

Performance Determining Factors in Indoor Climbing: One of The Contributions of Professor Maria Augusta Kiss to The Development of Sports Sciences in Brazil



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ABSTRACT

During over thirty years, Doctor Maria Augusta Peduti Dal' Molin Kiss has contributed effectively to the sports sciences development in Brazil. After this long period dedicated to the consolidation of knowledge and human resources in this area, another life cycle is fully completed in her career. Thus, the objective of this review is to honor Doctor Kiss in the occasion of her retirement, while showing the main anthropometric and physiological determinants of *indoor* climbing performance. Several findings indicate that body mass, body fat percentage, handgrip force, aerobic and alactic anaerobic metabolism, and movement economy are crucial to success in this sport. We feel privileged to have been involved in her brilliant carrier and to honor Doctor Kiss with this review.

Keywords: oxygen uptake, blood lactate, handgrip, body composition.

INTRODUCTION

Sport climbing came about in the beginning of the 1980 decade as a means of physical and technical training for high mountain climbers. Nevertheless, as the years passed by, it gained its own followers, especially due to its greater accessibility when compared to alps climbing. During the route ascents of the sport climbing, the athletes should reach the highest point of a given route with no use of artificial means. According to the International Federation of Sport Climbing, there are currently over 45 countries which regularly participate in indoor competitions held in continental and world-wide coverage. Consequently, many investigations have been carried out with the aim to assess the morphofunctional variables responsible for the success of these athletes. Thus, the aim of the present review article was to approach the main determinant factors of performance in sport indoor climbing.

The majority of the investigations described in this study is part of one of the advisory program of Doctor Augusta Peduti Dal' Molin Kiss⁽¹⁾, who will be mentioned with plenty of respect in this text as Professor Kiss. The "Kiss School of Guidelines" started in the year of 1981 and graduated until the present moment 27 Masters and 12 Doctors who currently play important roles in the national academic scenario. At this time, another cycle of her career has come to an end, which resulted in this review work in honor to her retirement. Nevertheless, the choice of the topic for this article was not an easy task, since Professor Kiss acted in many fields correlated to sports performance. She advised important research in continuous and intermittent sports from bioenergetic, neuromotor, morphological and of the autonomic system approaches. Certainly, this broadness makes a succinct and objective presentation of her contributions in a single article difficult. The choice for sport climbing as aim for the present review was not only due to our familiarity with the topic⁽¹⁻³⁾, but also due to a lack of articles on this sport. Therefore, in addition to honor Professor Kiss, we tried to fill in an existing scientific gap in the national literature on sport climbing. In this review article the relations between morphological and functional variables and performance in climbing will be presented.

Morphological and handgrip strength characteristics of sport climbers

Among the many variables which interfere on performance of the practitioners of sport climbing, morphological adaptations and handgrip strength have called attention from some researchers⁽⁴⁻⁶⁾. In the study by Watts *et al.*⁽⁶⁾ it was observed that among the semifinalist and finalist athletes of a qualifying phase of the Indoor Sport Climbing World Cup, only the fat-free mass presented statistically significant difference between groups, with the finalists presenting lower values compared to the remaining ones.

Grant *et al.*⁽⁴⁾ did not observe statistically significant differences in stature, total body mass (TBM), body fat percentage (%BF), arm and leg length among the elite climbers, recreational and control groups, respectively either. However, a relevant fact which can have interfered on these findings is the way the elite group was structured, since the authors have adopted wide performance amplitude as inclusion criterion. In other words, subjects who had performed easy and difficult route ascents participated in the elite group, which may have resulted in inclusion of subjects with intermediate level.

Contrary to the articles mentioned above, a study advised by Professor Kiss⁽²⁾ indicated the presence of differences in body composition among male climbers, elite as well as recreational, with the elite group presenting lower values of %BF. Differently from the paper by Grant *et al.*⁽⁴⁾, the subjects were placed either in the elite or recreational group from their respective levels of aptitude in Sport climbing, which provided higher homogeneity level among subjects within each group. These results indicate that the TBM and %BF may be important to performance of sport climbers. Theoretically, low value of these variables would be able to attenuate the overload imposed to the muscles exercised during the ascents.

Concerning the maximal handgrip strength (MHS), the responses presented in the literature on its contribution to performance of climbers are not conclusive yet. For instance, in the study by Watts *et al.*⁽⁶⁾ previously mentioned, the authors did not verify significant differences of MHS between the semifinalists and finalists of a qualifying of the Sport Climbing World Cup. In another subsequent study, Ferguson and Brown⁽⁷⁾ observed that the MHS of a group of elite climbers did not differ either from a sedentary group. However, in this investigation the TBM of the subjects was not measured, which made the assessment of the MHS in relation to the TBM impossible. Due to the need to maintain the TBM during the ascents, the MHS related to the TBM seems to be the most suitable way to express it^(5,6).

