Strength training and endurance performance: a descriptive review

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ABSTRACT
Objective: Relate strength and power training with Endurance performance; Describe the characteristics and conditions of strength and power training related to Endurance performance; Identify the characteristics of strength and power training, as well as their characteristic elements related to Endurance performance; Identify the determinants of Endurance performance. Methods: Descriptive literature review. Results: Strength training induces neural adaptations such as increased maximal strength, increased strength development rate, improved muscle stretching-shortening cycle, and morphological adaptations such as increased tendon stiffness, which are related to Endurance performance. Conclusion: Strength training with low volume and high percentage of 1RM and plyometric training has a positive relationship with Endurance performance, being highly recommended to include these trainings in the routine of practitioners of these modalities.

Keywords: Endurance, Strenght, Power, Performance.

1 INTRODUCTION

The physical performance capacity of the human being can be improved with continuous training and when this training causes adaptations that condition him to maintain a specific limit of the level of isometric strength or power of movements, it is called *Endurance*[1] (endurance) (ALLEN, LAMB AND WESTERBLAD, 2008) (BROOKS, 2011).

Performance in *Endurance* modalities (swimming, cycling and running) is directly determined by three factors well identified in the literature: Maximum Oxygen Consumption; The Oxygen Utilization Fraction and Neural Aspects (Economy of Motion[2]) (LARSEN AND SHEEL, 2015).

However, the influence of strength and power training on *Endurance* performance is still not fully understood by practitioners and training professionals directly linked to the care of these athletes and practitioners. This fact raises doubts that materialize mainly in the belief in the existence of the so

[1] In this work we have chosen to use the *Endurance* nomenclature in order to standardize the treatment given by the scientific literature.
[2] The term "running economy," "swimming economy," and "cycling economy" can be understood more broadly as movement economy.

called "concurrent training", situation in which strength and power training adaptations would compete with *Endurance training* adaptations when they are carried out in a combined way in a periodization, jeopardizing the performance in both (FYFE, BISHOP E SEPTO, 2014).

Considering these aspects, this work proposes to answer the following question: What is the relevance of strength and power training for the performance of *Endurance* athletes?

Answering this question adequately can contribute to scientifically support the work of professionals directly linked to the study, evaluation, and prescription of *Endurance* training.

In addition, a greater offer of productions in Portuguese language and of free access can contribute to the professionals who are still in training, subsidizing the training curricula for a field of action in clear expansion and with great academic-scientific shortages.

1.2 OBJECTIVES

GENERAL OBJECTIVE: To relate strength and power training to *Endurance* performance.

SPECIFIC OBJECTIVES:

To describe the characteristics and conditions of strength and power training related to *Endurance* performance

Identify the characteristics of strength and power training, as well as its characteristic elements related to *Endurance* performance;

Identify the determinants of *Endurance* performance.

1.3 JUSTIFICATION

The study is justified by two important aspects. First, there is the academic relevance, evidenced by the low academic scientific production on the subject available in Portuguese, which can hinder and compromise the access and "consumption" of these productions by professionals in the area. Reinforcing this aspect, it is identified that the products and services related to the universe of *Endurance* (swimming, cycling and running), which are in full expansion in the world and in Brazil, requiring professionals increasingly prepared to act with the specific demands of the field, whether these professionals are already trained or still in the process of training.

This massification of the practice also contributes to the increasingly consolidated formation of individuals with excellent performance in the sport, and this is yet another factor that demands specific, coherent, and intentionally organized professional intervention in order to obtain performance improvements and an increase in the competitive capacity of amateur and professional athletes.

Added to this aspect is the social relevance, directly linked to the ethical dimension of offering the consumer a product that is increasingly consistent with their desires and needs and supported by satisfactory scientific evidence, protecting the individual from situations of risk that they may be subjected to when they contract low quality services, outside of specific professional practice, or that are not scientifically supported.

2 METHODS

This study is characterized by a bibliographic review of the descriptive type, for which, we took the hermeneutic as the resource that enables the researcher to distance himself from the object of study, materializing in the text and in its reviews and interpretations the scientific conduct necessary for the investigative path (RICOUER, 1990); (MELO, 2016).

The phenomenology-hermeneutics approach in sciences, understands that the act of interpreting, the world, the phenomena or a text, are not neutral or even free of tensions, which permanently act between objectivity/subjectivity or understanding/explanation of a phenomenon (MELO, 2011).

The purpose here is not to exhaust the discussions on the subject, but to identify points of confluence in the literature that allow pointing paths for the intervention of the education professional who works or intends to work with the assistance of Endurance athletes, especially street running (GIL, 2002).

