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The finger flexors occlusion threshold in sport-climbers: an exploratory study on its indirect approximation

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ABSTRACT

Blood flow partially determines specific climbing endurance (SCE) as it mediates oxygen bio-availability in the finger flexors. Blood flow is related to occlusion threshold (OT), which is defined as the contraction intensity at which intramuscular pressure exceeds perfusion blood pressure resulting in the cessation of local blood flow. The OT is represented as an inflection point on a force-time graph when isometric force is registered and applied through maximal and continuous tests. Endurance time (ET) to exhaustion is influenced by the relative isometric applied force and is different for each climber. The aim of this study was to explore whether an approximation of the finger flexor´s OT in sport climbers through records of ET to exhaustion at different isometric relative intensities was possible. We measured maximum finger hang ETs at 6 intensities ranging from 85% to 35% maximal force in 34 sport climbers of advanced and elite level. The values obtained were analyzed by two different methods in an attempt to determine a change in the shape of the curve in the intensity-ET relationship graphs that approximated the OT for each climber. The results suggest that the finger flexor´s OT could be different among climbers, regardless of their strength and ability level. The presented methods do not accurately reflect the OT, but could indicate the intensity at which blood flow is restored in the active muscles. This is the first study to indirectly approximate the finger flexors OT in sport-climbers, a parameter that could be essential to assess SCE.

Key words: *blood flow, sport climbing, specific endurance, finger hangs*

INTRODUCTION

Climbing will be an Olympic sport in Tokyo 2021, thus it is crucial to identify how to improve performance in elite climbers. Climbing performance is determined by the climber's ability to recruit the finger flexor muscles at high intensities (8,26) and to recover from each of those efforts quickly (18). Recovery will impact specific climbing endurance (SCE) (4,24) which is determined by the local muscular endurance of the finger flexors which in turn is influenced by the magnitude and speed of re-oxygenation of these muscles during the rest phases between contractions (17). Local re-oxygenation is determined by blood flow in the aforementioned recovery times (19), since during the contraction phases in climbing, local blood flow is usually limited within these muscles (14). This is because muscle blood flow is greatly affected by the intensity of isometric contractions (20), and will be nonexistent above the critical level of occlusion tension or occlusion threshold (OT) (6,21).

The OT is defined as the contraction intensity at which the intramuscular pressure exceeds perfusion blood pressure (6,21). This intensity is specific for each muscle and person because it depends on myotypological and vascular factors that interact during isometric muscle contractions (6,21). When a muscle contracts isometrically above the OT its oxidative metabolism is limited and consequently local fatigue is increased (7,36). Although several studies have demonstrated the importance of blood flow in recovery and SCE (14,19,33), to the best of our knowledge no studies have evaluated SCE in climbers in relation to their OT. This could limit the validity of previous assessments as suggested by Staszkiewicz et al. (2002) (32), as the presence of blood flow during isometric contractions would mask the effect of local re-oxygenation in the recovery periods. Consequently, SCE assessments should be performed in similar hemodynamic conditions for all climbers (32), that is, with blood flow occluded by intramuscular pressure during the contraction phases, with researchers' having the need to know the OT intensity for each climber to perform a valid assessment. Nonetheless, the equipment used to assess microvascular blood flow (near-infrared spectroscopy (NIRS) or magnetic resonance imaging (MRI)) (12,22,35) and establish the OT intensity is generally unavailable to most climbing coaches. That is why Yamaji et al. (2000, 2002, 2004) (36-38) assessed OT through indirect methods, finding an inflection point in the force records obtained during maximum efforts maintained isometrically between 3 and 12 minutes. This point divided the force-time graph into a phase of a marked descent and a phase of steady state of force, reflecting the intensity at which local blood flow was restored (supplementary Figure 1).

