Physiological Demands of Indoor Wall Climbing in Children

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Abstract

The study aimed to assess the physiological demands of indoor wall climbing in children. Twenty five children (aged 8–12 years) from a climbing school, with a performance RP (red point) of IV to V+ UIAA (Union Internationale des Associations d'Alpinisme) scale, (5.4 to 5.7 YDS, Yosemite Decimal System and 4a to 5a Sport/French scale), participated in the study. All 25 children climbed the first vertical route (IV UIAA, 5.4 YDS, 4a Sport/French) and ten went on to complete the 110° overhanging route (IV+ UIAA, 5.5 YDS, 4b Sport/French). Both routes were climbed in a top rope style, at a self-selected pace. A portable gas analyser was used to assess the physiological response to the climbs. In addition, the time spent climbing by the children was recorded during the subsequent eight-week period. There were no significant differences found in the peak oxygen consumption between boys and girls, or for the route inclinations, with mean values of around 40 $ml \cdot kg^{-1} \cdot min^{-1}$. The children also achieved similarly high mean % values of HR_{max}, of between approximately 81 – 90%. To conclude, a typical children's climbing session involves short intermittent high intensity climbing, interspersed with longer periods of rest. It is possible that climbing in short intermittent bursts, as seen in the present research, may be considered high-intensity-training (HIT), with sufficient intensity to influence aerobic fitness in children.

Keywords: children, climbing, oxygen consumption, energy expenditure

Introduction

Regular physical activity and exercise are associated with numerous physical and mental health benefits in men, women and children (Garber et al., 2011). Despite increased knowledge about the importance of physical activity in everyday life, the number of diseases associated with movement insufficiency are increasing (Abrams & Levitt Katz, 2011; Must & Strauss, 1999; Wang, Gortmaker, Sobol, & Kuntz, 2006). Furthermore, inactivity in childhood has been found to influence activity patterns in adulthood (Hills, King, & Armstrong, 2007). As such, promoters of health related activities should offer sessions that are intrinsically interesting, in order to encourage lifelong participation.

Sport climbing has developed rapidly since the 80's, as demonstrated by the increasing number of both climbing walls and climbers. In France, there were five climbing walls in 1980, 54 in 1986, 600 in 1989 and 2266 in 2013 (Bourdeau, 1991; "Carte des murs d'escalade," 2013). In Germany, there are 79 climbing halls with a surface area larger than 1000 m^2, 430 walls with an area greater than 100 m^2 and 2400 other smaller facilities (Weinbruch et al., 2012). In the UK, the BMC reported the existence 343 walls in 2012. School climbing walls were not included in this figure and may increase the total number, as 14% of British school have integrated indoor climbing into their curriculum (Gardner, 2013). Children and youth (up to the age of 26) are the most frequent users of climbing walls and, according to FFME, represent more than half of sport climbers (La Fédération Française de la Montagne et de l'Escalade, 2014).

To date, research on physiology and energy expenditure in sport climbing has focused mainly on adult populations. Rodio et al. (2008) demonstrated that non-competitive rock climbing is an activity with sufficient intensity (≈ 28 $ml \cdot kg^{-1} \cdot min^{-1}$; 70% of $\dot{V}O_{2\,peak}$) for the maintenance of aerobic fitness. They proposed that total ascent time should be around 150 minutes per week to match the American College of Sport Medicine (ACSM) recommendations for activity levels (Garber et al., 2011); this is the equivalent to approximately 500-700 metres of climbing, per week (Rodio et al., 2008). Several other studies have documented $\dot{V}O_2$ consumption during various climbing protocols at between 20 - 45 $ml \cdot kg^{-1} \cdot min^{-1}$; they have also demonstrated that total $\dot{V}O_2$ consumption is influenced by other factors, such as locomotion pace, climbing difficulty, steepness of the wall, climbing style and climbing ability (Baláš et al., 2014; de Geus, O'Driscoll, & Meeusen, 2006; Draper, Jones, Fryer, Hodgson, & Blackwell, 2010; Mermier, Robergs, McMinn, & Heyward, 1997; Sheel, Seddon, Knight, McKenzie, & Warburton, 2003; Watts, 2004).