For the search on the *Pubmed* portal, the following descriptors were used: "'*strength training*' *and endurance*". There was no concern in making any temporal cut over the texts, but selecting those that were deemed more relevant to understand and explain the proposed problem.

All these texts were downloaded and cataloged using the *software Mendeley Desktop*[3] (V. 1.9.1). From the Capes Periodical Portal, the articles were read (title, abstract and keywords) and once selected, their DOI - *Digital Object Identifier,* was copied and inserted into the *software* for automatic *download* and archiving in their own folder. Later, in the Results and Discussion item, the evidence found is presented. The writing was conducted in order to describe and analyze the possible relations of strength and power training as Endurance performance, as well as the conditions in which these training should occur to achieve performance improvement.

The reading of the texts, considering they were mostly in English, was conducted, when necessary, with the help of an online translator (Google Translator). The availability of most of the texts was restricted, with payment of fees that could make the research unfeasible (ranging from U$25.00 to U$50.00), which was circumvented thanks to the link with the Federal University of Espírito Santo and the use of institutional e-mail for free access to the texts.

[3] Mendeley is a free reference manager (Elsevier Copyright) for storing, organizing, annotating, sharing and citing references and research data.

3 RESULTS AND DISCUSSION

In this chapter, as described in the methods, it is initially made a conceptual understanding about strength and power training and *endurance* training, as well as their characteristics and conditions of realization. Afterwards, the intervening factors in *Endurance* performance and the possible relations between strength and power training and *Endurance* performance will be described.

3.1 STRENGTH AND POWER TRAINING: CONCEPTS AND APPROXIMATIONS

The expression Force and Power implies a preexisting relationship between these quantities. In physics, the magnitude of this relationship is expressed, in a simplified way, by the formula: $P = F.V$, where P = Power; F = Force and V = Velocity. In this sense, it is not possible to talk about power without taking into account the force magnitude, nor the speed magnitude, or even to consider improving the power without improving the levels of force or speed. Power is, therefore, a product of the relationship between strength and speed.

In order to understand this relationship and its relevance to sports performance, it will be necessary to fulfill some study steps. In regards to muscle mechanics, it will be necessary to approach some relevant concepts, including: I - The Force-Time relationship; II - The Force-Speed relationship; III - Optimal training load (CORMIE, MCGUIGAN AND NEWTON, 2011).

I - The Force-Time Relationship

Sports performance requires, in the most diverse situations, that force be applied in the shortest possible time, being crucial to obtain the result and, therefore, to determine the winner.

The means to evaluate neuromuscular performance are varied, from 1 RM tests; Vertical and Horizontal Jumps (SJ - *Squat Jump* and CMJ - *Counter Movement Jump*); *Sprints* Performance (acceleration and Maximum Speed); Maximum Voluntary Contraction (MVC) Strength; Rate of Strength Development and Muscle Activation by electromyography, although the latter are methods that require more technological resources (IDE *et al.,* 2014).

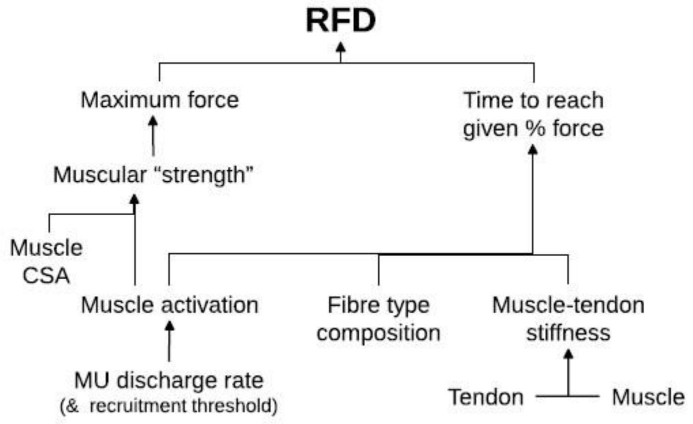
Higher Maximum Voluntary Contraction Force (Maximal Force and Peak Force) and Higher Rate of Force Development are especially relevant for sports performance, as they represent greater force production capacity and a greater ability to produce force faster (IDE *et al.,* 2014).

When comparing these two variables, the Rate of Strength Development also stands out for: a) a greater relationship with sport performance and functionality of daily tasks; b) greater sensitivity to detect acute and chronic changes in the functionality of the neuromuscular system and c) for being potentially controlled by several physiological mechanisms (MAFFIULETTI *et al.*, 2016).

