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Characterization and comparison of cardiorespiratory variables in boulder climbing during two routes of different difficulty levels

Caracterización y comparación de variables cardiorrespiratorias en escalada boulder durante dos rutas de diferente nivel de dificultad

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ABSTRACT

Evidence on physiological variables in bouldering climbing is relatively scarce. In the present study, cardiorespiratory responses were studied at different levels of this modality. Fourteen experienced climbers (6 women; age = 32.8±6.2 years) performed a maximal progressive test on a cycloergometer, determining peak VO_2, heart rate (HR) and respiratory minute volume (RMV), as well as VT1 and VT2 thresholds. Subsequently, the subjects performed climbing efforts of levels V1 and V3, of four minutes each, where peak VO_2, HR and RMV values were measured, as well as the relative VO_2 averages for each minute. Comparison between efforts was performed by repeated measures ANOVA. Regarding VO_2 and RMV, a significant difference was observed between the maximal result and the V1 and V3 levels ($p < 0.05$); although not between the two levels ($p > 0.05$). In relation to HR, the differences did not reach significance in any case ($p > 0.05$). In both modalities, VO_2 values corresponding to the first minute were below VT1. For V1, the average of minutes 2 and 3 was in the interthreshold zone, while minute 4 coincided with VT2. For V3,

the minute 2 average was observed in the interthreshold zone, while minute 3 coincided with VT2. The latter was exceeded in minute 4. The dissociation observed between HR and VO_2 indicates that HR alone would not be a reliable indicator of exertion load.

RESUMEN

Palabras clave:
Escalada boulder, escalada deportiva, metabolismo aeróbico, umbrales ventilatorios

La evidencia sobre variables fisiológicas en la escalada boulder es relativamente escasa. En el presente estudio se estudiaron las respuestas cardiorrespiratorias en diferentes niveles de esta modalidad. Catorce escaladores experimentados (6 mujeres; edad = 32.8±6.2 años) realizaron un test progresivo maximal en cicloergómetro, determinándose el VO_2, frecuencia cardíaca (FC) y volumen minuto respiratorio (VMR) picos, así como los umbrales VT1 y VT2. Posteriormente, los sujetos realizaron esfuerzos de escalada de niveles V1 y V3, de cuatro minutos cada uno, donde se midieron los valores de VO_2, FC y VMR picos, así como los promedios de VO_2 relativo de cada minuto. La comparación entre esfuerzos se realizó mediante ANOVA de medidas repetidas. Respecto al VO_2 y el VMR, se observó una diferencia significativa entre el resultado maximal y los niveles V1 y V3 ($p < 0.05$); aunque no entre ambos niveles ($p > 0.05$). En relación a FC, las diferencias en ningún caso alcanzaron significancia ($p > 0.05$). En ambas modalidades los valores de VO_2 correspondientes al primer minuto estuvieron por debajo del VT1. Para V1, el promedio de los minutos 2 y 3 se encontró en zona interumbral; mientras que el minuto 4 coincidió con el VT2. En V3, el promedio del minuto 2 se observó en zona interumbral, mientras que el minuto 3 coincidió con el VT2. Este último fue superado en el minuto 4. La disociación observada entre FC y VO_2, indican que la FC por sí sola no constituiría un indicador fiable de la carga de esfuerzo.

Introduction

Sport climbing, included for the first time as an Olympic sport in the Tokyo 2020 games, has experienced significant growth globally in recent years. In fact, the International Federation of Sport Climbing (International Federation of Sport Climbing [IFSC], 2020) estimates that by 2019 at least 140 countries had walls adapted for the practice of this sport, including more than 44.5 million practitioners worldwide in its indoor and outdoor modalities. With the aforementioned incorporation and consolidation of this discipline in the Olympic Games, it is to be expected that these figures have increased even more. In Uruguay, although there are no official numbers of practitioners, there are at least six gyms dedicated to its teaching and competition (Asociación Uruguaya de Escalada [AUDE], 2025). However, despite its growing popularity, relatively few studies have analyzed and compared physiological variables linked to performance at different levels of difficulty in bouldering. Furthermore, to the best of the authors' knowledge, there are no precedents in Uruguay.

The characteristics of the climbing effort (involving the simultaneous contraction of large muscle groups, continuously and for a period of time of several minutes) make cardiovascular and respiratory capacity fundamental determinants for the achievement of maximum performance (Callender et al., 2021). In this regard, a significant aerobic component (≈ 75% of VO_2 max) and demanding cardiorespiratory responses during exertion, which persist even for several minutes during recovery, have been recorded (Mermier et al., 1997). While recognizing the important contribution of non-oxygen-dependent energy pathways, sport climbing has traditionally been considered an aerobic endurance sport (Gomez et al., 2017).