Very few studies have focused on children's physiological responses to sport climbing. Watts et al. (2003) found competitive young climbers to be low in body mass and body fat, indicating a difference in body composition between climbing and non-climbing athletes, despite similar body mass indices. Similarly, recent research by Baláš et al. (2009) demonstrated the positive effects of eight weeks climbing on body composition, handgrip and upper-body strength in young climbers aged 10-17. It was found that the effects on body composition and strength were not significant when the distance climbed was below 40 metres per week, or when the climbing took place within school physical education classes (Baláš & Bunc, 2007; Baláš et al., 2009). In addition, Morrison and Schoeffl (2007) also examined the physiological response to climbing of young climbers, with a review focusing on the prevention of injuries and the avoidance of inappropriate climbing training.

To our knowledge, there has only been one study that has focused on the metabolic demands of climbing in children, conducted by Watts & Ostrowski (2014). The authors measured oxygen uptake and energy expenditure in children aged 10.9 ± 1.7 years during climbing. Their climbing protocol consisted of two types of movement, a continuous traverse and an interval traverse. They found traverse climbing on a bouldering wall similar in energy expenditure to sport/game activities and easy jogging, with a peak oxygen consumption during sustained and interval climbing of 31.8 ± 7.2 $ml \cdot kg^{-1} \cdot min^{-1}$ and 27.3 ± 6.2 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively. The physiological response to vertical top-rope climbing in children has not yet been evaluated.

Despite the sport of climbing being an activity practiced by children and youth, there is little scientific evidence about its health benefits. Knowledge of physiological responses during non-competitive indoor wall climbing will help in activity prescription by teachers and coaches. As such, study aimed to assess the physiological demands of indoor wall climbing in children.

Methods

Participants

Twenty five children (aged 8–12 years) from a climbing school volunteered to take part in the study: boys (n = 12; 9.2 ± 1.7 years) and girls (n = 13; 9.6 ± 1.8 years). Climbing ability was identical and climbing experience was similar for both sexes, as shown in Table 1. Climbing ability was assessed on the UIAA (Union International des Associations d'Alpinisme) scale. Climbing ability was self-reported by the participants, with subsequent verification by their instructors. Ethical approval was obtained for the study in accordance with University Ethics Committee regulations; all participants provided informed consent.

Body composition assessment

Body mass was measured on a digital scale (Tanita HD 366, Japan) to an accuracy of 0.1 kg. The weighing was performed without shoes, in sport clothes. Height was measured using a stadiometer, with the children standing in an upright position, without shoes, with arms beside the body. Body composition was assessed via whole-body bio impedance using the multi-frequency device Nutriguard-M (Data Input GmbH, Germany) on frequencies 5–50–100 kHz. Testing was undertaken in a supine position with the tetra polar configuration of electrodes. The percentage of body fat was calculated from the equations according to the manufacturer's guidelines.

Table 1. Mean values (± standard deviation) of body mass, high and body fat.

	Boys (n = 12)	Girls (n = 13)
Body mass (kg)	29.7 ± 5.6	33.6 ± 9.4
Height (cm)	134.3 ± 8.5	138.3 ± 10.8
Body fat (%)	9.5* ± 1.9	17.5* ± 2.9

* significant differences between boys and girls $p<0.05$

Energy expenditure measurement

Indirect calorimetry using oxygen consumption ($\dot{V}O_2$) and carbon dioxide production (CO_2) was used to assess energy expenditure during climbing. Ventilation, O_2 and CO_2 were recorded during the whole measurement with a portable gas analyser (MetaMax 3B, Cortex, Germany). The gas analyser was carried on a chest harness and, according to feedback from the participants, did not interfere with climbing movement. The measured values of expiratory gases were averaged every 20 seconds. Energy expenditure was calculated from the caloric equivalent of 20.9 kJ as already used in other climbing studies (Bertuzzi, Franchini, Kokubun, & Kiss, 2007; Mermier, Robergs, McMinn, & Heyward, 1997; Rodio, et al., 2008) and was expressed in $kJ\cdot min^{-1}\cdot kg^{-1}$ and in $kJ\cdot m^{-1}\cdot kg^{-1}$. The calibration of the gas analyser was performed according the manufacturer's guidelines. Heart rate was recorded via a chest belt (Polar SX 800, Finland). Maximum heart rate (HR_{max}) was estimated from the equation formula 220-age (Wilmore, Costill, & Kenney, 2008).