Interventions based on strength training have proven effective for the improvement of the Rate of Strength Development, mainly due to the frequency of the firing of action potentials for muscle contraction, i.e. an improvement in the functionality of the neuromuscular system (CUTSEM VAN, DUCHATEAU AND HAINAUT, 1998). Undoubtedly, this improvement is determinant not only for sports performance but also for the maintenance of functionality throughout life, especially for the elderly population. (BARRY, WARMAN E CARSON, 2005).

A breakdown of the mechanisms that lead to an increase in the Rate of Strength Development can be found in the diagram below.

Image 1 - Mechanisms that influence Rate of Force Development (RFD).



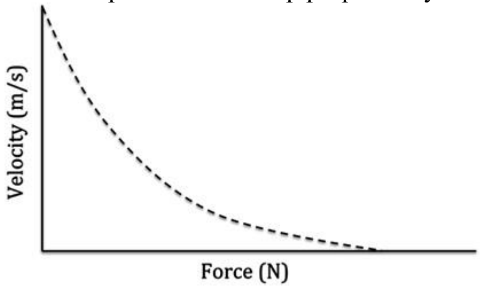
Source: (MAFFIULETTI *et al.*, 2016, P. 1104).

As depicted, Rate of Force Development (RFD) is influenced by numerous mechanisms within the neuromuscular system, and can be influenced by both maximum force (dependent on the firing rate of action potentials, muscle activation, and muscle cross-sectional area) and the time to reach a certain percentage of force (dependent on muscle fiber type and musculotendinous stiffness.

II - The Force-Speed Relationship

An explanation of the relationship between Force and Speed was first proposed by (Hill, 1938). In this work, which sought to understand the loss of heat during muscle contraction, it was identified that there is a relationship between the variables Force and Velocity, which when exposed in the Cartesian plane, can be represented by a hyperbola as in the image below:

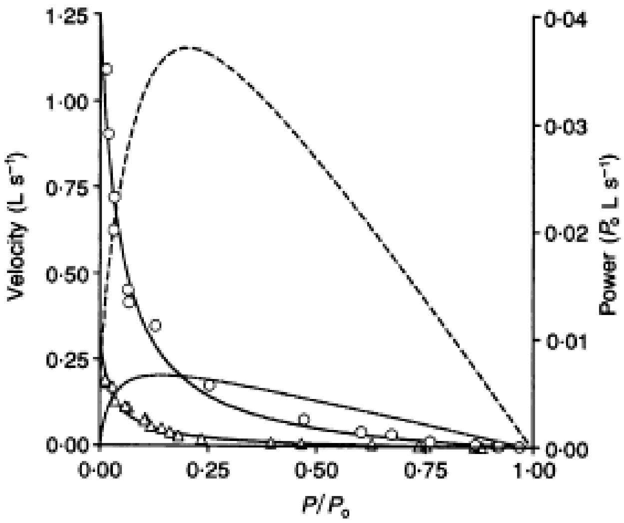
Chart 1 - Force-Speed Relationship proposed by Hill (1938)



(HAFF AND NINPHIUS, 2012, P. 03)

As exposed above, the greater the load applied to the muscle, the slower its contraction speed, and at the same time, the greater the contraction speed, the lower the load it can sustain. Thus, we could speak of an optimal load for strength and power training, which demands an understanding of the representation of the Strength-Speed-Power relation.

Graph 2 - Force-Speed-Power Relationship



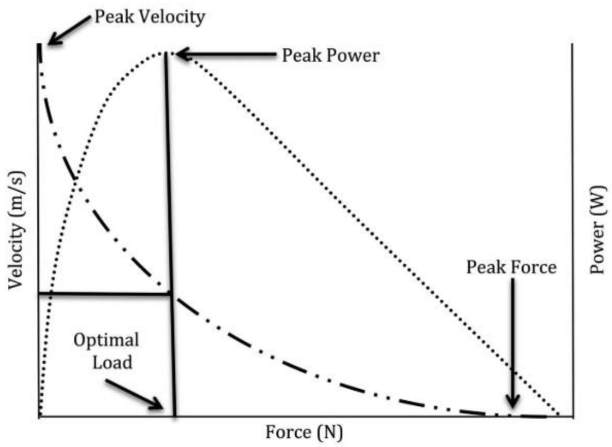
(BOTTINELLI ET AL, 1995, P. 580)

In the graph above, there are the Force-Speed curves, represented by the lines in hyperbola and the Force-Speed-Power curves represented by the lines in parabola, and for both, we considered Type I and Type IIB fibers. These data reinforce that there is an optimal relationship between Strength-Speed-Power aiming at improving neuromuscular performance, which we could call at this moment "optimal training load".(BOTTINELLI ET AL., 1996).