Due to the individual association between endurance time (ET) to muscle exhaustion and relative isometric applied force (21,38), it is reasonable to think that the inflexion point found by Yamaji et al. (2000, 2002, 2004) could be found through ET records obtained when performing isometric efforts to exhaustion at different relative intensities. The intensity-ET relationship graph drawn by these records can be found in previous literature (1,16). All these graphs show a tendency towards nonlinear functions (exponentials or potentials, mostly) at the lowest intensities (16,32) and linear trends at the highest intensities. The non-linear trend could be explained by a higher bioavailability of oxygen due to the presence of blood flow in the muscle (6), which would represent the almost steady state of force found by Yamaji et al. (2000, 2002, 2004). The linear trend would reflect the marked force descent reported by the mentioned authors caused by the lack of oxygen due to the absence of blood flow in the muscle (22) (see Supplementary Figure 1). Thus, the change in the shape of the curve (trend change) in the intensity-ET relationship graph could approximate the point (intensity) from which blood flow is restored in the active muscle.

The aim of this study was to explore whether an approximation of the finger flexor´s OT in sport climbers through records of ET to exhaustion during sustained finger hangs at different isometric relative intensities was possible.

METHODS

Participants

The inclusion criteria were to have: a) an experience of 3 or more years climbing; b) a minimum climbing training practice of at least 2 days per week during the past year; c) absence of finger injuries during the last 6 months, and d) to be able to perform a 40 second finger-hang on an edge size equal or smaller than the distal phalange of the middle finger. Participants were individually informed about the characteristics and risks associated with the study, and were given an informed consent to be signed. This study followed the declaration of Helsinki 1961 (revision of Fortaleza 2013), and the protocol was approved by the Ethics Committee of Clinical Research from the Government of Aragon (CEICA), Spain (PI13/0091). Finally, 34 sport climbers met all the inclusion criteria and voluntarily participated in the research project. This number of participants allowed us to detect large effects (11) in the correlation analyses used ($R = .5$) with a statistical power of .87, assuming a two tailed α of .05. Secondarily, the participants were also divided into two groups: advanced group (AG, n=14, 18 to 23 IRCRA red-point level) and elite group (EG, n=20, 24 to 27 IRCRA red-point level) according to the International Rock Climbing Research Association (IRCRA) current classification (13). In this case, we were powered to detect large effects ($R = .5$) with a statistical power of .44 and .62 respectively, maintaining the same probability error. Therefore, subgroup correlation analyses were merely exploratory due to the limited statistical power. The EG included two 28 and two 29 IRCRA red-point level participants who would be classified as super elite according to the IRCRA classification (13).

Procedures

The tests were carried out in 4 consecutive days at the same time each day. Temperature and humidity of the room in which measurements took place were similar for all participants, who were asked not to consume food or caffeine for at least 3 h prior to testing and avoid climbing and training the day before the tests. The sport climbers carried out a total of 3 tests each day (Table 1).

****TABLE 1 AROUND HERE****

All tests consisted of finger hangs using both hands at the same time and the shoulder/elbow angles at 180/0º flexion following previous study recommendations (5). Tests were carried out to exhaustion on a wooden edge of equal or lesser depth to that of the distal phalanx (precision 1 mm) at different intensities depending on the test. This edge size was selected because a different recruitment pattern could lead to differences in the distribution of blood flow among different climbers (6), and the finger flexor muscles recruitment has shown to be influenced by the edge depth in which the force is exerted, being the flexor digitorum profundus (FDP) the muscle preferably recruited in these edge depths (34). This exercise, which is performed with the forearm above the head, was an important element of specificity within the study, since perfusion pressure is modified when the hands work above the head (a usual situation during climbing) (15). Climbers were allowed to use an open crimp grip or a half crimp grip to hold on to the edge. Each climber chose the type of grip according to his or her perception of which grip allowed him to apply the maximal force and performed all the tests with the same type of grip, thus with the same recruitment pattern during all tests and always impacting on the FDP (34), which is the most important muscle for climbing performance (27). The full crimp was not allowed because it entails an increased risk of injury (30,31). The wooden edge profile was smoothed 4 mm to avoid the painful sensation related to finger hangs on sharp edges (2,3).

