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ORIGINAL

EVALUATION OF HAND'S FINGERS FLEXOR MUSCLES ENDURANCE IN CLIMBERS

LA RESISTENCIA DE LOS MUSCULOS FLEXORES DE LOS DEDOS DE LA MANO EN ESCALADORES

Núñez, V.M.[1]; Ramírez, J.M.[1]; Lancho, C.[2]; Poblador, M.S.[3] y Lancho, J.L.[3]

[1] PhD. Departamento de Ciencias Morfológicas, Universidad de Córdoba (Spain) cm1nnalv@uco.es, jmramirez@uco.es

[2] M.D. Centro ASPACE, Donostia (España) y Departamento de Ciencias Morfológicas, Universidad de Córdoba (Spain) carico86@hotmail.com

[3] PhD, M.D. Departamento de Ciencias Morfológicas, Universidad de Córdoba (Spain) cm1pofem@uco.es, cm1laalj@uco.es

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ABSTRACT

Purpose: To evaluate hand's fingers flexor muscles grip endurance during a specific climbing test, and to find out if there were differences between elite and recreational sport climbers. **Methods:** For this cross-sectional descriptive study, twenty-one male sport climbers were assigned to two different groups, recreational or elite. The participants performed two exercises on a multi-hold training board, one requiring sustained isometric exercise and the other requiring intermittent exertion. The variables studied were total work time, number of trials completed and mean heart rate per test. **Results:** Elite climbers endured suspension for an average of 7.64 minutes being this period longer than recreational climbers ($p < .001$); thus, elite group performed 23.14 more trials than recreational group ($p < .001$). Reliability in all evaluations was excellent. **Conclusions:** Hand's fingers flexor muscles grip endurance in continuous and intermittent exercises are the muscles that have more influence in sport climbing performance. In this regard, we have found significant differences between elite and recreational climbers.

KEYWORDS: isometric exercise, physical endurance, heart rate.

RESUMEN

Objetivo: evaluar la resistencia de los músculos flexores de los dedos de la mano en escaladores de elite y recreativos. **Métodos**: estudio descriptivo transversal. Veinte y un escaladores fueron asignados a dos grupos de rendimiento: recreativo y élite. Realizaron un ejercicio isométrico y otro de esfuerzo intermitente en una tabla de entrenamiento multiagarre. Se midieron el tiempo de trabajo total, número de ciclos completados y frecuencia cardíaca media en cada test. **Resultados**: los escaladores de élite mantuvieron el esfuerzo en suspensión 7.65 minutos más que los recreativos ($p < .001$) y realizaron 23,14 ensayos más ($p < .001$). La fiabilidad de las mediciones fue excelente. **Conclusiones**: la fuerza de agarre de los músculos flexores de los dedos en esfuerzo continuo e intermitente contribuye al rendimiento en escalada, con diferencias significativas entre los escaladores de élite y recreativos. El test específico creado para el estudio ha demostrado una adecuada validez discriminante.

PALABRAS CLAVE: ejercicio isométrico, resistencia física, frecuencia cardíaca.

INTRODUCTION

In climbing, performance during the ascent of a difficult route depends on the technical skills, psychological preparation, and especially, physical condition. Mental visualization of climbing steps, its subsequent implementation, and the decisive support of the hands and feet on the wall, are common patterns to all climbers which are repeated continuously during ascent (Giles, Rhodes and Taunton, 2006). The fall may be caused by the inability of one or more muscles to maintain grip as well as a bad tactical choice, either by poor technical execution or psychological weakness. It is crucial, therefore, to understand the nature and intensity of grip strength during the performance of a difficult route in order to decide what skills need to be improved during training.