III - Optimal load for Strength and Power training

Considering Hill's (1938) Force-Speed curves and the Force-Speed-Power curves and considering Power as the product of Force multiplied by Speed (P = F.V), optimal training load means organizing a Strength and Power training session at peak Power in relation to Force and Speed. This also means that this Peak Power is not exactly at peak Strength, nor is it exactly at peak Speed.

Graph 3 - Peak Strength-Speed-Power and Optimal Training Load



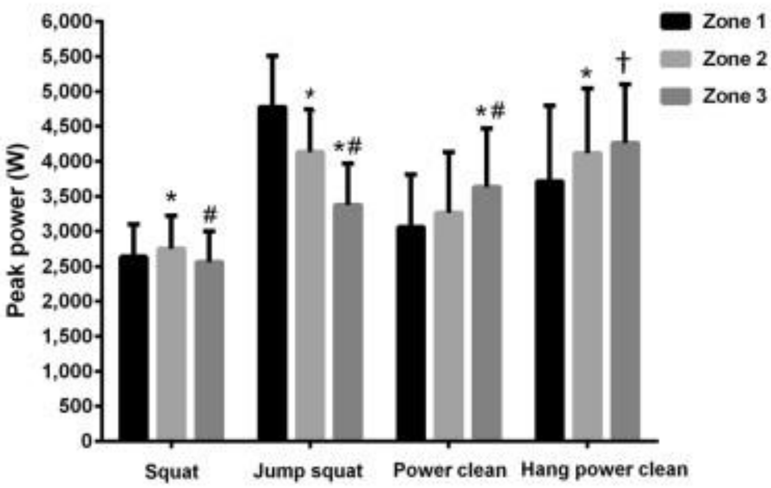
(HAFF and NINPHIUS, 2012, P. 4)

Represented above, *Peak Power* and *Optimal Load* are at points that are neither Peak *Force* nor Peak *Velocity*.

In a meta-analysis published in *Sports Medicine,* Soriano *et al.*, (2015) identified that this optimal load differs from one exercise to another and the percentages of 1 RM also differ from one exercise to another. The authors point out that each exercise offers the individual a unique biomechanical challenge, and it is understandable that the optimal load for power training exercises also changes. Therefore, we can talk about exercise-specific intensity zones for power training.

An overview of the intensity zones cited by the authors can be found in the figure below. As a parameter, the Intensity Zones were defined as follows: Zone 1 (light loads) from 0 to 30% of 1 RM; Zone 2 (moderate loads) >30% <70% of 1 RM and Zone 3 (high loads) ≥ 70% of 1 RM, for the following exercises: *Squat*, *Squat Jump*, *Power Clean* and *Hang Power Clean*.

Graph 4 - Optimal load for power training according to exercise (lower limbs)



(SORIANO ET AL, 2015, P. 1199)

The graph illustrates that for the *Squat* exercise the peak power output was found in Zone 2 >30% <70% of 1 RM, which did not occur in the *Squat Jump,* where the peak power output was found in Zone 1 from 0 to 30% of 1 RM. For the *Power Clean* and *Hang Power Clean* exercises, peak power output was found in Zone 3 ≥ 70% of 1 RM.

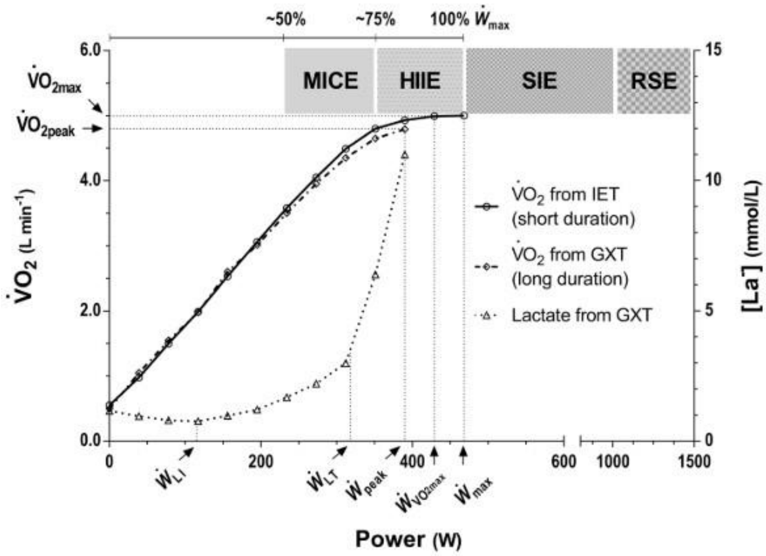
An important consideration made from this meta-analysis is that, in the same way that an optimal load was identified for the production of Power, the manipulation of training loads can lead to different adaptations depending on the intentions with which one undergoes it, so that different aspects of the Strength-Speed-Power curve can be trained from interventions from strength training (SORIANO ET AL, 2015), (SORIANO, SUCHOMEL , AND MARÍN, 2017).