The purpose of the present study was to characterize and compare cardiorespiratory physiological responses of two bouldering climbing routes of different difficulty, in particular V1 and V3. A secondary objective was to determine the Rate of Perceived Exertion (RPE) corresponding to the total route, as well as its possible difference according to the level considered. The results obtained could represent a novel contribution, helping to determine and differentiate the physiological demands occurring during the effort in both modalities; being also a potentially beneficial input for climbers, coaches and researchers in the area, in their search for strategies to optimize the training and performance processes in this sport.

Method

The present project was approved by the ethics committee of the Instituto Superior de Educación Física (ISEF) of the Universidad de la República (Udelar), Uruguay (resolution nr. 5/2021 of May 18, 2021).

Subjects

The subjects were selected by convenience, due to the link of one of the authors of this study (M.L.), as a teacher and climber, with the sports institution where the study was carried out. Inclusion criteria were established as follows: i) to be climbers of legal age (>18 years), practicing bouldering sport climbing with at least one year of experience; ii) to have a self-perceived level higher than V3; iii) not to be smokers; and iv) not to present

osteoarticular, respiratory or any other type of pathology that could affect climbing performance.

Twenty-two volunteers of both sexes were initially selected. All of them were informed orally and in written form about the objectives and characteristics of the study, after which they read and signed an informed consent form.

Procedures

Laboratory Evaluations

The initial evaluations were carried out at the Exercise Physiology Laboratory belonging to the Instituto Superior de Educación Física (ISEF), Udelar, Parque Batlle, Montevideo. First, after obtaining data on the subject's age, sex, and self-perceived level of climbing, body mass and fat mass percentage were determined using an electrical bioimpedance system (InBody-120, InBody Co., Korea), as well as height using a portable stadiometer (SECA 213, SECA, Germany).

Subsequently, subjects performed a maximal incremental exercise test on a cycloergometer (Cyclus 2; RBM elektronik-automation GmbH, Leipzig, Germany). The protocol began with a two-minute warm-up phase, during which the subjects pedaled at a cadence between 30 and 40 rpm, generating a power of 20W. At the end of this stage, they were asked to maintain a cadence equal to or greater than 50 rpm at all times, while the device software gradually and continuously increased the power at a rate of 25W per minute. The test ended when the subject reached fatigue, or was unable to sustain the established minimum cadence.

During that effort, direct breath-by-breath respiratory gas analysis was performed continuously using an ergospirometer (Cortex Metalyzer 3B; CORTEX Biophysik GmbH, Leipzig, Germany). In addition, HR was also measured using a sensor band (Polar H7; Polar Electro Inc., Finland), placed around the thorax at the level of the xiphoid process. The data were received via Bluetooth 4.0 technology and interpreted by the corresponding software (MetaSoft Studio). It also allowed the determination of the VT1 and VT2 thresholds.

During the evaluations, the temperature was controlled at all times by an air conditioning system between 22 and 24ºC (average 23.3ºC); while the ambient humidity was 53 ± 6.1%.

Field Evaluations

In the days following the laboratory evaluation, and within one week after the laboratory evaluation, evaluations were performed in a climbing gym. It consisted of the continuous performance of a V1 level route for 4 minutes, followed by a self-managed active pause of low intensity of 20 minutes, and then the performance of another 4-minute route, in this case of V3 level. Participants were asked to continuously perform the activity, avoiding stopping at the dams for more than 3 seconds, either to put magnesium on their hands or to take a break. They were also asked to climb the route as many times as possible during the stipulated time.

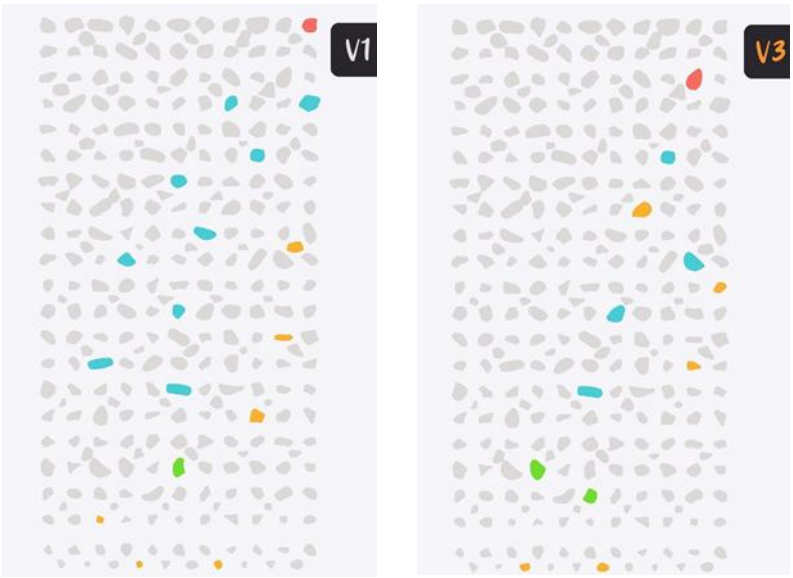
Prior to the start of the evaluation, each athlete performed a five-minute warm-up. Considering that in all cases these were athletes with sufficient experience in the bouldering modality, both the intensity and the exercises used during bouldering were allowed to be defined by each subject. In addition, immediately prior to the performance of both route V1 and route V3, the athletes were asked to remain at total rest for three