The target relative intensity in each test was reached adding hanging dumbbells by a quick draw to a climbing harness or using a pulley system when the intensity was greater or lower than body weight. The precision was controlled with a load cell (model 160, UTILCELL, Spain, CV=.02%) incorporated under the wooden edge. During the first day participants carried out the following tests:

1) The maximum hanging time on a 16 mm edge (MHT_16)

2) The minimum edge depth from which climbers could perform a finger dead hang for 40 s (MED_40).

3) The maximum added weight to hang 5 s on MED_40 (MAW_5). A progressive approximation was done until climbers reached a maximum of 5 s hanging.

MHT_16 was used to approximate edge depth in MED_40 due to the high association observed between these variables in previous studies (8), thus favoring a lower number of approximation repetitions. The following equations were used for the approach:

- When MHT_16 was ≥ 41mm: ((-0,2182* MHT_16)+25,313))
- When MHT_16 was ≤ 40mm: ((-0,4334*MHT_16)+33,221))

The tests and the warm-up are described in detail in a previous study (8). They were carried out in one day and were always performed in the same order. While participants were performing the day 1 warm-up, their general data were obtained.

The remaining three days the sport climbers performed the same tests every day. The first test was the MAW_5 re-test to adjust the intensity of the following tests that took place during the same session. The second and third tests were the maximum hanging time test (MHT) the climber could perform on a MED_40 edge at two different intensities (percentages of the results of the MAW_5 test): Day 2 (85% and 55%), day 3 (75% and 45%), day 4 (65% and 35%). These intensities were chosen because it is where the occlusion threshold (OT) has been found (traditionally between 40-70% maximal voluntary contraction) (6,16,21,22,29). The recovery time between tests was complete according to the feelings of each participant, with a minimum rest of ten times the effort time performed in the previous test.

Participants reported their climbing experience as the time climbing outdoors in years. Body weight (BW) was measured including the same harness for all participants, their own shoes and minimal clothes (Soehnle, precision 0.1 kg). Height was measured without shoes (metric tape, precision 0.01 m). Ability level was assessed through the best red-point ascent achieved in the previous 6 months (grade). MHT tests was measured in seconds with a digital chronometer CASIO© to all relative force intensities. Their differences were shown in seconds and percentages. MED_40 was measured in millimeters, and MAW_5 in kg relative to BW and MED_40 of the test (e.g. a climber that weighed 50 kg and was able to hang for 5 s with an extra weight of 10 kg on a 12 mm edge would obtain a score of: (((10 + 50) / 50) / 12) * 100) = 10). Tests were ended once: i) the contact was lost between the participant and the edge, ii) the initial posture was clearly altered through elbow elevation or back inclination, and iii) if the type of grip was changed during tests. The posture alterations were visually controlled by an experienced researcher (PBG).