The climbing is characterized by a succession of muscular actions to support (isometric effort) and vertically propel (isotonic effort), the first of them is the most frequently repeated in any type of route (Grant, Shields et al 2003; Watts Joubert et al 2003). Resistance therefore represents a limiting factor for climbers (Mermier, Robergs, McMinn, Heyward, 1997; Quaine, Vigoroux and Martin, 2003; Watts, 2004). The evaluation of the strength, particularly the strength of the flexor of the hand and fingers, is the most important objective of any study on climbing performance, since the muscles of the forearm play a crucial role in maintaining static positions during the ascent (Fryer, Stone et al 2015; Philippe, Wegst et al 2012). The dynamometer tests of isometric contraction are widely used to analyze and evaluate the strength of the flexor muscle of the hand (Cutts and Bollen, 1993; Grant, Hynes, Whittaker, Aitchison, 1996; Grant, Shields et al, 2003; Quaine, Vigoroux Martin 2003; Schöffl, Mockel et al 2006; Watts 2004; Watts, Gannon et al 1999). However, as that escalation is made of intermittent repetitions of isometric contractions and dynamic efforts, a purely isometric test may not be sufficiently specific when the stress applied during difficult ascents is evaluated.

Climbing involves various expressions of resistance. The muscles of the forearm connect a series of isometric contractions and specific movements to maximize strength in grip effort and maximum grip strength (Grant, Hasler et al 2001; Mermier, Robergs, McMinn, Heyward 1997; Schöffl, Klee , Strecker, 2004; Watts, Daggett, Gallagher, Wilkins 2000; Watts and Drobish, 1998; Wilkins, Watts and Wilcox, 1996). During a difficult ascent, success or failure depends on the optimization of both qualities.

This study aims to measure the resistance of the flexor muscles of the fingers during a specific climbing test developed by the authors and determine whether there are differences in resistance between elite and recreational climbers. The findings of such differences validate the discriminant ability of a method to evaluate the resistance of the flexor muscles of the fingers.

MATERIAL & METHOD

DESIGN

A cross-sectional descriptive study to evaluate the resistance of the flexor muscles of the fingers on two specific climbing test was conducted. From the results of a test of technical skill, participants were classified into two groups: elite climbers and recreational climbers, in order to compare experimental resistance measurements in both groups. The resistance of the flexor muscles of the hand is defined as the time to exhaustion in both tests. This study has been approved by the Department of Morphological Sciences, Faculty of Medicine, University of Cordoba.

PARTICIPANTS

21 male climbers participated in the study, with an average age of 28 years (± 5.41), an average weight of 67.49 (± 7.07) kg, average height of 174.02 (± 4.64) cm, and performance included climbing between 5.10a 5.14a (YDS). All participants had previously conducted a test of consistent performance in three routes of increasing difficulty (5.10b, 5.11c, 5.13b, (YDS)) repeated twice, with a 15 minute break between two routes. The results for the first attempt and the second attempt were recorded in each of the routes. The results, together with supplementary data (years of climbing experience, number of weekly workouts,

first try vs second attempt) were recorded to assign subjects to one of two experimental groups. These data are presented in Table 1.

The sample consisted of 7 participants assigned to the elite group of climbers (EE), with performance levels between 5.10a-5.11b (YDS) and 14 recreational climbers (ER), with performance levels between 5.11c-5.14a (YDS), according to the conversion used by Watts, Jensen et al (2008).

	EC (n=7) M±DE	RC (n=14) M±DE	Mann-Whitney U	p	Cliff Delta
Age (years)	28.6 ±5.9	28.1 ±5.4	-0.083	0.978	0.010
Height (cm)	176.2 ±4.9	172.9 ±4.3	-1.493	0.149	0.410
Weight (kg)	64.5 ±6.2	69.0 ±7.2	-1.120	0.287	0.310
Experiencie (years)	7.9 ±2.4	2.0 ±3.21	-3.678	<0.001	0.760
Weekly trainings	3 a 5	1 a 2			
First “in situ” test	7b-8a	6a-6c			
Trained “in situ” test	7c-8b^{+}	6b-7a			

Table 1. Age; weight, height and level of performance of elite climbers (EC) and recreational (RC) (M: medium; SD: standard deviation). Mann-Whitney nonparametric and Cliff Delta size effect; p: level of critical significance.

PROCEDURE

The specific grip strength was evaluated by a table of multi-grip training designed by the team of researchers at the Andalusian Climbing Training Center (Spain). Two tests (test 1 and test 2) were created to measure continuous and intermittent resistance respectively.