minutes, sitting in front of the wall and mentally visualizing the performance of the subsequent effort.

Figure 1 shows the grips defined for the present study in each of the modalities. The green holds correspond to the place where the hands must be placed at the moment of starting; the yellow ones can only be used by the lower limbs; the blue ones are free for any part of the body; and the red one corresponds to the top hold (the last one of the path, which must receive the stable contact of both hands).

Figure 1

Graphic representation of the routes made by climbers for both modalities.



At all times during exercise, the subjects used a portable ergo-spirometer (Metamax 3B-R2) (Figure 4), which according to the manufacturer's instructions was calibrated prior to each run. In addition, a Polar H7 band HR sensor (Polar Electro Inc., Finland) was used, similar to the laboratory test.

In addition, immediately after the completion of each of the four-minute blocks (V1 and V3), the patients were asked how intense they had perceived the effort of the entire route, both in terms of dyspnea and muscle fatigue, using the modified Borg scale (with values from 0 to 10, where 0 represents *no perceived effort*, and 10 represents *maximum effort*).

During the evaluations, the temperature inside the gymnasium was 26.2 ± 0.9ºC; while the humidity was 52.3 ± 9.7%.

Statistical Analysis

The results for continuous variables are presented as mean ± standard deviation; while for ordinal variables they are presented as median (interquartile range). To determine the possible differences in the values of the continuous variables analyzed in the different types of effort (maximal laboratory test, climbing level V1 and climbing level V3), the repeated measures ANOVA statistical test was used, after determining the assumptions of normality (Shapiro-Wilk test) and sphericity (Mauchly test). If the first of these assumptions was not met, the Friedman test for repeated measures was used. In

case of violation of the second assumption, the Greenhouse - Geisser correction was used. If statistically significant differences were observed, a post-hoc analysis was performed using the Bonferroni test. To determine the possible difference in effort preceptions (ordinal variable) between the V1 and V3 level routes, the Wilcoxon signed-rank test was used.

In all cases a significance level of $p < 0.05$ was established. Statistical analyses were performed using free JASP software (version 0.19.3; JASP Team 2024, University of Amsterdam).

Results

Of the 22 subjects initially selected for the study, only 14 were finally included in the data analysis. The main cause of exclusion corresponded to the impossibility of completing at least one of the scheduled evaluation instances, due to time availability limitations. Table 1 shows the characteristics of the subjects who took part in the study, as a whole and differentiated by sex.

Table 1

Characteristics of the participants

	Women (n = 6)	Men (n = 8)	Totals of the sample (n = 14)
Age (years)	33.8 ± 5.9	32.0 ± 6.7	32.8 ± 6.2
Mass (kg)	58.0 ± 4.3	75.3 ± 9.3	67.9 ± 11.5
Height (cm)	164.8 ± 6.5	177.8 ± 5.1	172.2 ± 8.6
BMI (kg/m2)	21.4 ± 1.9	23.8 ± 2.6	22.8 ± 2.6
Fat mass (%)	17.7 ± 4.7	12.1 ± 4.2	14.5 ± 5.1
Exp. esc. (years)	4.2 ± 1.2	6.6 ± 6.8	5.6 ± 5.2
Freq. ent. (s/s)	2.7 ± 0.6	3.0 ± 1.1	2.9 ± 0.9
VO_2máx (ml/kg.min)	42.8 ± 5.0	47.6 ± 7.3	45.6 ± 6.7

Abbreviations: Exp. esc. = climbing experience; Freq. ent. (s/s) = Frequency of Training (sessions per week)

Table 2 shows physiological variables measured in laboratory conditions using a progressive ramp test, as well as during climbing effort in V1 and V3 modes. Additionally, the results of relative peak VO_2, peak HR and peak ventilation are shown in Figures 2 to 4, respectively.