Climbing protocol

The climbing wall was 9.8 m high for the vertical (90°) route and 10.0 m for the overhanging (110°) route. Before climbing, participants were asked to perform a five-minute warm-up, which consisted of stretching, followed by five-minutes of easy bouldering. An experienced route setter created the two testing routes three weeks before the measurement, providing time for familiarisation of the climbing sequence for all participants. The difficulty and profile of the routes were chosen on the basis of the preferred routes of the children during their previous climbing lessons, as well as through discussion with their instructors. The first route was vertical (IV UIAA, 5.4 YDS, 4a Sport/French)), the second had an overhanging profile and was considered slightly more challenging (IV+ UIAA, 5.5 YDS, 4b Sport/French).

All 25 children climbed the first vertical route (Figure 1b); ten went on to complete the overhanging route. Despite the children reporting similar climbing ability, only ten were able to climb the route with an overhanging profile. Both routes were climbed in the top rope style at a self-selected pace. A three-minute resting recording was completed before climbing (Figure 1a). Participants then climbed the selected route to the last hold, from where they were rapidly lowered down (30 seconds) in order to repeat the same climb for a second time. The second repeat of the route was completed as it is common for climbing walls to be construction with a height of 15 meters. In order to achieve this distance of climbing on the current 10-meter wall the route was climbed twice, this also meant that a minimum of three minute climbing duration was then possible which has previously been found sufficient to achieve steady state (Watts, Daggett, Gallagher, & Wilkins, 2000). After climbing, participants rested until they returned to their initial pre-climbing values. Ten children then went on to climb an overhanging route according to the same climbing protocol. These children were selected through discussion with their instructors, based on the criteria that they were considered capable of completing route with an overhanging profile.

Table 2. Mean values (± standard deviation) of climbing distance, climbing experience and climbing ability for boys and girls

Climbing characteristics	**Vertical route**		**Overhanging route**	
	Boys (n=13)	Girls (n=12)	Boys (n=6)	Girls (n=4)
Climbed distance (m)	293 ± 194	279 ± 79	333 ± 217	252 ± 82
Climbing experience (years)	1.6 ± 1.1	1.5 ± 1.2	1.8 ± 1.1	2.3 ± 2.0
Climbing performance RP (UIAA)	IV to V+	IV to V+	IV+ to V+	IV+ to V+
(YDS)	5.4 to 5.7	5.4 to 5.7	5.5 to 5.7	5.5 to 5.7
(Sport/French)	4a to 5a	4a to 5a	4b to 5a	4b to 5a

In addition to the data collected above, the time spent climbing by the participant during climbing lessons was registered during the subsequent eight-week period, in all tested children (Table 2). During this eight-week period the climbing sessions (60 minutes) were comprised of routine preparatory and climbing tasks, which included presentation, kitting up in harnesses, dividing into groups and the climbing itself.

*** Figure 1a & 1b near here ***

Data analysis

Anthropometric characteristics and test results were evaluated using descriptive statistics (mean and standard deviation). Differences between girls and boys were assessed by t-test for independent samples. The significance level was set to $P = 0.05$. All statistical analyses were performed using statistical software SPSS for Windows Version 19 (Chicago, IL, USA).

Results

Significant difference was found between girls and boys in body composition, with boys having a significantly lower percentage of body fat than girls (Table 1). Table 3 shows the average values of ventilatory parameters, heart rate, energy expenditure and climbing time for boys and girls, with the two route inclinations. There were no significant differences in absolute and relative oxygen consumption between the boys and girls, or for the different inclinations, with values of around 40 ml·kg^{-1}·min^{-1} reported for both. Both routes took around 4 minutes to complete; it should be noted that this is an average time, the standard deviation was high and speed of individuals was very heterogeneous. The slowest climbing time (5.2 min) was on the overhanging route for girls and the fastest time (3.6 min) was on the vertical route in boys. Climbing time on the overhanging profile route was between 0.5 - 1.5 minutes slower than the climbing time on the vertical profile route.