Statistical analyses

All of the variables were described using means (SDs), medians (interquartile ranges) or frequencies (percentages) according to their corresponding distribution. ET and percentage of isometric force were graphically represented based on data obtained on the tests of the last three days. We used two different exploratory procedures in an attempt to indirectly approximate the OT. For the first approximation, we determined the intensity at which the linear trend adjustment was lost by comparing the explanatory power of linear and nonlinear trend models (i.e. potential, exponential or logarithmic, as examples of models that allowed us drawing non-linear or curvilinear trend lines) for the ETs obtained from the highest to the lowest intensity, and incorporated one by one at the intensity-ET relationship graph. Starting at the highest intensities, we considered that the first intensity that had a better non-linear adjustment with respect to the linear one could reflect the trend change object of the study ("linear vs. non-linear" approximation), naming the OT at the intensity immediately before that (see an example in Supplementary Figure 2). For the second approximation, differences in ET between each pair of the closest intensities were calculated. These differences were used to estimate time percentage increase between each pair of contiguous differences (from higher to lower intensity values). The first increase from the highest intensity that was equal or greater than 50% was interpreted as a possible indicator of the trend change object of the study ("percentage increased by pairs" approximation). We named the OT at the intensity immediately higher than the one where the mentioned increase was observed. An example of both "linear vs. non-linear" and "percentage increased by pairs" OT approximations is presented in Table 2. Due to the low number of women in the present sample and to the lack of differences between genders for high intensity isometric endurance tests (23,25), we did not stratify by gender. Concordance among estimations was assessed using the intra-class correlation coefficient (ICC) – and its 95% CI. We used Spearman correlations (R) to explore possible relationships between the approximated OT and climbing experience, sport level and fingers strength level (MAW_5), for the whole group and also separating participants into two levels of sport practice (advanced and elite climbers). All the tests were two-sided, and the significance level adopted was $\alpha < .05$.

****TABLE 2 AROUND HERE****

RESULTS

The general characteristics of participants are presented in Table 3. The intensity-ET relationship graphs for each individual participant can be found in Supplementary Figures 3 and 4. Table 4 shows the OT estimations using potential, exponential and logarithmic functions as well as the pair comparisons approximation. As shown in Table 4, potential, exponential or logarithmic functions showed a worst fit than the linear function in some participants for the evaluated intensities. The ICC among the approximated OT values obtained from all of the methods was of .92 (95% CI = .85 − .96). On average, the approximated OT in our study was found at intensities corresponding to 65.6 ± 8.9% of maximal strength, without significant differences between climbing groups (AG 65 ± 10.37%; EG 66 ± 7.88%; $p = .751$). Considering the whole group, there were no significant relationships between the estimated OT and climbing experience ($R = .29$; 95% CI = -.05 − .57; $p = .091$), ability level ($R <.01$; 95% CI = -.33 – .35; $p = .998$) and MAW_5 ($R = -.11$; 95% CI = -.43 − .24; $p = .549$). However, when separating the sample into two groups according to ability level, we found that the calculated OT was significantly related to climbing experience only in the EG ($R =.49$; 95% CI = .06 – .77; $p = .03$).

****TABLE 3 AROUND HERE****

****TABLE 4 AROUND HERE****

DISCUSION

The results from the present study draw an intensity-ET relationship graph which is in line with previous studies (1,16,28), with a trend change in all graphs that seems different for each climber. Due to the traditional association between ET to muscle exhaustion and relative isometric force, it seems reasonable to think that these trend changes represent a physiological change that has traditionally been associated with blood flow. The most important finding of this exploratory study is that it seems possible to assess this trend change from ET data using two models. Thus, it seems possible to approximate at which intensities there could be blood flow in the finger flexors of advanced and elite sport climbers, since the intensity corresponding to the OT is not exactly known. This finding could be relevant to measure SCE under controlled hemodynamic conditions.

In the present study we show two different methods (estimation through curvilinear function adjustments or through pairwise comparisons) through which a trend change can be detected in the recorded ETs at different isometric relative intensities. This change would represent a decrease in intramuscular pressure that would allow the restoration of blood flow in the active muscles (6,21). The bioavailability of oxygen in the muscle enables exponentially longer ETs especially when compared to those intensities at which the intramuscular pressure prevents blood flow (9,10,22). The intensity-ET relationship graphs reflecting the above have traditionally been present in the literature (1,16), but to the best of our knowledge, no study has used a method like the ones we propose to approximate the OT. The same physiological event has been assessed recording applied force or oxygenation kinetics in sustained maximum isometric contractions (36,38). These records allow the detection of an inflection point and associate it precisely with the intensity of the OT. Nevertheless, they require expensive and inaccessible tools for most training coaches unlike the finger hanging ETs registered in this study. Our handy procedure only provided information regarding the intensities at which one climber could have local blood flow. Because we did not know the real OT intensity, for statistical purposes of the present study we employed the approximated OT intensity for each participant that showed the highest level of agreement among the used methods (91% of the cases). When methods did not agree, the highest approximated OT intensity was selected (9% of the cases).