Table 2

Physiological variables measured in the laboratory and in the climbing effort in the modes V1 and V3 (n = 14)

	Laboratory	V1	V3	P-value
Relative peak VO_2 (ml/kg.min)	43.7 ± 6.1	37.6 ± 3.9	39.6 ± 4.8	< 0.001*
Peak HR (bpm)	174.7 ± 18.0	167.1 ± 13.3	169.6 ± 10.9	0.2
Peak RMV (l/min)	110.6 ± 21.1	76.8 ± 15.0	81.9 ± 21.1	< 0.001*

Note: Laboratory data correspond to a progressive maximal ramp test. * indicates statistical significance ($p < 0.05$). Abbreviations: HR = Heart Rate; RMV = Respiration Minute Volume; RPM = Respiration Minute Volume

In all the variables analyzed, the values recorded in laboratory conditions were higher than those observed during climbing efforts, the latter being higher in the V3 mode compared to V1. The post-hoc analysis for the relative peak VO_2 and peak RMV values determined a significant difference between the result obtained in the laboratory and the V1 modality ($p < 0.001$ for both variables) and between the laboratory and the V3 modality ($p = 0.015$ and $p < 0.001$ for VO_2 and ventilation, respectively). In contrast, no significant differences were observed between the values of V1 and V3 modes ($p = 0.2$ and $p = 1.0$ for VO_2 and ventilation, respectively). Regarding peak HR, the differences observed in no case reached statistical significance ($p > 0.05$); although the values were higher in the maximal progressive test compared to the V1 (96% of maximum) and V3 (97% of maximum) modes.

Figure 2

Relative VO_2 peak obtained through a progressive ramp test in the laboratory (Lab), and in the climbing modes V1 and V3. Bars indicate 95% confidence interval

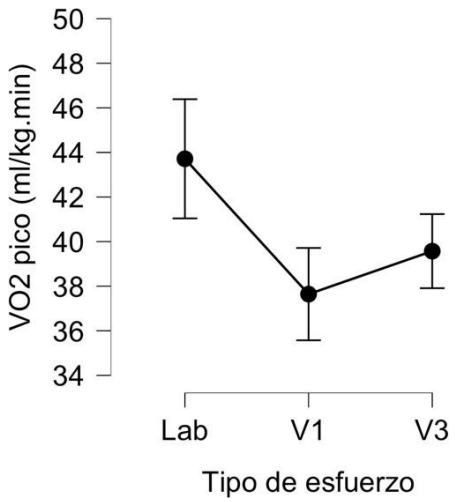


Figure 3

Relative peak heart rate obtained by progressive ramp test in laboratory (Lab), and in V1 and V3 climbing modes. Bars indicate 95% confidence interval

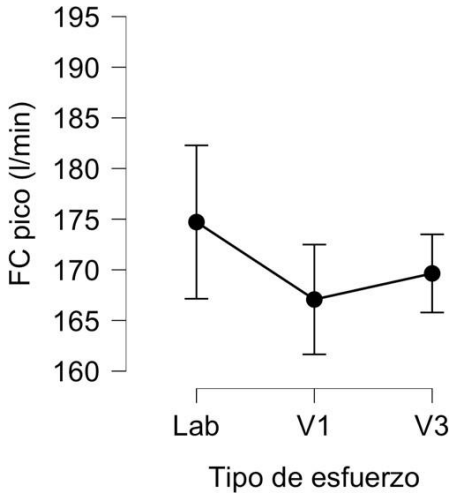


Figure 4
Peak Respiratory Minute Volume obtained by a progressive ramp test in the laboratory (Lab), and in the V1 and V3 climbing modes. Bars indicate 95% confidence interval

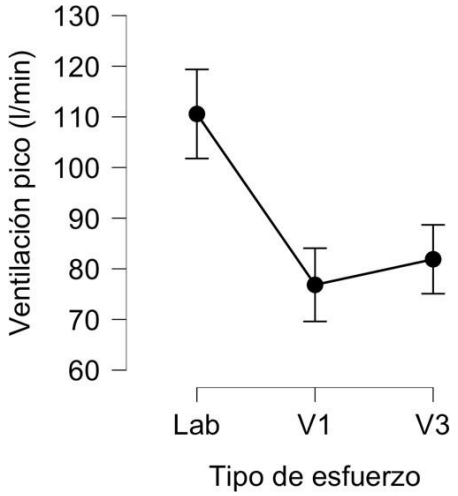


Table 3 shows for both climbing modalities, the average and standard deviation of the relative VO_2, HR and RMV variables, differentiated for each of the four minutes of effort (corresponding to the total duration of each route). In addition, Figures 5 and 6 show the relative VO_2 averages for each minute of climbing, in relation to the first (VT1, 27.2 ml/kg.min) and second (VT2, 35.7 ml/kg.min) ventilatory thresholds and peak VO_2, measured in the progressive ramp test performed in the laboratory, for V1 and V3, respectively.