3.2 *ENDURANCE* TRAINING: CONCEPTS AND APPROACHES

Endurance is understood as the ability to withstand fatigue, delaying exhaustion, maintaining a specific level of isometric strength or power of movements (ALLEN, LAMB AND WESTERBLAD, 2008) (BROOKS, 2012). Fatigue, in turn is understood as a progressive decline in performance while exhaustion is identified as the inability to continue an activity (ALLEN, LAMB AND WESTERBLAD, 2008).

Specifically regarding the increase of *Endurance*, the methods used to induce adaptations favorable to it are mainly around continuous methods (emphasis on training volume) and interval methods (emphasis on training intensity). These trainings and the way they can be organized and distributed have absolutely individual conditions, directly related to the individual's capacity. A description of how this distribution can take place can be found in the diagram below:

Graph 5 - Characterization of *Endurance* training methods (in cyclists).



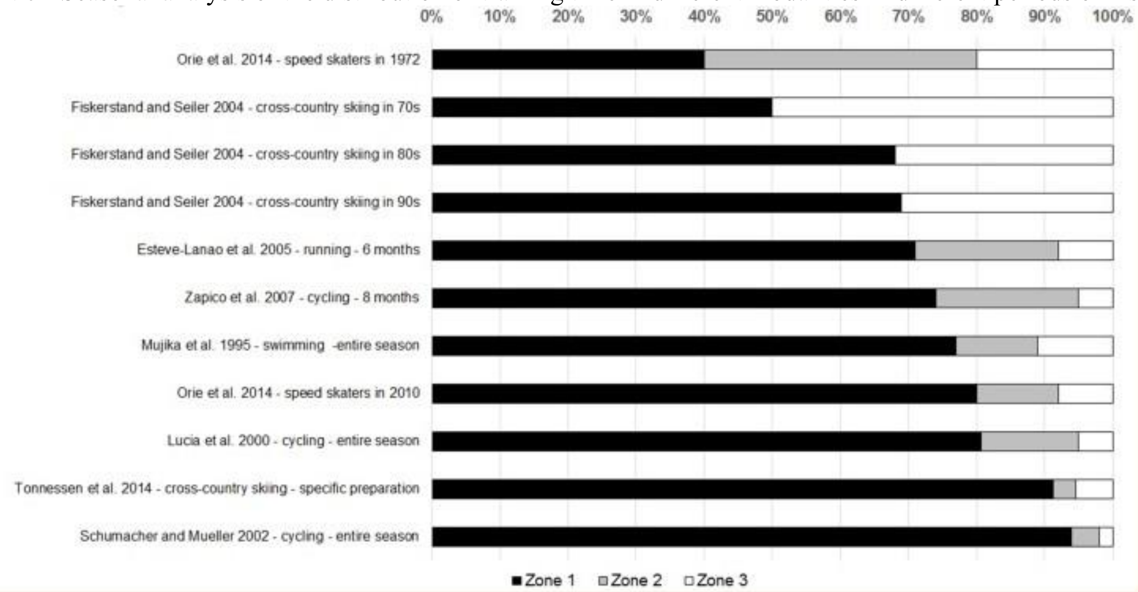
(GRANATA, JAMICK, AND BISHOP, 2018. P. 1545)

In cycling, an exercise or training at moderate intensity (*MICE*) should be performed around 50-75% of maximal power (Pmax), while exercises or high intensity interval training (*HIIE*), in addition to the short duration, should involve up to 100% of Pmax. In addition to these, there are also the so-called *sprinting* exercises or training (*SIE)* with duration greater than 10 seconds and intensity above 100% of Pmax. Finally, the maximum *sprints (all out)* with duration less than 10 seconds and maximum intensity (GRANATA, JAMICK, AND BISHOP, 2018. P. 1545).

Such exercises or workouts have relative potential to develop adaptations favorable to the increase of *Endurance*, however, their distribution and proportion by the so-called training zones will differ considerably. For training zones and their divisions, we will use the work of Lourenço *et al.*, (2007)(2007) , in which they describe three intensity zones: Zone 1 or low intensity, situated below and up to the ventilatory threshold; Zone 2 or moderate intensity, situated between the ventilatory threshold and the Respiratory Clearing Point; and finally Zone 3, with intensity above the Respiratory Clearing Point.

Regardless of the sport, the distribution of time spent in each training zone has changed significantly in recent decades. On this, Stöggl and Sperlich (2015) bring data that illustrate this statement.