Table training multi-grip is a solid wooden frame in which resin gripping dams shaped like a ledge of various sizes and grips are fixed (Figure 1). Specifically, five ledges symmetrically aligned with decreasing contact area. Each ledge protrudes enough to ensure that during the suspension the hand is not in contact with other footholds.

Figure 1. Multi-grip training (side view).

Gripping dams are fully horizontal and rounded throughout their length, being the arc proportional to the thickness of the gripping dam in order to ensure optimum support of all fingers, simulating two types of grip frequently used in studies of climbing: inclined (slope grip) and terminal (crimp grip).

The exact size of the grip was calculated in terms of the curvature radius, which defines the difficulty of the dam. The grips with greater curvature reproduce the inclined dam, while in strip grips these are characterized by a smaller curvature. Each dam is 20% smaller than the previous one (in descending order). The vertical slope at the end point of the dam #5 is 5 mm, being the arc with most open grip, resulting in reduced compression of the distal phalanges (Figure 2)

Test 1

The endurance test of continuous isometric grip (test 1) consisted of measuring the time during which each climber was held on to ledge number 1 training table whose surface is the greatest. A chronograph was used to perform such registration. Each climber was allowed a warm up session consisting of 5 sets of three sets of five seconds in suspension. It allowed the use of magnesium powder to prevent sweat and strengthen adherence to the ledge. Lateral movement and grip with one hand was also authorized. The test ended when both hands were no longer in contact with the ledge. The test was repeated after a rest period of 30 minutes.

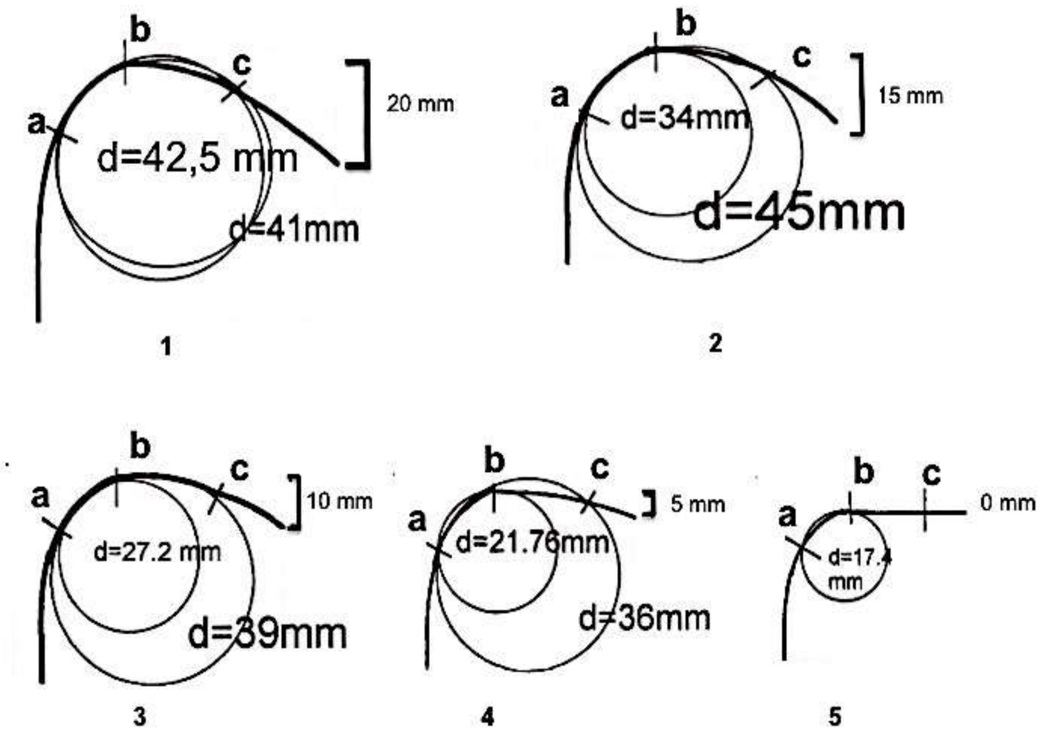


Figure 2. Technical design of the contact surface. Dimensions and multi-grip table training; dams 1, 2, 3, 4 and 5 a: support proximal joint of the fingers; b: support middle joint of the models; c: support distal finger joint.

