 45° to the lateral side of the body; iliac crest, immediately above the marked iliocristale (the point on the most lateral aspect of the iliac tubercle on the iliac crest). The Durnin equation (Durnin and Womersley 1974) was used to estimate the body density, and then body fat percentage was calculated using the equation described by Siri (1961).

Physiological responses

For each test session, upon arrival at the test site, each participant was weighed without shoes and allowed to warm up as desired via stretching and easy traverse climbing on a separate structure from the testing terrain.

Following the warm-up, each climber was fitted with a portable breath-by-breath expired air analysis system (Oxycon Mobile; CareFusion/Jaeger, CA). The Oxycon Mobile instrumentation weighed approximately 950 g and was carried via an adjustable vest harness sized to each participant. The instrument was calibrated according to manufacturer's specifications with known calibration gases prior to each test. The climber was interfaced with the analyzer via a Triple-V flow sensor mounted to a face mask, which covered the nose and mouth. A selection of face mask sizes was available to ensure a proper fit for each participant. Data were transferred continuously via telemetry to a portable microcomputer and backed up onto a data card onboard the analyzer. Expired air data were recorded continuously during climbing and during a 10-min sitting recovery period immediately after climbing.

Breath-by-breath data for ventilation (V_E), VO_2, expired carbon dioxide (VCO_2) and respiratory exchange ratio (RER) were averaged over 10-s intervals and exported to Excel spreadsheet prior to analysis. Metabolic equivalent values (METs) were estimated by dividing VO_2 ml kg^{-1} min^{-1} by 3.5 ml kg^{-1} min^{-1}.

Heart rate was recorded via a chest strap transmitter (Polar Electro OY, Kempele, Finland), which was coded for the expired air analyzer telemetry receiver. The HR data entered the analyzer data file along with the breath-by-breath expired air analysis data and were averaged over 10-s intervals for final data analysis.

Energy expenditure rate in kcal min^{-1} was calculated from the 10-s interval data via the method of Weir (1949):

$$\text{EE rate}\ \left(\text{kcal min}^{-1}\right) = V_E \times [1.044 - (0.0499 \times F_EO_2)]$$

where, V_E = expired ventilation in l min^{-1} (STPD) and F_EO_2 = fraction of oxygen in expired air. Energy expenditure in kcal min^{-1} was converted to absolute energy expenditure in kcal by dividing the EE rate by 6 for each 10-s interval.

For comparison, a caloric factor of kcal l^{-1} VO_2 was determined from RER according to the method of Zuntz (1901). Oxygen uptake in l min^{-1} was subsequently multiplied by the Zuntz caloric factor to provide EE in kcal min^{-1}. Energy expenditure in kcal min^{-1} was converted to absolute energy expenditure in kcal by dividing the EE rate by 6 for each 10-s interval.

EE for climbing (EE_{CLM}) and recovery (EE_{REC}) in kcal were calculated as the sums of the 10-s interval data for the period of climbing and the 10-min recovery period, respectively. Total EE (EE_{TOT}) was calculated as the sum of all 10-s interval data for climbing plus recovery. EE_{CLM} was also expressed as percentage of the EE_{TOT}, via EE_{CLM}/EE_{TOT} (%EE_{CLM}). All EE variables were calculated for both the Weir and Zuntz method.

For each climbing trial, once the climber was lowered to the floor, a rating of perceived exertion (RPE) was provided, according to the Borg scale of 6–20, by pointing to a printed chart (Borg 1974). Then, the rope was disconnected from the participant's harness by a research technician and the climber sat in a chair and remained seated and interfaced with the expired air analysis system for the 10-min recovery.

Statistical analysis

All the variables met the assumption for normal distribution using Kolmogorov–Smirnov's test. The data are presented as mean and standard deviation (SD), unless otherwise indicated. Differences between ascents 1, 4, 6 and 9 were analyzed by one-way analysis of variance (ANOVA) for repeated measures. Tukey's HSD adjustments were used for pairwise comparisons. Statistical analyses were performed using "Statistical Package for the Social Sciences (SPSS)" software 18.0 (SPSS Inc., Chicago, IL, USA). The significance level was set at $P \leq 0.05$.