Table 3
Physiological variables differentiated for each minute of effort, in both climbing modalities (n = 14)

	Climbing mode V1			
	M1	**M2**	**M3**	**M4**
Relative VO_2 (ml/kg.min)	22.5 ± 2.9	32.5 ± 2.3	34.9 ± 2.7	35.7 ± 3.9
HR (bpm)	146.8 ± 13.0	162.0 ± 12.4	165.5 ± 12,7	166.6 ± 13.3
VMR (l/min)	39.2 ± 7.4	57.0 ± 7.6	66.4 ± 9.9	74.5 ± 13.6

Climbing V3 mode				
	M1	**M2**	**M3**	**M4**
Relative VO_2 (ml/kg.min)	22.5 ± 2.8	33.2 ± 3.2	35.8 ± 2.8	38.4 ± 3.6
HR (bpm)	148.2 ± 12.8	163.1 ± 10.5	166.5 ± 11.5	170.3 ± 11.8
VMR (l/min)	40.5 ± 7.8	61.7 ± 12.8	72.4 ± 14.5	81.9 ± 20.3

Abbreviations: M = minute; MRV = Minute Volume Respiration

Figure 5

Average relative VO_2 achieved in each minute of effort for V1, in relation to the average values of VT1, VT2 and peak VO_2 observed in a progressive ramp test in the laboratory. Abbreviations: M = minute; VT = ventilatory thresholds.

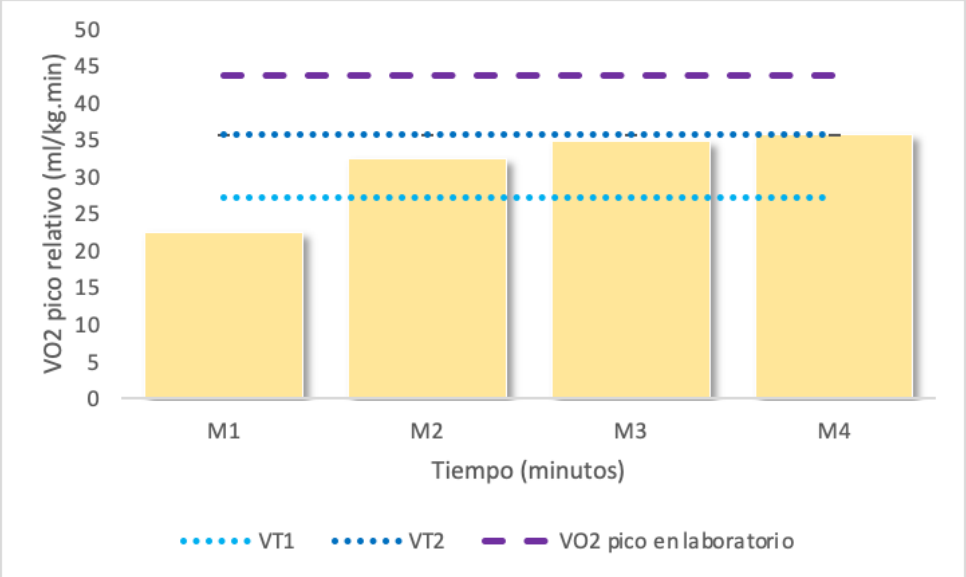
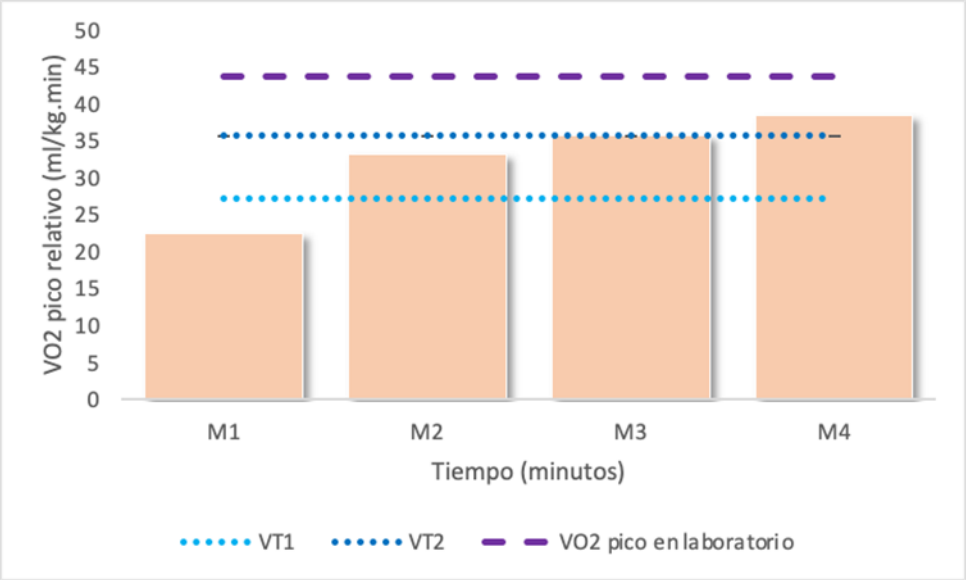