We approximated the OT with a reasonable accuracy (10%) as indicated in each intensity-ET relationship graph by the occlusion threshold area (OTA). The OTA corresponds to the relative intensities spectrum in which blood flow is most likely to occur, thus it would cover from the approximated OT to the immediately lower assessed intensity (see Supplementary Figures 3 and 4). Regarding the types of approximations, we found a high level of agreement between all used methods, but achieving an approximation to the OT for all the analyzed participants only by the “percentage increased by pairs”. This could be due to the range of relative intensities used and the small number of data that made up our intensity-ET relationship graph. Perhaps non-linear models would achieve better adjustments with a greater number of data and at lower intensities. For example, Frey & Law (2010) reported in their meta-analysis on the intensity-ET relationships for different joints that the potential model had a better fit when compared to the exponential for ranges of intensities that covered up to 10%-15% of the maximum force. Overall, OT approximations carried out in our study agreed in more than 90% of the cases, although the “percentage increased by pairs” method seems more sensitive to the detection of changes in linear trends for low number of records such as those assessed in our study. In any case, both procedures require validation through the evaluation of direct physiological variables, so future research is guaranteed.

We did not find an association between the approximated OT and ability level or finger strength. Therefore, the intensities in which there seems to be blood flow in the finger flexors of the climbers vary regardless of their ability level. This is of critical importance since SCE has been related to local re-oxygenation which is influenced by local blood flow. The studies that have assessed SCE so far have done it at the same relative intensity for all climbers, so they might not have assessed all climbers under the same hemodynamic conditions. This fact could limit the validity of these assessments (32) because local re-oxygenation would take place not only in the recovery periods between contractions for all climbers, but also in the contraction phases for some climbers. Moreover, although we had a limited statistical power for the subgroup correlation analyses, we found a statistically significant association between the approximated OT and climbing experience in elite climbers, which could entail that a larger amount of time climbing could generate deeper vascular adaptations like those found by previous studies (14,33). Although these adaptations would not entail an increased OT in elite climbers, as we did not find differences between ability levels, the adaptations could allow more experienced climbers to maintain the OT at a similar intensity to that of lower level climbers with a lower maximal force. The above suggestion is based on the inverse relationship that has been demonstrated between the maximum isometric force and the OT (6,21).

To the best of our knowledge, this is the first study that performed an indirect approximation to the OT in climbers and has suggested that sport climbers might present different hemodynamic conditions at the same isometric relative intensity. This finding could be relevant for future researchers and coaches to approximate the individual OT with accessible methods and measure SCE under controlled hemodynamic conditions (e.g. with all participants without blood flow in the finger flexors during the contraction phases). Future research should consider performing the assessments in a random order to avoid a learning effect which could have influenced results of the present study. Although the approximated OT has not been associated with performance in our study, it seems like vascular adaptations which could influence this parameter could be trainable and might be associated with a larger volume of climbing practice. The level of agreement between our assessments suggests that all used methods could be valid to approximate the OT, but because they were all indirect methods this suggestion should be confirmed through direct assessments of blood flow using NIRS in future studies. The above is especially true to the pairs comparison approximation, a method that we used in preliminary observations with good results and which has been the only one that has not lost experimental participants in this study.

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Supplementary Figure 1. Example of endurance times and their linear (above the inflection point) and nonlinear (below the inflection point) trends. Graph adapted from Yamaji et al. (2004)

The graph presents a continuous register of maximal force during six minutes with simultaneous oxygen kinetics (Deoxy-Hb only, to simplify the graph) through which Yamaji et al., (2004) calculated an inflection point that corresponds to the occlusion threshold (OT). The gray diamonds represent an example of the endurance times reached in isometric contractions to exhaustion at different relative intensities. These diamonds are connected with a line that reflects two different trends: a linear one (continuous line at higher intensities, above the inflection point) and a non-linear trend (discontinuous line at the lowest intensities, below the inflection point)

Supplementary Figure 2. Intensity-endurance time relationship graphic example of the "linear vs. non-linear" approximation method from data of one participant.