Results

Characteristics of the study participants by gender are shown in Table 1. All participants presented a climbing experience of at least 3 years and a climbing frequency in season of at least 2 days per week. Climbing parameters of the study sample for ascents 1, 4, 6 and 9 are shown in Table 2. Results from one-way ANOVA for repeated measurements showed that climbing time was significantly higher ($P < 0.001$) for ascent 1 (2.02 ± 0.55 min) compared with ascents 4, 6 and 9 (1.56 ± 0.40, 1.50 ± 0.35, 1.38 ± 0.31 min, respectively). No significant differences were observed in peak values for V_E, VO_2, HR, VCO_2 and METs among ascents. However, significant differences were found for EE_{CLM} (kcal; $P < 0.001$) in ascent 1 compared with ascents 6 and 9 (17.16 ± 4.56 vs. 13.05 ± 4.39 and 11.59 ± 3.22 kcal, respectively) and ascents 4 versus 9 (14.6 ± 4.9 vs. 11.6 ± 3.2 kcal, respectively) when using the Zuntz equation. Similar results were observed when using the Weir equation (Table 2). These differences in EE_{CLM} were also noted when expressed as a percentage of EE_{TOT} using both Zuntz and Weir equations ($P < 0.001$). Significant differences were also observed in EE for recovery ($P = 0.031$ and 0.027 using Zuntz and Weir equations, respectively) and EE_{TOT} (climbing + recovery time; $P = 0.025$ and 0.034 by Zuntz and Weir equations, respectively). However, the Tukey's HSD pairwise comparisons revealed significant differences only between ascents 1 versus 4 for EE recovery (31.0 ± 4.7 vs. 34.2 ± 6.1 and 31.0 ± 4.7 vs. 34.7 ± 6.5 kcal by Zuntz and Weir equations, respectively) and between ascents 4 versus 9 for EE_{TOT} (48.8 ± 10.7 vs. 43.8 ± 6.4 and 49.3 ± 11.1 vs. 43.7 ± 6.3 kcal using Zuntz and Weir equations, respectively).

Table 1 Climbing experience, performance and body composition characteristics of the study sample

	Males ($n = 8$)	Females ($n = 1$)
Age (years)	32.3 ± 15	26.0
Climbing experience (years)	12.3 ± 10.3	6.0
Climbing frequency in season (days per week)	3.4 ± 0.7	3.0
Climbing frequency in season (days per month)	13.6 ± 6.3	12.0
Current climbing frequency (days per week)	2.5 ± 0.8	2.0
Current climbing frequency (days per month)	10.0 ± 4.4	8.0
Onsight climbing performance (range)	5.11a–5.12b	5.11a
Height (cm)	172.4 ± 6.5	170.5
Weight (kg)	64.2 ± 7.1	60.2
Body mass index (kg/m^2)	21.5 ± 1.2	20.7
Σ4 skin folds (mm)[a]	38.5 ± 17.0	68.3
Body density (kg/m^2)	1.06 ± 0.01	1.03
Body fat (%)	16.6 ± 5.3	31.6

Data are expressed as mean ± SD, except for onsight climbing performance (range)

[a] Σ4 skin folds: triceps, biceps, subscapular and iliac crest

Discussion

The present study was designed to analyze the physiological responses during repeated ascents of a climbing route in a sample of experienced rock climbers over a 10-week period. The results suggest that climbing time (min), EE_{CLM} (kcal) and $\%EE_{CLM}$ decrease over the repetitions, while there does not seem to be any modification in the other physiological peak parameters such as V_E, VO_2 or HR.

The climbing VO_2 and HR peak values observed in this study were within the range of previous studies (Espana-Romero et al. 2009a; Sheel 2004; Watts 2004). Regarding EE (kcal min^{-1}), only two studies have been conducted previously for rock climbing activity. Mermier et al. (1997) studied the EE in 14 rock climbers who performed three trials of increasing difficulty, easy (5.6), moderate (5.9) and difficult (5.11+). Watts and Drobish (1998) assessed the physiological responses in 16 rock climbers over a climbing route at different angles (80°, 86°, 91°, 96° and 102°, respectively). The EE values reported in these studies ranged from 9.31 to 12.61 kcal min^{-1} (Mermier et al. 1997) and from 10.4 to 11.2 kcal min^{-1} (Watts and Drobish 1998) and were a bit higher than those obtained in our study (range of 7.3–7.9 kcal min^{-1}).

Table 2 Climbing parameters of the study sample ($n = 9$ climbers) in the 1st, 4th, 6th and 9th ascents