Figure 6

Average relative VO_2 achieved in each minute of effort for V3, in relation to the average values of VT1, VT2 and peak VO_2 observed in a progressive ramp test in the laboratory. Abbreviations: M = minute; VT = ventilatory thresholds



In both climbing modalities, and for all the variables considered, a very noticeable increase in values was observed from minute 1 to minute 2, and subsequently a successively less marked increase until reaching a maximum in the last minute of effort.

Particularly with regard to relative VO_2, in both modalities the average values for the first minute were observed below the VT1 threshold (zone 1 according to the three-phase model of Skinner and McLellan [1980]). In the case of the V1 mode, the average value of minutes 2 and 3 was found in the interthreshold zone (zone 2 of the model); while the average value of minute 4 coincided with the VT2 threshold, corresponding to 81% of the peak VO_2 reached in the laboratory. In the case of the V3 mode, the mean value of minute 2 was observed in the interthreshold zone, while the mean value of minute 3 coincided (practically) with the VT2 threshold. The latter was then exceeded at minute 4, reaching 88% of peak VO_2 and within zone 3 of the aforementioned model.

Table 4 shows the values corresponding to the RPE according to the modified Borg scale for both modalities and for both dyspnea and global muscle fatigue.

Table 4

Subjective sensation of exertion (RPE) for V1 and V3 modalities (n = 14)

	Mode V1	**Mode V3**	**P-value**
Dyspnea	7.0 (3)	7.5 (3.75)	0.3
Muscle fatigue	7.5 (3)	8.0 (2)	0.6

Note: Data are presented as median (interquartile range). They correspond to the sensation of effort measured by the modified Borg scale, for the entire route. Statistical significance was determined by the Wilcoxon signed-rank test

For both routes, the reported value of muscle fatigue was slightly higher than that reported for dyspnea, although with a large dispersion and without the difference reaching statistical significance ($p > 0.05$). Likewise, the V3 modality proved to be more

demanding in this respect than the V1 modality, although again the differences were slight and not significant ($p > 0.05$).

Discussion

In the present study, respiratory and cardiovascular variables were analyzed in male and female bouldering climbers, comparing V1 and V3 levels. To the best of the authors' knowledge, this would be the first study with these characteristics in Uruguay. In addition, at the international level, studies have been conducted with similar protocols (de Moraes Bertuzzi et al., 2007; Sheel et al., 2003) but focused on sport climbing, with a scarcity of data on bouldering.

The results indicate that both the relative peak VO_2 and peak RMV observed during the route were significantly lower ($p < 0.05$) than those achieved in the maximal progressive test (81% and 88% of the maximum for V1 and V3, respectively). In relation to the respiratory demand, this fact reflects the submaximal condition of the climbing effort in the routes analyzed. On the other hand, with regard to peak HR, no significant differences ($p > 0.05$) were observed between the three types of effort; the values reached during climbing were lower but very close (> 95%) to those obtained under maximal conditions.

These observations would indicate a loss of linearity between HR and VO_2 during climbing, with a disproportionate increase in the former relative to the latter. In this sense, the linearity between both variables that is observed in progressive treadmill or cycloergometer tests, as well as in cardiovascular endurance sports such as cycling or long-distance running, would not be verified (López Chicharro et al., 2013).

This observation was also reported by Mermier et al. (1997) and by Sheel et al. (2003) in both male and female climbers of experienced competition or elite level, as well as by de Moraes Bertuzzi et al. (2007) in elite and recreational climbers, during the performance of routes of different degrees of relative difficulty (easy, moderate or difficult). Under these conditions, HR increases of up to 40% above the corresponding VO_2 percentage were observed.

Leaving aside the possible psychological stress caused by the use of the gas analyzer to which the athletes were not accustomed, a possible explanation for this fact could be given by the fear of falling and anxiety. However, with respect to the former, it should be noted that in the bouldering modality the height of the wall is reduced (15 feet or 4.5m), to which is added the presence of a sufficiently cushioned surface to receive the athlete with minimum risk. Regarding the latter, Fryer et al. (2012) observed that the levels of somatic and cognitive anxiety prior to the start of the route did not play a significant role in this regard, at least in climbers with a certain degree of experience as is the case in the present work. This could be explained by the ability of experienced climbers to differentiate perceived risk from real risk.