Test 2

To test intermittent isometric resistance, climbers made short isometric contractions with a period of incomplete recovery, from those ledges with increased gripping surface (dams 1 and 2) to those with a smaller area grip (ledges 3, 4 and 5). Bilateral timekeeping system was used: 2 assistants recorded working time and rest periods respectively. Heart rate was recorded with a digital heart rate monitor Polar s610®.

The protocol of progressive effort used involved counting the number of repetitions completed during periods of low to high intensity, using dams 1, 2 and 3 consecutively (Table 2). In each period, the stress / rest ratio was 3: 1; recovery was incomplete, thus simulating the conditions of real climbing.
For warm-up, climbers completed the exercises for the period 1 (see Table 2), with a subsequent rest 5 minutes before starting the test.

Climbers were completing periods consecutively, and they all failed to complete the test consisting of 12 periods. Each ledge, followed by a pause after each suspension of 5 seconds. For example, in period 1 6 replicates were performed on the ledge 1; in period 2, 5 repetitions on the ledge 1 and the sixth on the ledge 2; and so on (Table 2).

The test ended when the climbers were so fatigued as to drop from the table. The time was recorded with the maximum number of repetitions and the maximum heart rate achieved. The test was repeated after two hours of rest.

Pd	Pr	R	Ra	T R (s)	D (s)	T P (s)	D Pr (s)	T Pd (s)	P Pd (s)	Tt (s)
1	R1	6	6	15	5	90	30	90	30	120
	R2	*		*	*	*	*			
	R3	*		*	*	*	*			
2	R1	5	11	15	5	75	25	90	30	240
	R2	1	1	15	5	15	5			
		*		*	*	*	*			
3	R1	4	15	15	5	60	20	90	30	360
	R2	2	3	15	5	30	10			
	R3	*		*	*	*	*			
4	R1	3	18	15	5	45	15	90	30	480
	R2	3	6	15	5	45	15			
	R3	*		*	*	*	*			
5	R1	2	20	15	5	30	10	90	30	600
	R2	4	10	15	5	60	20			
	R3	*		*	*	*	*			
6	R1	1	21	15	5	15	5	90	30	720
	R2	5	15	15	5	75	25			
	R3	*		*	*	*	*			
7	R1	*	21	*	*	*	*	90	30	840
	R2	5	20	15	5	75	25			
	R3	1	1	15	5	15	5			
8	R1	*	21	*	*	*	*	90	30	960
	R2	4	24	15	5	60	20			
	R3	2	3	15	5	30	10			
9	R1	*	21	*	*	*	*	90	30	1080
	R2	3	27	15	5	45	15			
	R3	3	6	15	5	45	15			
10	R1	*	21	*	*	*	*	90	30	1200
	R2	2	29	15	5	30	10			
	R3	4	10	15	5	60	20			
11	R1	*	21	*	*	*	*	90	30	1320
	R2	1	30	15	5	15	5			
	R3	5	15	15	5	75	25			
12	R1	*	21	*	*	*	*	90	30	1440
	R2	*	30	*	*	*	*			
	R3	6	21	15	5	90	30			

Table 2. Protocol intermittent progressive effort (test 2). Pd: Period; Q: prey; R1, R2 and R3 :: dam ledges 1, 2 and 3; A: repetitions; Ra: accumulated repetitions; Tr (s): repetition time; D (s): rest time; TP (s): time in the dam; DPRs (s): Rest on the dam; TPD (s): work period; SGP (s) Pause for period; Tt (s): Total time.

MEASUREMENTS

In the continuous isometric resistance test, time (seconds) during which each climber remained in the dam number 1 was registered. This test was performed twice in succession with an interval of 30 minute break in between.

For intermittent isometric resistance test the following measures in the two repetitions of the test were recorded, with a rest period of 2 hours between the two:

a) Period: the longest period achieved in the protocol.

b) Total time (minutes): time used in the test.