The linear regression is compared with non-linear ones (exponential, logarithmic and potential), of the obtained endurance times (ETs) from the highest to the lowest isometric force intensities. Each time an additional datum is included and also a new coefficient of determination (relating ET and isometric force percent) is calculated. Starting at the highest intensities, we considered that the first intensity where there was a better non-linear adjustment with respect to the linear one (highlighted in our second graph) could reflect a change in the hemodynamic condition object of study passing from an occlusion to a non-occlusion state, naming the OT at the intensity immediately before that (75% in this example).

Supplementary Figure 3. Endurance time (ET) and percentage of isometric force in elite climbers

* IRCRA level

^ MAW_5: Maximum added weight (kg) to hang 5 seconds on the edge from which they could perform a finger dead hang for 40 seconds.

OTA = Occlusion threshold area

Supplementary Figure 4. Endurance time (ET) and percentage of isometric force in advanced climbers

* IRCRA level

^ MAW_5: Maximum added weight (kg) to hang 5 seconds on the edge from which they could perform a finger dead hang for 40 seconds.

OTA = Occlusion threshold area

Table 1. Tests sequence

Day 1	Day 2	Day 3	Day 4
1. Endurance test (MHT_16)	1. Strength re-test (MAW_5)	1. Strength test (MAW_5)	1. Strength test (MAW_5)
2. Endurance test (MED_40)	2. Endurance test (MHT_85% of the MAW_5)	2. Endurance test (MHT_75% of the MAW_5	2. Endurance test (MHT_65% of the MAW_5)
3. Strength test (MAW_5)	3. Endurance test (MHT_55% of the MAW_5)	3. Endurance test (MHT_45% of the MAW_5)	3. Endurance test (MHT_35% of the MAW_5)
Real example of one participant			
1. MHT_16: 40 seconds	1. MAW_5 = 65kg(BW) + 24 kg(AW) = 89 kg TW	1. MAW_5 = 64 kg (BW) + 25 kg (AW) = 89 kg TW	1. MAW_5 = 65 kg (BW) + 23 kg (AW) = 88 kg TW
2. MED_40: 16 mm	2. MHT_85% MAW_5 = ET with AW 10,5 kg (*) = 28 seconds	2. MHT_75% MAW_5 = ET with AW 3 kg (*) = 40 seconds	2. MHT_65% MAW_5 = ET with WR -8,5 kg (*,**) = 58 seconds
3. MAW_5: 65 kg (BW) + 25 kg (AW): TW: 90kg	3. MHT_55% MAW_5 = ET with WR -17 kg (*,**) = 75 seconds	3. MHT_45% MAW_5 = ET with WR -25,5 kg (*,**) = 101 seconds	3. MHT_35% MAW_5 = ET with WR -36,5 kg (*,**) = 130 seconds

MHT_16 = Maximum hanging time on a 16 mm edge. MED_40 = Minimum edge depth from which climbers could perform a finger dead hang for 40 seconds. MAW_5 = Maximum weight climbers could support while hanging for 5 seconds on the MED_40 edge. MHT = Maximum hanging time. ET = Endurance time. BW = Body weight. AW=added weight. TW=Total weight. WR=Weight reduction (*) Precision of 0,5 kg (**) Weights used calculated with a load cell that was placed under the edge to adjust intensities taking into account the friction force of the pulley system.

Table 2. Example of the "linear vs non-linear" (a) and "percentage increased by pairs" (b) OT approximation for one participant.