In the work by Grant *et al.*⁽⁵⁾ it was found that elite female climbers presented higher values of MHS than recreational and control climbers, corroborating that this variable is important to sport climbing practice. Additionally, the study by Grant *et al.*⁽⁵⁾ corroborates the hypothesis of correlation between MHS and performance in sport climbing, since the elite climbers presented significantly higher values of MHS, when compared to the recreational climbers and the control group. Corroborating the results mentioned above, Quaine *et al.*⁽⁸⁾ verified that, besides the MHS, the elite climbers were able to perform intermittent contractions (five seconds of contraction by five of rest at 80% MHS) for longer than the beginning climbers.

To sum it up, when homogeneous subgroups, but with different performance levels are compared, the elite climbers tend to present lower values than the %BF and TBM compared to intermediate climbers and the control group; however, they commonly do not differ concerning other anthropometric variables. Despite some divergence presented, the MHS tends to be an important variable for performance of the climbing athletes, being much more expressed related to the TBM.

Physiological Responses during Sport Climbing

The first studies which used sport climbing in their experimental models had as aim to assess the responses of some functional variables, without necessarily associating them to performance in this modality⁽⁹⁾. Among these, we can mention the work by Jannot *et*

al.⁽¹⁰⁾, in which it was observed that recreational climbers presented lower values of heart rate (HR) before and during ascents of two routes of indoor sport climbing with different difficulty levels, when compared to subjects who have not had any experience in this sport yet. The authors also noted that the subjective perceived exertion differed between groups after the tasks mentioned above, indicating hence that recreational climbers perceived exertion with lower magnitude than the other group. The highest values of HR in the group which did not have experience were justified by the authors to the high anxiety levels informally described by the subjects. Additionally, the lowest HR values and the lowest perceived exertion presented by the recreational group during the climbing routes were indirectly related to the higher technical ability of this group.

Other investigations, used ergometers specific to sport climbing with the aim to observe the values of maximal oxygen uptake ($\dot{V}O_{2max}$) in activities which require different proportions of muscle mass. Ballor *et al.*⁽¹¹⁾ compared the $\dot{V}O_{2max}$ values of physically active subjects through a test performed on treadmill, ergometric bicycle and an ergometer simulating ascents (VersaClimb[®] 2000), obtaining values of $65.5 \pm 2.8 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, $61.4 \pm 2.6 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ and $61.0 \pm 2.6 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, respectively. These results suggested that the ergometer used to simulate the ascents demanded values similar to the $\dot{V}O_{2max}$ when compared to the ones of the ergometric bicycle, but lower in approximately 6 to 7% than the one observed on the treadmill. Moreover, the existence of linearity between oxygen uptake ($\dot{V}O_2$) and HR was suggested concerning the work increase during sport climbing. However, the first studies which actually observed the correlations between physiological variables and performance in sport climbing came about from the middle of the 1990 decade (table 1).

Billat *et al.*⁽¹²⁾ assessed the participation of energy metabolism in elite climbers during the route ascents of indoor sport climbing. In this experiment, the subjects were submitted to maximal ergospirometric tests performed on treadmill and with arm extension and flexion (pulling test). Subsequently, they performed ascent of two routes of indoor sport climbing of high difficulty. During these routes, the time partials at which the athletes performed dynamic and isometric muscle actions with upper limbs, the total ascent time, the HR, the $\dot{V}O_2$ as well as lactate blood concentrations ([La]) during recovery (three minutes) were measured. The HR

Table 1. Responses of the physiological variables of climbers in laboratory tests and during the route ascents of sport climbing.

Study	$\dot{V}O_2$ peak on sport climbing (ml·kg ⁻¹ ·min ⁻¹)	Ergometer	% of $\dot{V}O_{2max}$ used on sport climbing	[La] after sport climbing (mM)
Billat <i>et al.</i>	R ₁ = 24.9 ± 1.2 R ₂ = 20.6 ± 0.9	Treadmill	R1 = 46 ± 4.9 R2 = 37 ± 5.4	R1 = 5.7 ± 0.9 R2 = 4.3 ± 0.8
Booth <i>et al.</i> (1999)	F = 32.5 ± 2.0	Specific to climbing	75	
Sheel <i>et al.</i> (2003)	F = 20.1 ± 0.3 D = 22.7 ± 3.7*	Ergometric bicycle	F = 45.3 D = 51.2	N.M.
Mermier <i>et al.</i> (1997)	F = 20.7 ± 8.1 M = 21.9 ± 5.3 D = 24.9 ± 4.9	N.U.	N.U.	F = 1.6 ± 0.6 M = 2.4 ± 0.6* D = 3.2 ± 0.9* ¹