Table 3. Mean values (± standard deviation) of oxygen consumption ($\dot{V}O_2$), ventilation ($\dot{V}_E$), respiratory coefficient (RER), heart rate (HR), energy expenditure and time of climbing for two different angles in children during climbing.

Variables	Vertical route		Overhanging route	
	Boys (n=13)	Girls (n=12)	Boys (n=6)	Girls (n=4)
$\dot{V}O_{2peak}$ (l·min^{-1})	1.17 ± 0.22	1.24 ± 0.33	1.26 ± 0.30	1.27 ± 0.16
$\dot{V}O_{2peak}$ (ml·kg^{-1}·min^{-1})	39.6 ± 4.4	37.1 ± 4.5	42.8 ± 2.5	40.5 ± 5.6
$\dot{V}_E$ (l·min^{-1})	33.0 ± 4.8	34.7 ± 8.7	37.4 ± 6.3	38.9 ± 10.0
RER	0.91 ± 0.01	0.91 ± 0.06	0.95 ± 0.09	0.99 ± 0.05
HR_{peak} (beats·min^{-1})	170 ± 15	180 ± 9	176 ± 21	190 ± 14
% of HR_{max} (%)	81 ± 7	86 ± 5	84 ± 10	90 ± 7
Energy expenditure (kJ·min^{-1})	24.5 ± 4.7	25.9 ± 7.0	26.3 ± 6.3	26.5 ± 7.3
Energy expenditure (kJ·min^{-1}·kg^{-1})	0.82 ± 0.16	0.77 ± 0.21	0.89 ± 0.26	0.79 ± 0.23
Energy expenditure (kJ·m^{-1}·kg^{-1})	0.15 ± 0.03	0.14 ± 0.04	0.19 ± 0.05	0.20 ± 0.06
Time of climbing (s)	217 ± 48	220 ± 68	254 ± 56	309 ± 6

Finally, the time spent climbing by the children was averaged from recordings completed during a subsequent eight weeks of climbing sessions (8-16 training sessions). The average pure climbing time during a 60 minutes training session was 11.3 ± 4.3 min. Children climbed approximately three routes per 60 minutes session, on a wall approximately ten metres high. The energy expenditure of climbing during one climbing hour, in the case of vertical climbing routes, was estimated to be 277 ± 53 kJ for boys and 293 ± 79 kJ for girls and in the case of overhanging climbing routes for boys 297 ± 71 kJ and for girls 271 ± 83 kJ.

Discussion

The present study aimed to assess children's physiological response to indoor climbing. Children's oxygen consumption during climbing on a preferred route was observed. The research sample consisted of 25 children who had been climbing for 1.5 ± 1.2 years. The climbing ability of the children ranged from IV to V+ UIAA (5.4 to 5.7 YDS, 4a to 5a Sport/French), which classified them among Lower Grade (Level 1) climbers, according to grading scales produced by Draper et al. (2011).

To date, only one study has examined energy expenditure in children (10.9 ± 1.7 years) during climbing (Watts & Ostrowski, 2014). This study compared oxygen consumption during five minutes of sustained traverse climbing and a set of five interval climbs comprised of one-minute of traversing and one-minute of rest in a sitting position. Watts & Ostrowski used the Weir method for energy calculation and found the intensity of interval climbing (16.4 ± 5.5 kJ·min^{-1}) to be significantly higher than sustained climbing (14.3 ± 5.5 kJ·min^{-1}); they also measured a peak oxygen consumption during sustained climbing on a vertical profile route that was 5.3

$ml \cdot kg^{-1} \cdot min^{-1}$ lower than our study. This may be explained by the climbing protocol and style of climbing used in Watts and Ostrowski's study (traverse bouldering vs. climbing with rope) or the difference in climbing experience and ability of the participating children.