Registered ET at each intensity	Relative force intensity (%)	85%	75%	65%	55%	45%	35%
	Maximum hanging ET (s)	28	40	58	75	101	130
Linear	Relative force intensity (%) plotted	85-75%	85-75-	85-75-	85-75-65-	85-75-65-55-	

vs. non-linear approximation (a)			65%	65-55%	55-45%	45-35%		
	Maximum hanging ET (s) plotted	28-40	28-40-58	28-40-58-75	28-40-58-75-101	28-40-58-75-101-130		
	Lineal adjustment (R^2)	1	.986	.993	.982	.977		
	Logaritmic adjustment (R^2)	1	.994 (*)	.997	.997	.998		
	Exponential adjustment (R^2)	1	.999 (*)	.994	.995	.994		
	Potential adjustment (R^2)	1	.999 (*)	.981	.975	.961		
	OT approximation and relative intensities with/without blood flow	Without BF	BF Restored	With BF				
		OA (≥75%)	OTA (< 75%)	BFA (< 65%)				
Percentage increased by pairs approximation (b)	Differences between contiguous ET (s)	-	75%-85% (A)	65-75% (B)	55%-65% (C)	45%-55% (D)	35%-45% (E)	-
			12	18	17	26	29	
	Percentage difference relative to the next contiguous endurance time difference (%)	-	(B-A/A)*100	(C-B/B)*100	(D-C/C)*100	(E-D/D)*100	-	
			50%	-6%	53%	12%		
	OT approximation and relative intensities with/without blood flow	Without BF	BF Restored	With BF				
		OA (>75%)	OTA (75-65%)	BFA (< 65%)				

BF: blood flow; ET: endurance time; (*): first coefficient of determination that corresponds to a nonlinear trend model which presents a better fit when compared to the lineal fit for the graphed times (graphic example in Supplementary Figure 2); OT (a): Occlusion threshold was approximated as the intensity before the one that generated a better nonlinear fit starting at the highest intensities. OT (b): Occlusion threshold was approximated as the intensity just before the first one that generated a percentage decrease equal or greater than 50% starting at the highest intensities. OA=Occlusion Area or intensities with probable occluded blood flow. OTA=Occlusion Threshold Area or intensity spectrum where the occlusion would appear; BFA=Blood Flow Area or intensities with probable blood flow; -=No data available

Table 3. Characteristics of study participants

Variables	Range	Total Group (n = 34)	Advanced (n=14)	Elite (n=20)
Age (years) †	20 – 46	34.76 (5.79)	36.36 (5.51)	33.65 (5.85)
Males(%)/Females (%) ‡		32 (94.1%) / 2 (5.9%)	13 (92.9%) / 1(7.1%)	19 (95%) / 1 (5%)
BW (Kg) †	42.90 –	65.64 (6.63)	67.15 (7.26)	64.59 (6.11)

	77.00			
Height (m) †	1.53 – 1.85	1.73 (0.07)	1.75 (0.08)	1.71 (0.07)
BMI (Kg/m^2) †	18.33 – 24.91	21.85 (1.39)	21.73 (1.23)	21.93 (1.52)
Rock climbing experience (years) †	4 – 28	13.26 (5.52)	11 (5.07)	14.85 (5.38) (*)
Sport level (IRCRA) &	20 – 29	24 (23 – 26)	23 (23 – 23)	26 (24 – 27) (**)
MAW_5 [(((kg + Bw)/Bw)/mm) × 100] †	2.90 – 24.73	12.08 (5.18)	9.09 (3.91)	14.17 (4.99) (*)

BW: Body weight. BMI: body mass index. IRCRA: International Rock Climbing Research Association scale. † Mean (SD). ‡ Frequency (%). & Median (interquartile range). * Significant difference p <.05. ** Significant difference p < .001.

Table 4. Occlusion threshold estimations using potential, exponential and logarithmic functions as well as the pair comparisons approximation for each participant.