Chart 6 - Seasonal analysis of the distribution of training time in different modalities in different periods of history

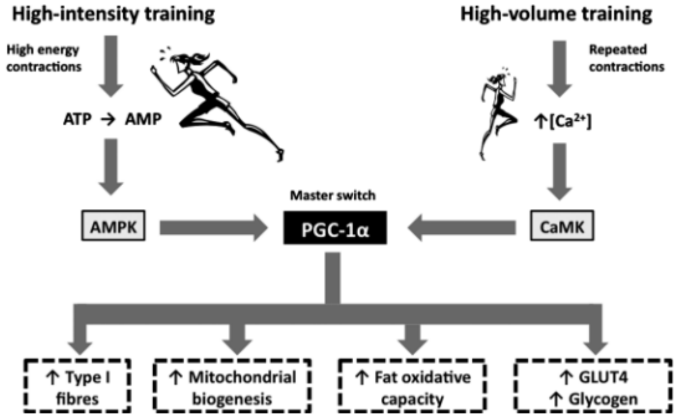


(STÖGGL SPERLICH, 2015, P. 6)

In the 1970s, 80s, and 90s, the understanding of the training process for *endurance* improvement involved spending much more time training at moderate and high intensity than today, where high-intensity training takes up a very small part of training. In a review of how Olympic champion athletes distributed their training Tønnessen *et al.* (2014) identified that these athletes trained up to 90% of the time in continuous sessions of low intensity, corresponding to zone 1.

Regarding how much each type of training in each zone can improve the adaptations that favor *Endurance,* it is safe to say that both Zone 1 training, Zone 2 and Zone 3 training, and consequently continuous or interval training are effective means.

Image 2 - Influence of volume-intensity on physiological adaptations to Endurance training



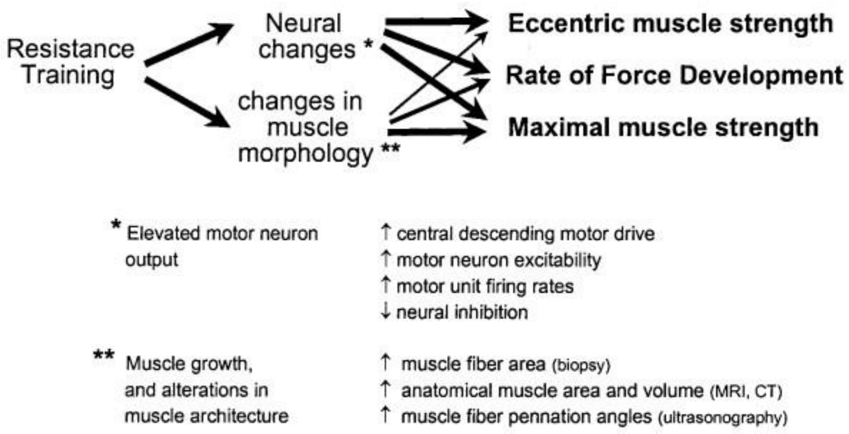
(LAURSEN, 2010, P. 7)

Both intensity-focused workouts (*HIIT* Interval Training) and volume-focused workouts (Continuous) are capable of triggering the signaling of adaptations favorable to the development of *Endurance.* The choice to spend more time in low-intensity workouts may be related to the reduction of neural and structural mechanical stress involved in high-intensity workouts.

3.3 STRENGTH AND POWER TRAINING FOR *ENDURANCE* SPORTS

Resistance training is capable of promoting neural and morphological adaptations that may be beneficial to sports performance. To better illustrate these adaptations, let's consider the representation below

Image 3 - Adaptations to Resistance Training



(AAGAARD, 2003, P. 66)

Resistance training is able to promote strong (thick arrows) neural adaptations in the human body, strongly influencing eccentric strength, rate of force development, and maximal muscular strength; as well as strong morphological adaptations with strong gains in maximal strength, moderate (middle arrows) gains in rate of force development, and little change (thinner arrows) in eccentric muscular strength (AAGAARD, 2003, P. 66).

In this sense, training organized in a way that enhances neural adaptations "will induce gains in muscle strength with no or only a small increase in muscle and body mass, which will benefit certain individuals and athletes" among which are *Endurance* athletes (AAGAARD, 2003, P. 66).

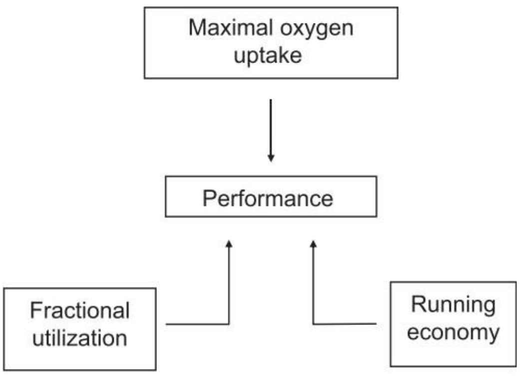
Training that results in improved neural function and muscle mass gains, on the other hand, "will benefit not only sprinter-type athletes, but also elderly individuals, as for the frail elderly this provides an effective means of improving daily physical function." (AAGAARD, 2003, P. 66).