Total Reps: number of repetitions completed during periods of low to high intensity using dams 1, 2 and 3 consecutively.

Repetitions (Dam 1 Dam 2 Dam 3): number of full repetitions, respectively, in each dam.

STATISTICAL ANALYSIS

Means and standard deviations were calculated to describe variables. Nonparametric tests (Mann-Whitney test for two independent samples) were applied to compare elite and recreational climbers. To assess the effect statistic Cliff Delta size was calculated. The test-retest reliability was analyzed in all actions through the intra-class correlation coefficient with a confidence interval of 95% (CCI, 95%). significant differences $p \leq 0.05$ were considered. Data were analyzed with SPSS, v software. 21.0.

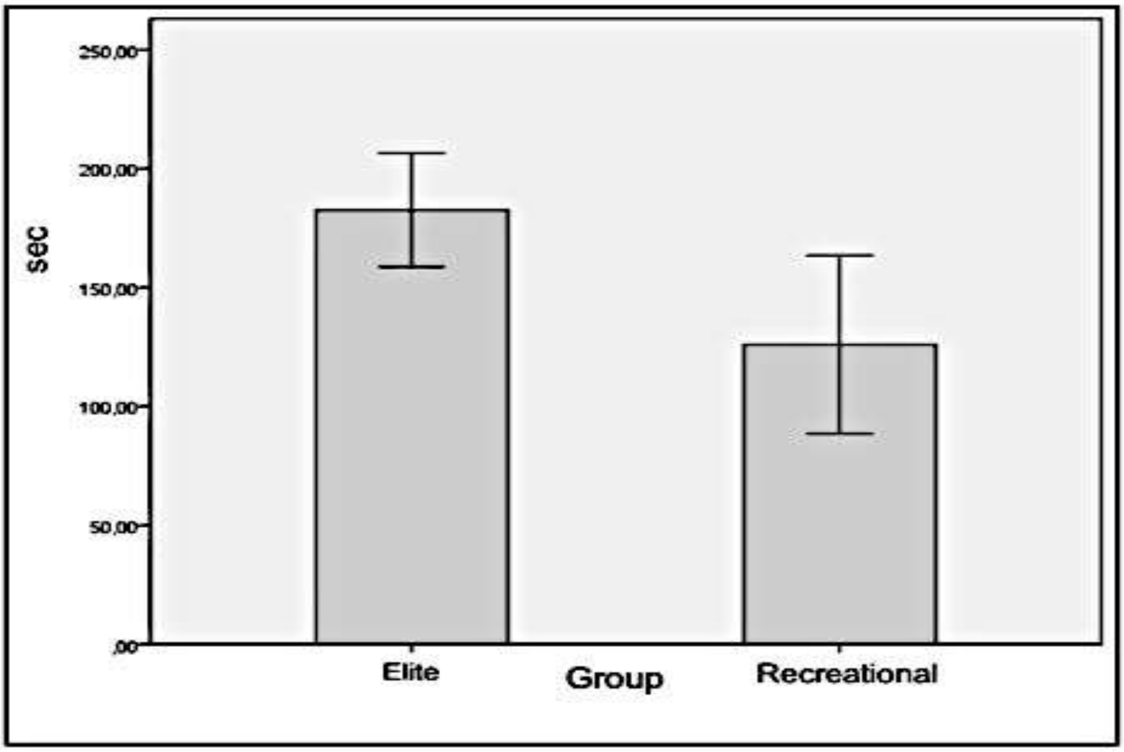
RESULTS

The results obtained in continuous resistance tests (test 1) and intermittent (test 2) reveal that EC exhibit more grip resistance than the RC in both tests (Table 3).