	Ascent 1	Ascent 4	Ascent 6	Ascent 9	*P*	Post hoc pairwise comparisons					
						1–4	1–6	1–9	4–6	4–9	6–9
Climbing time (min)	2.02 (0.6)	1.56 (0.4)	1.50 (0.4)	1.38 (0.3)	<0.001	>	>	>	–	–	–
Rating of perceived exertion	12.2 (1.3)	12.2 (3.6)	11.8 (2.5)	11.0 (1.9)	0.457	–	–	–	–	–	–
Peak heart rate for climbing (b min^{-1})	157.0 (20.8)	155.6 (19.4)	156.1 (15.1)	148.9 (16.7)	0.192	–	–	–	–	–	–
% Heart rate max[a]	83.5 (10.9)	83.5 (11.5)	83.1 (8.9)	79.4 (11.2)	0.332	–	–	–	–	–	–
% Heart rate max (range)	59.9–99.4	67.4–102.4	70.6–96.4	65.8–101.2	–						
Ventilation peak (BTPS) (l min^{-1})	60.0 (8.9)	62.3 (14.0)	58.8 (9.5)	57.9 (9.9)	0.389	–	–	–	–	–	–
VO_2 peak (ml kg^{-1} min^{-1})	36.9 (4.9)	36.0 (5.2)	36.1 (3.7)	36.8 (3.7)	0.872	–	–	–	–	–	–
VO_2 peak (l min^{-1})	2.390 (0.376)	2.400 (0.379)	2.320 (0.364)	2.377 (0.357)	0.236	–	–	–	–	–	–
VCO_2 peak (ml kg^{-1} min^{-1})	31.4 (4.5)	31.0 (2.9)	30.1 (3.0)	30.1 (4.7)	0.403	–	–	–	–	–	–
VCO_2 peak (l min^{-1})	1.980 (0.254)	2.001 (0.310)	1.931 (0.267)	1.905 (0.381)	0.581	–	–	–	–	–	–
Respiratory exchange ratio peak	1.17 (0.08)	1.17(0.10)	1.16 (0.06)	1.13 (0.06)	0.352	–	–	–	–	–	–
METs peak	10.6 (1.4)	10.3 (1.5)	10.3 (1.1)	10.5 (1.1)	0.873	–	–	–	–	–	–
Peak EE rate for climbing + recovery by Weir et al. (kcal min^{-1})	11.22 (1.98)	11.68 (1.78)	11.44 (1.89)	11.36 (1.60)	0.755	–	–	–	–	–	–
Peak EE for climbing by Weir et al. (kcal min^{-1})	7.6 (1.8)	7.9 (1.8)	7.7 (1.7)	7.2 (1.3)	0.406	–	–	–	–	–	–
EE for climbing by Weir et al. (kcal)	17.0 (5.1)	14.6 (5.0)	13.2 (4.5)	11.5 (3.2)	<0.001	–	>	>	–	>	–
EE for recovery by Weir et al. (kcal)	31.0 (4.7)	34.7 (6.5)	33.2 (5.8)	32.2 (4.7)	0.027	<	–	–	–	–	–
Total EE for climbing + recovery by Weir et al. (kcal)	48.0 (8.2)	49.3 (11.1)	46.4 (10.0)	43.7 (6.3)	0.034	–	–	–	–	>	–
$\%EE_{CLM}$ by Weir et al.[b]	34.8 (7.2)	29.0 (4.8)	27.8 (4.5)	26.0 (5.7)	<0.001	>	>	>	–	–	–

Data are presented as mean (SD), unless otherwise indicated. *P* was calculated by one-way ANOVA for repeated measures. Post hoc pairwise comparisons were calculated by Tukey's HSD. Example of pairwise comparison: the symbol > in the column 1–4 indicates a significant difference ($P < 0.05$) in the direction 1 > 4. – non-significant. Statistical power range in variables with $P < 0.05$ was between 70 and 100%

EE energy expenditure, *CLM* climbing

[a] Peak heart rate as a percentage of age-predicted heart rate maximum

[b] Energy expenditure values using Zuntz's equation have been omitted from this table for an easier reading. The results are virtually the same compared to those obtained using Weir's equation

To the best of our knowledge, this is the first time that EE_{TOT} (climbing time +10 min recovery) has been analyzed in this particular sport discipline. Also, there are no previous studies examining physiological responses during repeated ascents of a climbing route.

According to our results, EE_{CLM} (kcal) and $\%EE_{CLM}$ seem to decrease over the repetitions. This could be related to the fact that progressively faster climbing resulted in less energy expended during the actual climbing. A different pattern was observed for the initial comparison period between ascents 1 and 4 where EE for climbing did not significantly decrease, while EE for recovery increased. During the interval between ascents 1 and 4, the faster rate of climbing may have produced metabolic and physiologic consequences that resulted in increased EE during the recovery period. Any such consequences appear to resolve with repetition, since further changes in total EE between ascent 4 and the final ascent 9 appear to be due to decreased EE_{CLM} alone.