Another possible cause for the loss of HR/VO_2 ratio could be related to the use during climbing of intermittent isometric contractions, particularly at the level of the upper limbs, limiting blood flow to the active muscles. These contractions are fundamentally determined by grips performed at a level above the plane of the heart, which elicits an increase in muscle sympathetic nervous activity, mediated by the metaboreflex pathway; concomitantly determining an increase in HR (Michikami et al., 2002). Additionally, during the present study the breaks during exertion were limited, not

allowing time for climbers to shake and relax their hands and upper limbs; which could have eventually reduced the disproportionate increase in HR (Fryer et al., 2012).

The bouldering modality, compared to other modalities such as *lead* or difficult climbing, requires efforts of shorter duration, but greater localized muscular effort, to which is added a considerable participation of non-oxygen-dependent metabolism in conjunction with aerobic sources of obtaining metabolic energy (Callender et al., 2021). In accordance with this, in a study with recreational and elite climbers, carried out on a 10m high wall and with easy, moderate and difficult level routes (25 moves on average), it was determined that for both groups and for the three routes used, the predominant energy metabolism was aerobic or oxidative, followed by a very important contribution of non-oxygen-dependent alactic metabolism or phosphagen, and a smaller contribution of non-oxygen-dependent lactic or glycolytic metabolism. In all cases, it was determined that ATP production considering the cumulative contribution of non-oxygen-dependent pathways (lactic and alactic) was higher than that of aerobic pathways (de Moraes Bertuzzi et al., 2007). All this would contribute to a disproportionate increase in HR as well as blood pressure (Callender et al., 2021).

This fact, together with the fact that the results indicate that the athletes did not reach a stable state during the time demanded by the effort, lead us to propose that HR would not be the best tool to estimate the intensity of the aerobic load in this type of work. This was also suggested by Mermier et al. (1997), who indicated that the HR / VO_2 ratio that is verified in aerobic type efforts should not be used in the analysis of climbing, or for the prescription of training load intensity for this sport. In this sense, other tools such as RPE or muscle O_2 saturation monitoring using portable sensors could represent a better option.

The important contribution of predominantly isometric contractions, particularly at the level of the finger flexor muscles as well as the shoulder girdle, has led to categorizing this climbing modality as a sport of strength rather than cardiovascular and respiratory endurance (Kuepper et al., 2009). In relation to this, it has been suggested that recreational climbers do not require a high level of relative aerobic capacity (Watts et al., 2000). In agreement, the male and female climbers in the present study presented VO_2max levels slightly higher than those estimated for healthy inactive adults (women: 38.6 ml/kg.min vs 42.8 ml/kg.min; males: 47.2 ml/kg.min vs 47.6 ml/kg.min; hypokinetics and climbers respectively) (Barrios Vergara et al., 2018); but lower than those observed in adult endurance athletes in maximal cycloergometer tests (women: 49.1 ml/kg.min vs 42.8 ml/kg.min; males: 51.9 ml/kg.min vs 47.6 ml/kg.min; endurance athletes and climbers respectively) (Wiecha et al., 2023).

It has even been determined that elite level climbers have an average VO_2max between 52 and 55 ml/kg.min (Watts, 2004), similar to that observed in gymnasts (España-Romero et al., 2009) but which is notoriously lower than that reported for endurance athletes such as elite cyclists (>68 ml/kg.min) (Kuepper et al., 2009). It is worth mentioning that these values were obtained in progressive tests performed on a treadmill or cycle ergometer, which implies efforts to which the climbers may not have been accustomed; something that should be taken into account when interpreting the results.

Considering the aforementioned muscular effort demand, it would be foreseeable that localized fatigue in the forearm flexor muscles would be a more important determinant of performance than systemic fatigue (predominantly aerobic in nature), as suggested in previous studies (Schöffl et al., 2004, 2006; Sheel, 2004). In accordance with this, in the present work, the muscular RPE for the total route was superior, for both levels, to the aerobic RPE (in terms of dyspnea). However, it should be noted that the

differences in the averages were minimal (0.5 points in both cases) and not significant ($p > 0.05$). This would indicate that, in terms of performance in efforts similar to those of the present work, muscular endurance training (particularly of the anterior forearm lobe and shoulder girdle muscles) would be of similar relevance to improving aerobic endurance. However, the fact that the subjects had no previous experience with the use of the modified Borg scale, or other similar scales, implies that these results should be considered with caution.