In principle, it can be said that different training methods can positively influence the Power-Strength curves. That said, it is up to the professional of the training area to know not only the peculiarities of training methods as well as the demands required by different sports or individual physiological demands, providing the athlete or practitioner with a variation of stimuli capable of an adequate preparation, a condition identified in the literature as the Principle of Specificity of training (LIRA AND ANDRADE, 2016).

This specificity demands the consideration, by the coach, of issues such as "the predominant metabolic pathway, the muscle groups, the regime of muscular work and the modality of force used for the sport gesture" (LIRA AND ANDRADE, 2016, P. 477).

In this way, Larsen and Sheel (2015) identify that the performance of long-distance runners (for example) and consequently *Endurance* athletes in general is determined by three factors, as outlined below:

Image 4 - Performance Factors in Long Distance (*Endurance*) Runners



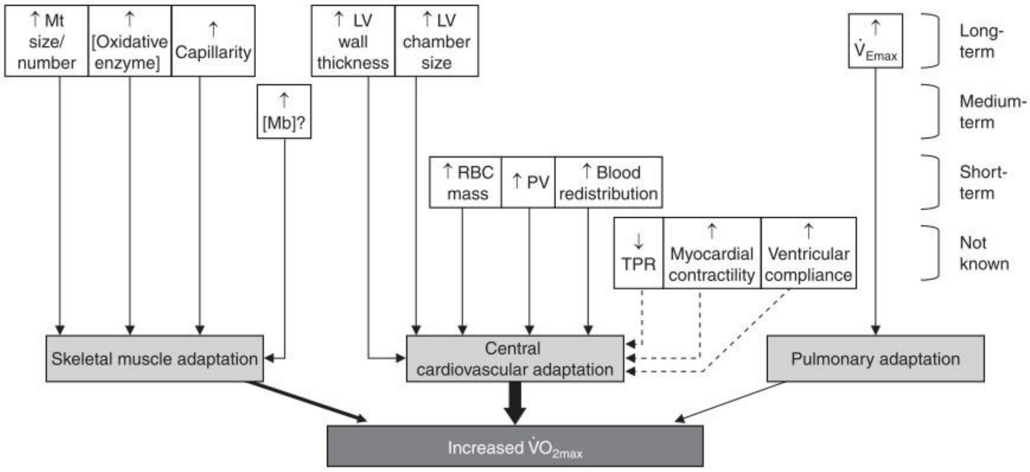
(LARSEN AND SHEEL, 2015, P. 111)

Maximal oxygen *uptake* has been directly linked to *Endurance* performance capacity in humans (HILL, LONG AND LUPTON, 1924). This correlation involves mechanisms related to both the transport and use of O2: "cardiac output, pulmonary gas exchange, hemoglobin, blood flow, muscle O2 extraction and resynthesis rate of aerobic ATP (LARSEN AND SHEEL, 2015, P. 111).

The average values for VO2max found in elite runners are around 70-85 mL/kg/min for men, and about 10% lower for women, which is mainly "due to a lower hemoglobin concentration and higher body fat levels" (SALTIN AND ASTRAND, 1967, P. 355-357).

There are several intervening factors in the improvement of VO2max. These factors can be described in the form of muscular, cardiovascular, and pulmonary adaptations, as shown below.

Image 5 - Determinant adaptations in the improvement of VO2max.



(MIDGLEY, MCNAUGHTON AND WILKINSON, 2006. P.125)

As mentioned above, improvements in VO2max are determined, not only by the obvious cardiovascular adaptations (increase in thickness and ventricular capacity - VL; increase in red blood cells - RBC; increase in plasmatic volume - PV; improvement in the capacity of blood redistribution; decrease in peripheral resistance - TPR; increase in myocardial contractile capacity and increase in ventricular compliance) and pulmonary (increase in minute ventilatory capacity - VEmax), as well as by adaptations in the skeletal muscle, identified as increased number and size of mitochondria (Mt size/ number), increased concentration of oxidative enzymes, increased capillarization, and increased concentration of myoglobin (Mb).