	EC (n = 7) M±Sd	RC (n = 14) M±Sd	Mann-Whitney Z	p	Cliff Delta
Test 1 (Isometric Effort)					
Isometric Test (s)	182.7±23.9	126.1±37.5	-2.632	0.007	0.61
Test 2 (Intermittent Effort)					
Period	8.8±0.8	5.0±1.0	-3.671	<0.001	1.00
Total time (min)	17.6±1.5	9.9±1.9	-3.671	<0.001	1.00
Total Repetitions	52.7±4.5	29.6±6.1	-3.670	<0.001	1.00
Repetitions Dam 1	21.0±0.0	19.6±1.7	-2.402	0.038	0.57
Repetitions Dam 2	26.7±2.1	9.9±4.5	-3.676	<0.001	1.00
Repetitions Dam 3	5.0±2.8	-	-	-	
FC max (lat/min)	136.7±6.5	134.1±7.1	-0.638	0.535	0.17
FC (average)	90.7±5.3	91.8±3.9	-0.262	0.799	0.07

Table 3. Isometric and intermittent effort in recreational and elite climbers (standard deviation of average M) performance. nonparametric Mann-Whitney and Delta Cliff size effect, p: level of critical significance.

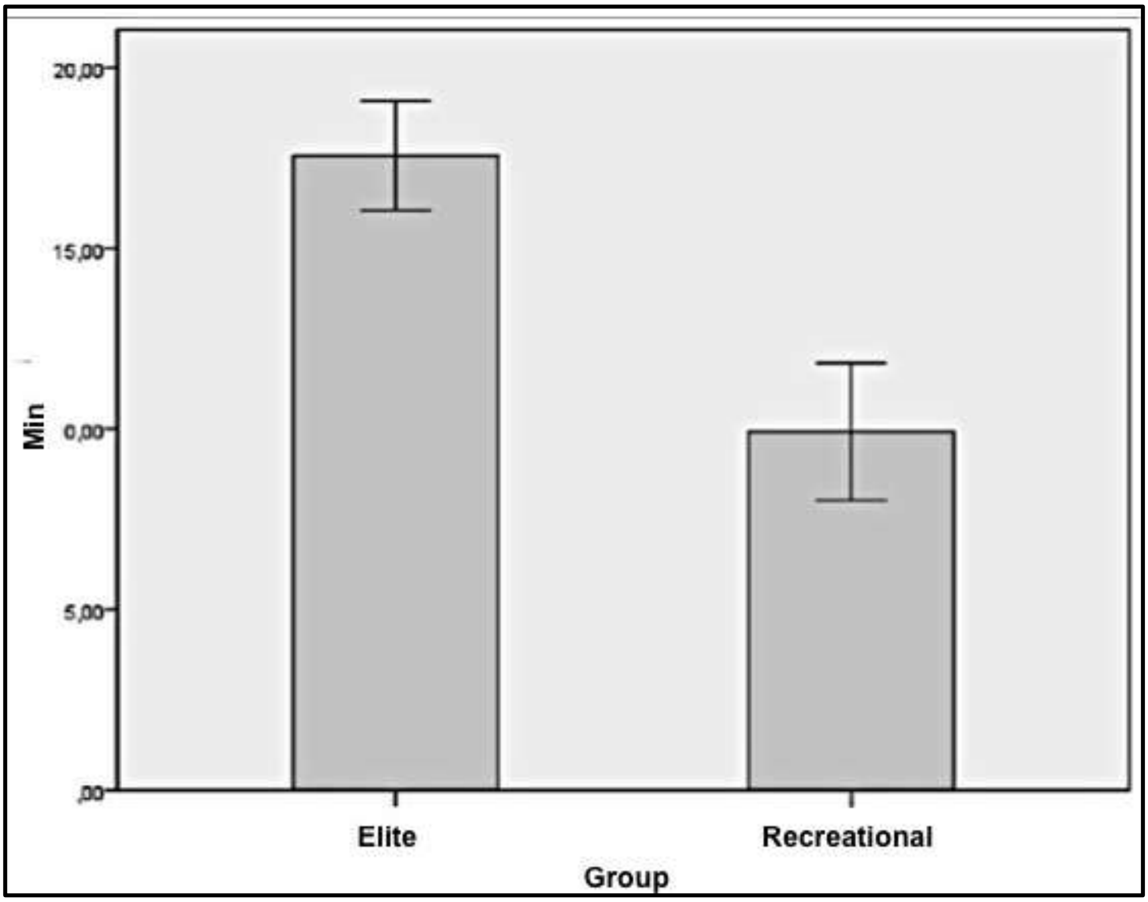
Data from test 1 showed that the average time of the group EC (182.67 ± 23.9 s) in continuous suspension was 56.5 seconds greater than that of RC (126.08 ± 37.5 s) (Figure 1), being a statistically significant difference (p = 0.007). Statistical Cliff Delta indicates a large effect size. The CCI shows that the test-retest reliability is excellent in this type of test (ICC = 0.96; 95% CI: 0.90 to 0.98).



