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 10 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·kg⁻¹·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, 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 is 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 1980s, as demonstrated by the increasing number of both climbing walls and climbers. In France, there were 5 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 m², 430 walls with an area greater than 100 m² 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 La Fédération Francaise de la Montagne et de l’Escalade (FFME), represent more than half of sport climbers (FFME, 2014).

To date, research on physiology and energy expenditure in sport climbing has focused mainly on adult populations. Rodio, Fattorini, Rosponi, Quattrini, and Marchetti (2008) demonstrated that non-competitive rock climbing is an activity with
Morrison and Schoffl (2007) examined the reviewed studies focused on the metabolic demands of competitive indoor wall climbing will help in activity prescription by teachers and coaches. As such, the study aimed to assess the physiological demands of outdoor 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 I. 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.

| Boys (n = 12) | Girls (n = 13) |
|---------------|---------------|
| Body mass (kg) | 29.7 ± 5.6 | 33.6 ± 9.4 |
| High (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.

**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.

**Energy expenditure measurement**

Indirect calorimetry using oxygen consumption (VO₂) and carbon dioxide (CO₂) production was measured.
used to assess energy expenditure during climbing. Ventilation, oxygen and carbon dioxide production 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 s. 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 et al., 1997; Rodio et al., 2008) and was expressed in kJ·min⁻¹·kg⁻¹ and in kJ·m⁻¹·kg⁻¹. The calibration of the gas analyser was performed according to the manufacturer’s guidelines. Heart rate was recorded via a chest belt (Polar SX 800, Finland). Maximum heart rate (HRmax) was estimated from the equation HRmax = 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 5-min warm-up, which consisted of stretching, followed by 5 min 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); 10 went on to complete the overhanging route. Despite the children reporting similar climbing ability, only 10 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 3-min logging 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 s) 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 metres. In order to achieve this distance of climbing on the current 10-metre wall the route was climbed twice, this also meant that a minimum of 3-min 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
Climbing performance RP (UIAA) IV to V

Climbing experience (years) 1.6

Climbed distance (m) 293

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

| Climbing characteristics                  | Vertical route     | Overhanging route | Girls (n = 12) | Boys (n = 6) |
|-------------------------------------------|--------------------|-------------------|----------------|--------------|
| 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     |

the criteria that they were considered capable of completing route with an overhanging profile.

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 II). During this eight-week period the climbing sessions (60 min) were comprised of routine preparatory and climbing tasks, which included presentation, kitting up in harnesses, dividing into groups and the climbing itself.

Data analysis

Anthropometric characteristics and test results were evaluated using descriptive statistics (mean ± 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 I). Table III 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 min 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 and 1.5 min slower than the climbing time on the vertical profile route.

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-min training session was 11.3 ± 4.3 min. Children climbed approximately three routes per 60-min session, on a wall approximately 10 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 5 min of sustained traverse climbing and a set of five interval climbs comprised of 1 min of traversing and 1 min of rest in a sitting position. Watts and Ostrowski (2014) 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·kg⁻¹·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 $\text{VO}_2$ values in young and adult climbers varying between 20 and 54 ml·kg⁻¹·min⁻¹ (Bertuzzi et al., 2007; Booth,
Marino, Hill, & Gwinn, 1999; de Geus et al., 2006; Draper et al., 2010; España-Romero et al., 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 pace, the climbing ability of participants, likely to be due to a combination of differences in difficulty, inclination of climbing routes. Espana-Romero et al. (2012) demonstrated a decrease in adults’ energy expenditure during sustained or intermittent climbing.

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 and 40 ml·kg⁻¹·min⁻¹. Both vertical and overhanging routes demanded a similar physiological response.

Steady-state conditions in VO₂ are necessary for the correct evaluation of energy expenditure (Machado Reis, 2011). Watts et al. (2000) found that 3 min of sustained climbing were sufficient to achieve a plateau in VO₂. However, it was not known if this plateau represented a metabolic steady state or a climbing specific VO₂max. According to the results of the present study, 3 min were not enough to achieve steady-state VO₂, as illustrated in Figure 2. Watts and Ostrowski (2014) achieved a near steady state during a 5-min long climb, but a true steady state may not have been reached, since VO₂ 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.

An important parameter in VO₂ consumption seems to be climbing experience or climbing technique, as reported by both Draper, Jones, Fryer, Hodgson, and Blackwell (2008) and Balas 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. España-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·kg⁻¹·min⁻¹ during repeated ascents of a climbing route, but the climbing time decreased by 30 s, 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.

Table III. Mean values (± standard deviation) of oxygen consumption (VO₂), ventilation (VE), 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)    |
| VO₂peak (l·min⁻¹)         | 1.17 ± 0.22    | 1.24 ± 0.33       | 1.26 ± 0.30     | 1.27 ± 0.16      |
| VO₂peak (ml·kg⁻¹·min⁻¹)   | 39.6 ± 4.4     | 37.1 ± 4.5        | 42.8 ± 2.5      | 40.5 ± 5.6       |
| V̇E (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      |
| HRpeak (beats·min⁻¹)      | 170 ± 15       | 180 ± 9           | 176 ± 21        | 190 ± 14         |
| % from HRmax (%)          | 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·m⁻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          |
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 metres of climbing 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 metres climbing per 60-min lesson). Gibala, Little, MacDonald, and Hawley (2012) support low-volume HIT (protocol with 30 s × 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·kg⁻¹·min⁻¹ in children of 9–15 years old. Fawkner, Armstrong, Potter, and Welsman (2002) arrived at similar maximal oxygen consumption in a previous study of children (11–12 years), with values 50.3 ± 6.3 ml·kg⁻¹·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·kg⁻¹·min⁻¹ and 46.0 ml·kg⁻¹·min⁻¹ for the 15-year old, whereas for girls the optimal cut-offs were 37.4 ml·kg⁻¹·min⁻¹ and 33.0 ml·kg⁻¹·min⁻¹ for the 9 and 15-year olds, respectively. The children in the current study achieved the VO₂peak around 40 ml·kg⁻¹·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 adaptations 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 VO₂ measured during the ascent and recovery times. Total energy cost for men and women was approximately 0.28–0.33 kJ·kg⁻¹·min⁻¹. Our results are significantly higher, by about 0.46 kJ·kg⁻¹·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, Sjödin, Forsberg, & Svedenhag, 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·kg⁻¹·min⁻¹. A typical children’s climbing session may represent high intensity interval training, as it involves short intermittent high intensity climbing activity, interspersed with longer periods of rest. In contrast to previous studies, a steady state does not increase proportionally to body mass (Bergh, Sjödin, Forsberg, & Svedenhag, 1991).

**Disclosure statement**

No potential conflict of interest was reported by the authors.

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