*Statistically higher than the easy route; ¹ = statistically higher than the moderate route; R₁ and R₂ were difficult routes, but with the same level of difficulty; N.M. = non-measured; N.U. = non-used; E = easy route; M = moderate route; D = difficult route; % of $\dot{V}O_{2max}$ = percentage value demanded in climbing.

responses represented 85.8% and 93.0% for route 1 (R1) and 77% and 84% for route 2 (R2), of the maximal values obtained in the tests performed on treadmill and arm extension and flexion, respectively. The total ascent time was similar between routes, but the time of dynamic muscle action was higher on R1. Generally speaking, the $\dot{V}O_2$ responses to R1 and R2 were around 42% of the data obtained on treadmill and 104% of what was observed in the arm extension and flexion test. Based on these data, Billat *et al.*⁽¹²⁾ concluded that, the oxidative metabolism develops a secondary role in indoor sport climbing, since during the ascents low fraction of $\dot{V}O_{2max}$ obtained on treadmill is required.

Sheel *et al.*⁽¹³⁾ verified the contribution of the oxidative system from the comparison of laboratory data with field data. Therefore, the sport climbers were submitted to the following situations: a) during a maximal ergospirometric test performed in cyclo-ergometer for lower limbs; b) in ascent of an easy route; c) in ascent of a difficult route. Interestingly enough, the choice of the route difficulty was in relation to the highest level climbed by the subjects, adopting two or three levels below maximal for the difficult and easy routes, respectively. Continuous measurements of HR and $\dot{V}O_2$ were obtained during the ascents. Although the total time of ascension is not different between routes, the HR was higher in the difficult route when compared to the easy one. The $\dot{V}O_2$ presented the same behavior in the different situations. However, when these variables were assessed in percentage concerning the maximal values obtained in the cycle ergometer, the responses obtained in the respective situations were out of proportion, with the $\dot{V}O_2$ presenting lower increase (difficult route = 51.2%; easy route = 45.3%) than the HR (difficult route = 89.6%; easy route = 66.9%). Based on these results, the authors confirmed the absence of linearity between the $\dot{V}O_2$ and HR in climbing, regardless of the level of difficulty of the routes. The higher $\dot{V}O_2$ in the difficult routes compared to the easy ones suggests that during indoor sport climbing practice, there is increase of the contribution from the oxidative system due to the increase of difficulty.

Booth *et al.*⁽¹⁴⁾ adopted the same strategy when comparing data obtained in laboratory tests with the ones obtained during an easy route of rock sport climbing. Initially, a maximal ergospirometric test with ergometer specific to sport climbing was applied, during which the highest value of $\dot{V}O_2$ ($\dot{V}O_{2peak-climbing}$), of HR ($HR_{peak-climbing}$) and of [La] after the test [$La_{peak-climbing}$] in elite climbers were measured. In a separate occasion, the same variables were measured during and immediately after route ascension. Due to the high portion of $\dot{V}O_{2peak-climbing}$ required during route ascension ($\cong 75\%$), it was concluded that the oxidative metabolism is a priority in energy transfer during rock sport climbing practice. According to these authors, the divergence with the results in the study by Billat *et al.*⁽¹²⁾ is due to the different methods used for measurement of $\dot{V}O_{2max}$, since it was speculated that higher amount of muscle mass is used in the test performed in the ergometer specific to climbing, when compared to the arm flexion and extension test used by Billat *et al.*⁽¹²⁾. Nevertheless, the muscle mass involved in these tests would be still lower than in the test performed on treadmill. In other words, the results of these studies are highly dependent on the cycle ergometer used to obtain the $\dot{V}O_{2max}$.

Interestingly, the first study which determined the bioen-

ergetic contributions in climbing without the need of comparison with laboratory tests was carried out under Professor Kiss' advisory. Bertuzzi *et al.*⁽³⁾, measured during climbing with routes with different levels of difficulty, the oxygen uptake, the equivalent of oxygen to lactate and the excess post-exercise oxygen consumption (EPOC) to establish the contributions of the aerobic, anaerobic and lactic metabolisms, respectively. In this investigation, it was demonstrated that both energetic systems, aerobic and alactic (ATP-CP) are crucial to success in this sport. Supposedly, the ATP-CP system is important to more difficult movements performed during climbing, while the aerobic system would contribute both to energy supply during route ascension and to recovery of the ATP-CP system during the short pauses performed by the climbers. Moreover, it has also been demonstrated in this study that the elite climbers had lower energy cost during ascension of an easy route when compared to recreational climbers. Similarly to what suggested to running and cycling, these results indicate that the movement economy is an important variable to performance of climbers. Probably, this movement economy response is due to the differences of motor control presented by these groups of climbers.