Graph 1. Performance (total time in seconds) of elite and recreational climbers in the isometric test (error bars: ± 1 standard deviation).

In the intermittent resistance test (test 2), elite climbers have reached an average period of 8.8, compared with the period 5 which on average climbers have reached in the recreational group. Regarding reliability, there is excellent consistency in test sampling between the test and retest (ICC = 0.91; 95% CI: 0.80 to 0.96). In addition, elite climbers spent an average of 7 minutes longer than recreational climbers when suspended (17.57 ± 1.50 min vs 9.93 ± 1.9 min, respectively (Figure 2), and made 23.14 more repetitions (52.71 ± 4.50 vs 29.57 ± 6.12 respectively.) the CCI shows high reliability for total sleep time (ICC = 0.98; 95% CI: 0.94 to 0.99) and for the total number of repetitions (ICC = 0.99; 95% CI: 0.97-1.00). In dams 1, 2 and 3 elite climbers were able to carry out a greater number of repetitions that recreational climbers(see Table 3). The CCI shows a high internal consistency (shelf 1: ICC = 0.85, 95% CI: 0.66 to 0.93; ledge 2: ICC = 0.99, 95% CI: 0.96 to 0.99; ledge 3: ICC = 0.95; 95% CI: 0.73 to 0.99). The differences were highly significant (p <0.001).

Instead, there were no significant differences between groups in maximum heart rate (p = 0.535). Elite climbers showed a maximum heart rate of 136.71 ± 6.5 beats per minute, compared with 134.07 ± 7.1 of recreational climbers.



Graph 2. Performance (total time in seconds) of elite and recreational climbers in the intermittent test (error bars: ± 1 standard deviation).

DISCUSSION

The results point to the existence of differences between elite and recreational climbers, which could affect performance in climbing. It also confirms that the multi-grip table training is adequate and reliable for assessing climber performance.

Regarding the reliability of the training table, these results show that it is a consistent method to assess resistance in elite and recreational climbers. Other studies have evaluated the reliability for power tests (Laffaye, Collin, Levernier, Padulo, 2014; Draper, Dickson et al 2011), but, to our knowledge, this study is pioneer in the assessment of resistance.

In cinematic terms, escalation is primarily to push & pull: legs and arms push & pull (Booth, Marino, Hill, Gwinn 1999). Overuse of the pushing force of arms leads to a decrease in efficiency because the smaller muscles of the arms fatigue faster than the larger muscles of the legs, leading to decreased performance in climbing and increased physiological stress (Janot, Steffen, Porcari, Maher 2000).

During the climb, the gripping force of the fingers is a decisive factor (Quaine and Vigouroux, Martin 2003; Vigoroux, Quaine, Labarre-Villa, Moutet 2006). Sometimes it is necessary to apply a high force steadily to ensure the maintenance of a static position on the wall. In other cases, the use of force support or suspension are performed intermittently.

The results obtained in the tests 1 and 2 indicate different degrees of adaptation between elite and recreational climbers for both types of resistance. This confirms the importance of the flexor muscles of the arm during a difficult ascent. It also confirms the value of the tests performed in this study as specific performance measures in climbing.

Elite climbers reached higher performance in both tests than recreational climbers. These findings are similar to those obtained by other authors (Green and Stannard 2010; Mermier, Janot, Parker, Swan 2000; Quaine, Vigouroux, Martin 2003) which suggest during progress in the ascent, inexperienced climbers arrive fatigued and are less able to maintain the position of support or suspension. Elite climbers have a greater degree of adaptation, due to the greater ability to perform an isometric effort of the muscles of the forearm (Schöffl, Mockel et al, 2006; Sheel 2004).