Participant	Potential (a1)	Exponential (a2)	Logarithmic (a3)	Pairs (b)	OT(%) used for statistics (*)
1	(-)	55% (.988)	75% (.999)	55%	55%
2	55% (.965)	55% (.985)	75% (.999)	55%	55%
3	55% (.984)	55% (.993)	65% (.999)	55%	55%
4	(-)	(-)	55% (.981)	55%	55%
5	75% (1)	75% (.998)	75% (.982)	75%	75%
6	75% (.999)	75% (.995)	75% (.977)	75%	75%
7	75% (.993)	75% (.998)	75% (.995)	55%	75%
8	75% (.998)	75% (1)	75% (.984)	75%	75%
9	75% (.995)	75% (.989)	75% (.971)	75%	75%
10	75% (.996)	75% (.990)	75% (.971)	75%	75%
11	75% (.995)	75% (.999)	75% (.996)	65%	75%
12	65% (.992)	65% (.995)	75% (.999)	65%	65%
13	65% (.982)	65% (.989)	65% (.944)	65%	65%
14	75% (.999)	75% (.999)	75% (.994)	75%	75%
15	65% (.982)	65% (.981)	65% (.947)	65%	65%
16	75% (.994)	75% (.986)	75% (.952)	75%	75%
17	(-)	(-)	55% (.995)	55%	55%

18	(-)	55% (.971)	65% (.974)	65%	65%
19	75% (1)	75% (.999)	75% (.991)	75%	75%
20	65% (.969)	65% (.964)	65% (.932)	65%	65%
21	(-)	(-)	(-)	45%	45%
22	55% (.965)	55% (.983)	75% (.999)	55%	55%
23	(-)	(-)	45% (.978)	55%	55%
24	65% (.952)	65% (.963)	65% (.964)	65%	65%
25	65% (.969)	65% (.948)	75% (.999)	65%	65%
26	75% (.963)	75% (.947)	75% (.911)	75%	75%
27	(-)	(-)	55% (.996)	55%	55%
28	45% (.969)	45% (.992)	55% (.997)	55%	55%
29	75% (.942)	75% (.922)	75% (.893)	75%	75%
30	(-)	65% (.961)	65% (.97)	65%	65%
31	(-)	65% (.989)	75% (.999)	65%	65%
32	75% (.998)	75% (1)	75% (.999)	65%	75%
33	65% (.972)	65% (.982)	65% (.983)	65%	65%
34	(-)	45% (.962)	55% (.967)	65%	65%
Mean (SD)	68.33% (8.68)	66.38% (9.53)	68.64% (8.59)	64.41% (8.51)	65.59% (8.86)

Approximations of occlusion threshold (OT) are presented through two models: (a) 'linear vs. non-linear', and (b) 'percentage increased by pairs'. In the (a) approximation figures represent the intensity (percentage) at which the linear trend adjustment for the endurance time was lost by comparing the explanatory power of linear versus nonlinear trend distributions (i.e. a1 = potential, a2 = exponential, and a3 = logarithmic distributions). R^2 values, which corresponds to the first best fit obtained with respect to the linear fit starting at the highest intensity, are showed in brackets. (-) = no adjustment was better than the linear one. In a 26.4%, 14.7% and 2.9% of the cases it was not possible to adjust the OT with potential, exponential or logarithmic distributions respectively. In the (b) approximation figures represent the intensity immediately higher than the one where the ≥50% endurance time increase was observed between each pair of closest intensities (also starting at the highest intensity). Model (b) gave data for 100% of the participants. The OT calculated with models (a) and (b) did not always agree (58.8%, 67.6% and 61.7% of agreement for a1), a2) and a3) respectively). (*)= OT value used to develop the statistics regarding ability level, climbing experience and MAW_5 on this study, which was determined as the percentage that presented more concordance between the models used, or as the highest percentage if there were no matches. The ICC among all of the approximations was of ICC = .92 (95% CI = .85 –0.96).