Facing the other methodology for determination of which components effectively contribute to the success in this sport, Mermier *et al.*⁽¹⁵⁾ used a multiple regression model to observe the level of correlation of the morphological and functional variables with performance in two indoor sport climbing routes. Forty-four subjects (24 men and 20 women) were submitted to laboratory tests, and later to two routes which started relatively easy and ended with high difficulty. The variables which best explained performance in climbing were muscle strength of the knee and shoulder flexor and extensor groups, handgrip strength, upper and lower limbs power, handgrip endurance at 50% of MHS, the %BF and higher level of ability in climbing, explaining for about 39% of the total variance of the model. Contrary to the popular belief among climbers and trainers that anthropometric variables (for instance, stature) play a more important role than the functional ones, in climbing performance these results indicate that both morphological and functional variables are important to indoor climbing. However, it is worth mentioning that the sample of this study was excessively heterogeneous and that the correlation between the number of subjects and the amount of investigated variables may have harmed the multiple regression analysis used in this study.

In one of the few investigations with physical training, Olosa *et al.*⁽¹⁶⁾ observed the behavior of mean power generated in four repetitions at 50%, 60%, 70% and 80% of a maximum repetition, in an exercise which predominantly used the dorsal muscle groups. Five elite climbers participated in this experiment during a period of six months of physical preparation for the main competitions, totalizing six assessments during the study. Significant differences of mean power generated between the different moments were not when these were assessed in an absolute way. However, when the power generated with external load which was closest to the TBM of each subject was assessed, a variation during the training program with a tendency to increase in the end (figure 1) was observed. These results indirectly corroborate the importance of muscle power of the upper limbs in performance of indoor sport climbing as well as the need of calculating the functional vari-

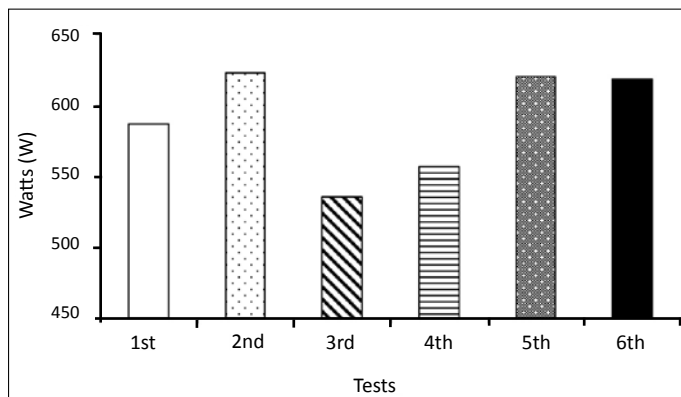


Figure 1. Graphic representation of the values of power generated by subject 4 during the training period with external load of 50% of a maximal repetition. Statistical treatment was not applied (adapted from Olase *et al.*, 2003).

ables concerned with the TBM, since this morphological component directly influences on the specific adaptations of this sport.

Finally, there are also further studies guided by Professor Kiss about sport climbing which are under analysis for scientific journals at this moment. In the first study, seven elite climbers of national level, seven recreational climbers and seven control subjects were submitted to a maximal progressive test in upper limbs for aerobic aptitude variables (Pires *et al.*, unpublished data). Results of this study suggest that climbers present higher level of aerobic aptitude in upper limbs when compared to control subjects, since the elite climbers presented higher exhaustion time, $\dot{V}O_{2max}$ and ventilatory threshold (first threshold) than the control subjects. A second study proposed a specific test to climbing, named Fit-climbing test (Bertuzzi *et al.*, unpublished data). The aim was to validate a field test of easy application for this sport. The data of this work are very promising, since the *Fit-climbing*

test was able to discriminate athletes with different performance levels due to the influence of movement economy in climbing. Probably, this study will bring the possibility of using a new field test for sport climbing.

FINAL CONSIDERATIONS

Summing up, several results indicate that body mass, body fat percentage, handgrip strength, aerobic and alactic anaerobic metabolism, as well as movement saving, are crucial to success in sport climbing. It is worth mentioning that a considerable part of these findings was obtained in studies guided by Professor Kiss. Her participation in different sub areas of sports sciences played an important historic role in which defines the cultural context in which the biological study of sport performance is currently carried out, especially by her followers. It is our privilege to have appreciated and participated in this brilliant path of Professor Kiss, and honoring her with this work review.

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