Physical exhaustion is characterized in climbing in fatigue on forearm, changes in blood pressure, increased heart rate and lactate levels in blood (Bertuzzi, Gagliardi, Franchini, Kiss 2001), especially on more difficult routes (Sheel, 2004).

The adaptive response to isometric exercise is due in part to increased blood flow and vascular area, as well as adaptations of the musculature involved (Fryer, Stoner et al 2015; O'Leary, Augustyniak, Ansorge, Collins 1999) , leading to improved vasodilatory capacity and increased nutrient supply and disposal of metabolic waste in rest periods. Ultimately, this strengthens the ability of the climber for repeated and sustained contractions (Ferguson and Brown 1997).

The heart rate also changes during a difficult route. The values obtained in the test 2 suggest that cardiac demand was not very high, so no significant differences between elite and recreational climbers were observed. However, other authors have shown a remarkable increase in heart rate during climbing, noting further that this parameter increases with the difficulty of the route (Janot, Steffen, Porcari, Maher, 2000; Schöffl, Mockel et al 2006; Sheel , 2004; sheel, Seddon et al 2003; Watts and Drobish, 1998). More research to study changes in heart rate during climbing, and possible differences between experts and recreational climbers is necessary because in this study this difference could not be observed.

Schöffl et al (2006) found a positive correlation between increased heart rate and difficulty of the route. The increase of cardiac activity has been attributed to the repeated isometric contraction of the flexor muscles of the fingers (sheel, 2004), which causes not only an increase in blood pressure (Ferguson and Brown, 1997), but also an increase in heart rate disproportionate in relation to VO2 (Billat, Palleja et al 1995; Mermier et al 2000; Schöffl et al 2006; Sheel, 2004; Watts and Drobish, 1998).

In test 2, climbers exercised until exhaustion was caused by the number of contractions and by locking technique. The grip strip (crimp grip) requires a greater grip force on slope (slope grip).

Therefore, it is essential to clarify why the heart rate did not increase with increasing flexor activity in this study. One possible explanation is linked to the technical requirements of climbing.

Maintaining the position is primarily achieved through the feet. However, expert climbers also make a tactical use of hands to find the most appropriate support, mainly using foot movements involving precise strategic steps (Bourdin, Teasdale, Nougier, 1998).

More experienced climbers spend less energy than inexperienced climbers, even in the most complicated routes. The skill and technique play a key role in energy expenditure, while influencing the cardiac response to exercise (Janot et al 2000).

The psychological aspects should also be taken into account to explain the performance in difficult routes. A high heart rate may be more related to psychological factors such as anxiety, with the degree of physiological exhaustion (Sanchez, Boschker, Llewellyn 2010). Janot et al (2000) found that heart rate is higher than experienced climbers in recreational climbers, both before hitting the road, as during the act of climbing. In tests conducted in this study, climbers have a limited level of perceived risk, and therefore, the psychological challenge has not been a key factor.

Although the heart rate is elevated for climbing, apparently, the biggest increase in experienced climbers occurs during the early stages of the activity (Schöffl et al 2006); on the contrary, the increase in heart rate in the last stage of climbing is superior in recreational climbers than in elite ones (Ferguson and Brown, 1997).

The psychological control is an important component climbing. Changes in heart rate can occur in situations of extreme difficulty, as well as in times of physical exhaustion, due to the degree of psychological stress, which varies depending on the technical skill and experience climber to overcome these situations.

Finally, the ability to perform repeated grips in different positions and using different grips seems to determine performance in climbing. This capability, combined with high technical capacity and adequate physical and psychological preparation, allows elite climbers to scale for longer than recreational climbers and achieve higher performance.

CONCLUSIONS

The results of this study are of interest for resistance training climbers for two reasons:

First, these results reinforce the notion that the flexor muscles of the fingers are key to achieving higher performance in climbing. Preparers should take this into consideration when setting the resistance training.

Secondly, it has developed a reliable and consistent method for assessing the resistance of the flexor muscles of the fingers, which includes a multi-grip table for training that has shown a high discriminatory power between recreational and elite climbers.

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