In relation to the difference observed between the V1 and V3 climbing levels, as expected, higher values were obtained for all the variables analyzed (peak VO_2, peak HR and peak RMV) in the latter with respect to the former. However, the differences did not reach statistical significance, suggesting that physiological demand does not differ significantly between the two routes studied. In contrast, Mermier et al. (1997) studying experienced climbers of both sexes found significant differences ($p < 0.05$) in HR, blood lactate concentration, VO_2 and caloric expenditure when comparing between different levels of climbing difficulty. However, and unlike the present study, in that work, walls with different degrees of inclination were used to increase the difficulty (90, 106 and 151 degrees), which could explain the aforementioned differences.

With regard to the physiological demands observed in the present study differentiated by minute of effort, although their values increased successively from the first to the last minute of the route, their values were notably lower in the first minute compared to the other three, and without reaching a clear stable state at the end of the effort. Considering the three-phase model of VO_2 kinetics, the findings would indicate that during the first minute the subjects were predominantly in phase I or cardiodynamic component, represented by low relative VO_2 levels. Additionally, in the final three minutes the findings would indicate that the climbers were in phase II or primary component of the model, observing a slow but continuous increase in VO_2 (slow component of VO_2 kinetics), without reaching phase III or steady state (Harvey, 2011). This dynamic is to be expected, since during most of the effort the athletes were at intensities above VT1, and close to (or even exceeding) VT2. At these intensities of exertion, four minutes may not be sufficient to achieve physiological stability.

In addition, the fact that the athletes reached intensities close to VT2 during a significant percentage of the total time of effort, would account for an important contribution of the glycolytic system during the route. This is in agreement with that reported by Callender et al. (2021), who indicate that competitive bouldering demands an important cardiorespiratory effort, evidenced by high VO_2max percentages and a prolonged effort time above VT1. In addition, de Moraes Bertuzzi et al. (2007) found peak capillary blood lactate values close to 4.0 mMol/L in recreational (4.4 ± 1.6 mMol/L) and elite (3.9 ± 1.8 mMol/L) climbers for an easy and difficult difficulty route, respectively. Although the relationship between lactatemia and VT2 may vary significantly between subjects, it has been established that at the latter threshold the blood lactate concentration is approximately 4.0 mMol/L (Faude et al., 2009). In this sense, the athletes are close to their VT2, which corresponds to the findings of the present study.

These results would indicate that, during the routes studied, both at the V1 and V3 levels, metabolic energy production depends to a large extent on the glycolytic system. Although it is necessary to be cautious with the interpretation of these results since the determination of thresholds is dependent on the protocol used, these findings could represent a contribution at the time of planning the physical preparation of climbers.

The present study had limitations, including a relatively small sample size. However, it should be considered that previous similar research has used samples of comparable size. In addition, it would have been desirable to have athletes with

experience in the performance of tests involving the use of gas analyzers, as well as in the use of subjective sensation of effort scales. In addition, it is necessary to mention that two of the climbers participated in the study after between four and six weeks of sports inactivity, which in all cases was not caused by sports injuries. Finally, in relation to the use of portable ergospirometers, it has been suggested that excessive movement and hyperventilation associated with exertion could affect the recording of the equipment (McArdle et al., 2015). In any case, we consider that the type of stresses analyzed in the present work did not determine a loss in the accuracy of the recorded measurements.

Conclusions

In the present work, acute physiological responses, in particular those linked to the contribution of aerobic metabolism, were studied during the performance of two routes of different difficulty in bouldering climbing. A marked dissociation between HR and VO_2 was observed, possibly related to the predominance of intermittent isometric contractions in the upper limbs. These results reinforce the idea that, in this discipline, HR alone is not a reliable indicator of effort load, and it is advisable to complement its monitoring with other tools.

Likewise, a significant contribution of non-O_2-dependent glycolytic metabolism in energy production is highlighted, even in routes of low or moderate difficulty. This underlines the need to include training strategies oriented to the development and optimization of this energetic pathway, in order to achieve optimal performance.

Considering the growth in the popularity of sport climbing in recent years, both globally and in Uruguay, we believe that more scientific studies are needed in this area. In this sense, it would be advisable to carry out similar studies in bouldering and other modalities, with a larger number of subjects, involving the performance of maximal progressive tests adapted to the technical reality of this sport, and incorporating the analysis of complementary physiological variables, such as lactatemia and in particular functional near infrared spectroscopy (NIRS) for monitoring the level of muscle O_2.

This non-invasive technology would allow more precise information to be obtained on local oxygenation dynamics, especially in the finger flexor muscles, which are highly stressed during exertion. Its application could contribute to a better understanding of the physiological mechanisms involved in performance and fatigue in climbers of different levels, as well as constitute a useful tool for programming and controlling training intensity.

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