Recent studies have reported peak $\dot{V}O_2$ values in young and adult climbers varying between 20 - 54 $ml \cdot kg^{-1} \cdot min^{-1}$ (Booth, Marino, Hill, & Gwinn, 1999; de Geus, et al., 2006; Bertuzzi, et al., 2007; Draper, et al., 2010; Espana-Romero, Jensen, Sanchez, Ostrowski, Szekely & Watts, 2012; Mermier, et al., 1997; Rodio, et al., 2008). The large differences in oxygen consumption observed are likely to be due to a combination of differences in climbing pace, the climbing ability of participants, difference in route difficulty, inclination of climbing route and the style of climbing. De Geus et al. (2006) and Bertuzzi et al. (2007) used a similar climbing protocol to the present study: top rope self-paced climbing, vertical and slightly overhanging profiles and near to the maximum ability of the climbers (one or two UIAA degrees under their maximum), $\dot{V}O_{2peak}$ consumption in adult climbers was reported as 44.1 ± 5.8 $ml \cdot kg^{-1} \cdot min^{-1}$ and 36.0 ± 5.5 $ml \cdot kg^{-1} \cdot min^{-1}$ on 15.5 meter and 10 metres high wall, respectively. These large differences in $\dot{V}O_{2peak}$ may be a consequence of differing climbing route difficulty, ability of the participants and time spent climbing the route, which is related to the height of the wall. Bertuzzi et al. (2007) examined climbers' performance on route two degrees under their maximum climbing ability, with a climbing time 83.9 ± 20.1 seconds. It is possible that this time was too short for a sufficient evaluation of metabolic demands during climbing.

An important parameter in $\dot{V}O_2$ consumption seems to be climbing experience or climbing technique, as reported by both Draper et al. (2008) and Baláš et al. (2014). Both authors demonstrated that climbers with higher climbing experience, expressed as years of climbing or climbing ability, had substantially lower oxygen cost during submaximal climbing than lower grade climbers. A typical phenomenon for climbing courses is the repetition of climbing routes. Romero et al. (2012) demonstrated a decrease in adults' energy expenditure during climbing over a 10-week period. The climbers achieved the same values of oxygen consumption of around 36 $ml \cdot kg^{-1} \cdot min^{-1}$ during repeated ascents of a climbing route, but the climbing time decreased by 30 seconds, which led to a decrease of energy expenditure of 4.3 kcal. It is important to note, that this phenomenon may influence the assessment of physical activity demands of climbers with better climbing ability, it is likely that more experienced climbers will need higher volume of climbing to experience similar health benefits as climbers with a lower climbing ability.

A representative example of the oxygen kinetic whilst climbing a vertical route is shown in Figure 2. Figure 2 demonstrates that the peak values observed were similar during the first and the second climb of the vertical route and that a steady state of oxygen consumption was not achieved. The peak oxygen consumption ranged between 30 - 40 $ml \cdot kg^{-1} \cdot min^{-1}$. Both vertical and overhanging routes demanded a similar physiological response.

*** Figure 2 near here ***

Steady-state conditions in $\dot{V}O_2$ are necessary for the correct evaluation of energy expenditure (Machado Reis, 2011). Watts et al. (2000) found that three minutes of sustained climbing were sufficient to achieve a plateau in $\dot{V}O_2$. However, it was not known if this plateau represented a metabolic steady state or a climbing specific $\dot{V}O_{2max}$. According to the results of the present study, three minutes were not enough to achieve steady-state $\dot{V}O_2$, as illustrated in Figure 2. Watts and Ostrowski (2014) achieved a near steady-state during a five minutes long climb, but a true steady state may not have been reached, since $\dot{V}O_2$ continued to increase at a slow rate during the climbing period. More research is necessary in this area to understand the mechanisms of oxygen kinetic in children during sustained or intermittent climbing.

Climbing seems be a suitable physical activity for children to develop muscular strength and endurance (Baláš & Bunc, 2007; Baláš, et al., 2009). Baláš et al. (2009) found that indoor wall climbing with a higher volume of metres climbed, can influence grip strength, upper body muscular endurance and the amount of relative body cellular mass after eight weeks of indoor wall climbing in youth aged 10-17 years old. According to their study, it appears that 80 meters per week in beginner and moderately experienced climbers is sufficient for maintaining or developing upper body strength. These authors consider the distance climbed an important factor to assess the effect of climbing. In addition, Janssen (2007) presented physical activity guidelines for school-aged children and youth, with recommendations to engage in ≥3 sessions/week of moderate to vigorous activities that last ≥20 min or accumulate 30 min of moderate physical activity each day. In the current study, children climbed around 35 metres per climbing lesson. With such a low climbing distance the question arises, can we expect any health benefits from the activity?