It is acknowledged that rock climbing activity requires combined arm and leg work, and is characterized by dynamic moves interspersed with periods of isometric muscular contractions (Booth et al. 1999; Espana-Romero et al. 2009a; Ferguson and Brown 1997; Mermier et al. 1997). It has been observed that climbing speed normally slows and isometric holding increases with the difficulty of climbing (Booth et al. 1999). Altogether, this evidence suggests that in our study the faster movement over the repetitions probably reduced the overall time of isometric work and thereby lowered the total climbing energy expenditure. This could also be related to a concomitant improvement in the participants' climbing technique. Since the kcal/min values for climbing remained unchanged, while the %EE for climbing progressively decreased, it is unlikely that the improvement in performance was simply due to a metabolic adaptation and could be more neuromuscular in nature. The reduction in absolute energy expenditure during climbing may be related to lower fatigue and less risk of falling. A shift in some of the total energy expenditure into the recovery period, as observed between ascents 1 and 4, could be a benefit for climbing single-ascent routes and competition routes, where there is less of a time constraint during recovery, rather than in longer multi-pitch ascents, where recovery is crucial for the next pitch of climbing. On the other hand, the increment in EE for recovery between ascent 1 and 4 could explain the facts that EE_{TOT} is the highest in ascent 4, and the subsequent significant difference in EE_{TOT} observed between ascents 4 and 9. Whether these results can be applied to other climbing routes, where the holds, movements or even the ability rate are different, are not known and warrant further research.

The climbing route rating, 5.10a in YDS and 6a in French system, can be considered submaximal relative to our climbers' ability. It may be suggested that economy changes may not be possible with repetition of a submaximal route, since the technical aspects are already within the capabilities of the climbers. However, previous results from other activity models do not support this assumption. For an experienced runner, running may not be considered as a technically challenging activity; however, changes in economy may be expected with repetition over time. Previous authors (Saunders et al. 2004) determined that reliable measures of running economy need to be obtained at speeds eliciting ≤85% of $VO_{2\ max}$. We think that this theory can be extended to rock climbing through a difficult route, 15–20% below a subject's top capability. This route range was also chosen to make certain that a climber would not fall, as a fall would eliminate a trial and interject a degree of extra practice on the route.

The 10-min recovery period was selected to provide an assessment of most of the EPOC (excess post-exercise oxygen consumption) and to minimize the overall time required by the participants. Ten minutes recovery was selected for all participants since a previous study (Watts et al. 2000) indicated that, following a single ascent of a competition-style route, most of the EPOC is accomplished within 10 min of resting recovery. However, as a possible limitation, we have to acknowledge that maximal incremental tests were not performed and, therefore, we do not know our participants' VO_{2max} or whether the passive recovery VO_2 returned to a resting level during the 10 min.

The Weir (1949) and Zuntz (1901) equations have been used previously in research in different fields, including Public Health (Doucet et al. 2003; Lorello et al. 2008; Shew et al. 2000) and Sport Sciences (Brugniaux et al. 2010; McDaniel et al. 2002; Stewart and Stewart 2007; Westerterp et al. 1992). Within the Sport Sciences, these EE equations have been used in the study of disciplines such as ultra-endurance running (Stewart and Stewart 2007), cycling (McDaniel et al. 2002) and mountaineering (Westerterp et al. 1992). They have also been used as the gold standard in validity studies (Brugniaux et al. 2010). Therefore, we considered these equations as appropriate to be used in rock climbing studies. It should be highlighted that the Weir and Zuntz equations have different assumptions regarding substrate utilization and calculate EE from different expired air analysis variables. However, we feel it is interesting to provide EE by both methods to show that they provided similar data and the same pattern over the 10-week period. This confirms that subsequent research on energy expenditure during climbing may use either method.

The participants were not provided direct information about their performances for each trial nor were their previous trials discussed prior to subsequent climbing. Climbers were given an option to preview the route immediately prior to each test ascent to enhance climbing performance (Sanchez et al. in press); however, there was no direct discussion of the route with the researchers.

Thus, any modifications in techniques or specific movement paths (if they occurred) were self-determined by each individual climber. Further research is therefore required to determine if "coaching" or providing information to the climber will have an effect on subsequent performance and energy expenditure.

Some possible limitations of this study should be recognized. First, the relatively low number of participants and the selection of a non-homogeneous sample of sport climbers could be a limitation. Secondly, we did not specifically control the participants' training regimen during the study. However, they were all encouraged to keep their normal habits and to avoid exhausting exercise 24 h previous to climbing in the testing sessions. Also, the hydration status of the participant was not taken into account; yet the participants were asked to avoid eating 2 h prior to the climbing session. We also would like to highlight that the contribution of the physiological components may vary as the nature and difficulty of climbing change. On the other hand, it should be also highlighted that the high degree of technology used for the measurements (such as continuous expired air analysis and EE calculated during actual climbing on an indoor wall) and the strict standardization of the field work are notable strengths of the study.

In conclusion, performing repeated ascents of a climbing route decreased the climbing time and absolute energy expenditure during climbing. Initially, the decrease in climbing energy expenditure is accompanied by an increase in energy expenditure during recovery; however, by the ninth ascent, the total energy expenditure of the task is lower than for ascent 1.

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