It is possible that climbing in short intermittent bursts, as seen in the present research, may be considered high-intensity-training (HIT). Children climbed some of the routes continuously, but most paused whilst on the route. In our study, in the follow up data collection children spent approximately one sixth of lesson time actually climbing at moderate or vigorous intensity (calculated from meters climbing per 60-miunte lesson). Gibala et al. (2012) supports low-volume HIT (protocol with 30 s x 4-6 repeats, 4.5 min rest, three sessions per week) as a potent and time-efficient training method for inducing central (cardiovascular) and peripheral (skeletal muscle) adaptations, which are linked to improved health outcomes. HIT has also been shown to significantly improve aerobic fitness in children (Baquet et al., 2010; de Araujo et al., 2012).

Adegboye et al. (2011) defined a minimum intensity of exercise required to develop low aerobic fitness in children and adolescents from four European countries. They assessed aerobic fitness through a maximum cycle ergometer test, where the maximal value of oxygen consumption was approximately 42 - 52 $ml \cdot kg^{-1} \cdot min^{-1}$ in children 9-15 years old. Fawkner et al. (2002) arrived at similar maximal oxygen consumption in a previous study of children (11-12 years), with values 50.3 ± 6.3 $ml \cdot kg^{-1} \cdot min^{-1}$ for boys and 43.9 ± 6.1 for girls, using a cycle ergometer, during maximal test to voluntary exhaustion. Adegboye et al. (2011) found the optimal cut-offs, above which effective development of aerobic fitness will occur, for 9-years old boys to be 43.6 $ml \cdot kg^{-1} \cdot min^{-1}$ and 46.0 $ml \cdot kg^{-1} \cdot min^{-1}$ for the 15-year old, whereas for girls the optimal cut-offs were 37.4 $ml \cdot kg^{-1} \cdot min^{-1}$ and 33.0 $ml \cdot kg^{-1} \cdot min^{-1}$ for the 9 and 15-year olds, respectively. The children in the current study achieved the $\dot{V}O_{2peak}$ around 40 $ml \cdot kg^{-1} \cdot min^{-1}$, which should represent a sufficient intensity to support the health of children through climbing.

Rodio et al. (2008) used the respiratory exchange ratio, non-protein equivalent, for the evaluation of energy cost during rock climbing. They investigated physiological adaptions in non-competitive rock climbers in order to assess whether rock climbing fulfils sports medicine recommendations for maintaining a good level of aerobic fitness. Total energy cost was calculated from the total $\dot{V}O_2$ measured during the ascent and recovery times. Total energy cost for men and women was approximately 0.28 – 0.33 $kJ \cdot kg^{-1} \cdot min^{-1}$. Our results are significantly higher, by about 0.46 $kJ \cdot kg^{-1} \cdot min^{-1}$. This may be due to inferior movement economy or lower body mass in children. It was shown that oxygen uptake does not increase proportionally to body mass (Bergh et al., 1991). Thus, the energy expenditure per kg of body mass might be higher for children than for adults.

Conclusion

In conclusion, we found indoor wall climbing to be a physical activity with sufficient intensity to influence aerobic fitness in children. The peak oxygen consumption during top rope climbing was around 40 $ml \cdot kg^{-1} \cdot min^{-1}$. A typical children's climbing session may represent High Intensity Interval (HIT) training, as it involves short intermittent high intensity climbing activity, interspersed with longer periods of rest. In contrast to previous studies, a steady state of oxygen consumption after three minutes of climbing was not achieved; as such, it is difficult to estimate an accurate value of energy expenditure for climbing in younger children. Finally, as young climbers improve an increase in either volume (distance or time of climbing) or intensity (difficulty of routes) may be necessary to maintain climbing intensities of the level found in this study.

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Table of content

Children are not just adults in a smaller body; therefore, we cannot assume that physical activity has same effects on them as adults. The current study determines the physiological demands in children during indoor wall climbing.

Running title

Physiological Demands of Indoor Wall Climbing for Children

Captions for Figures

Figure 1. a) Rest before climbing b) Climbing test

Figure 2. Representative example of the oxygen consumption pre-climbing, during and post-climbing of a vertical route.