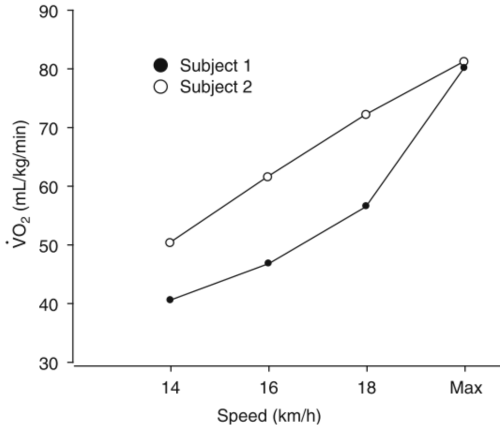
The *Fractional* Utilization of VO2max (*Fractional Utilization*) corresponds to the percentage of VO2max used for a given task (a 10,000-meter run, for example). Karlson et al (1968 apud Larsen and Sheel, 2015) identified 100% of VO2max being used in a 5,000-meter run and fractions of 97-98% of VO2max being used in 10,000-meter runs.

Corroborating with these statements, Billat *et al.*(2003) identified elite Kenyan runners with a VO2max utilization fraction capacity between 93-96%. High VO2max utilization fractions have also been reported among both men and women, whether Kenyan or European (TTAM ET AL., 2012)This ability was also found in Kenyan adolescents (LARSEN ET AL, 2005).

This ability to use a higher fraction of oxygen and which is directly related to superior performance in elite runners, is also related to some physiological factors already identified, such as muscle fiber type, concentration of oxidative enzymes in leg muscles, plasma lactate and ammonia response and capillarization (LARSEN AND SHEEL, 2015).

The *Running Economy* factor, on the other hand, is directly related to the VO2 cost necessary to sustain a given running speed (or cycling power), so that, "the lower the VO2 at a given submaximal running speed, the better the running economy" (LARSEN AND SHEEL, 2015, P. 114).

Graph 7 - Comparison of running economy between two 10 km runners

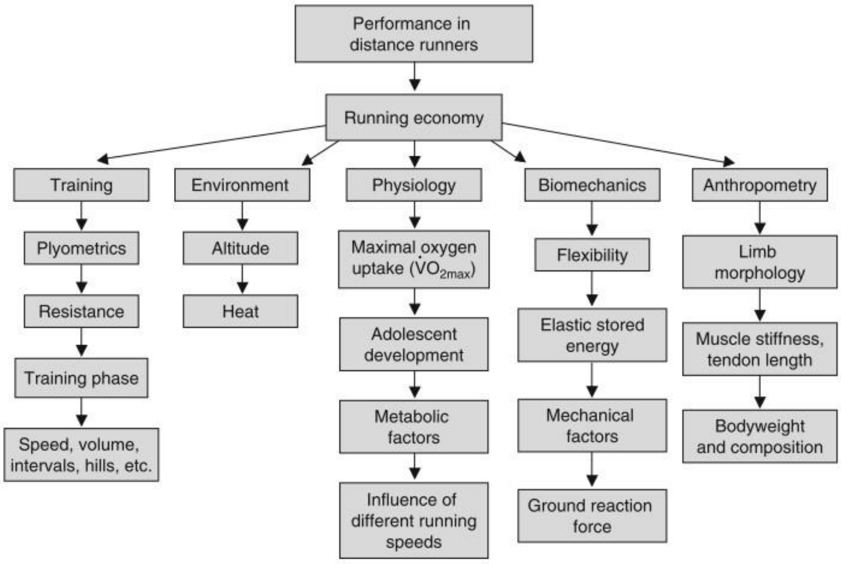


(SAUNDERS *ET AL.*, 2004. P. 467)

In the graph, it is possible to identify that subject 2 is able to sustain the same running speed (14, 16, and 18 km/h) at a lower VO2max cost, making it possible to say that he has a better running economy than subject 1. This data also suggests that subject 2 is able to sustain such speeds for a longer time than subject 1.

The intervening factors in running economy (economy of motion) are multiple and can be subdivided into different categories, such as: training, environmental, physiological, biomechanical, and anthropometric factors.

Image 6 - Factors affecting running economy (economy of motion)



(SAUNDERS ET AL., 2004. P. 470)

The table above highlights elements that can be directly influenced by strength training interventions, including training factors (*Plyometrics* and *Resistance*), biomechanical factors (*Elastic stored energy*, *Mechanical factors*, and *ground reaction*), and anthropometric factors (*muscle stiffness tendon length)*.

Moreover, the scheme contributes to the identification of the role of strength training in the training process of runners and other *Endurance* athletes, given its potentiality to induce neural and morphological adaptations, which are mostly directly related to the improvement of Endurance performance (AAGAARD, 2003).

This improvement can be identified in the work of (Spurrs, Murphy and Watsford, 2003)who used pliometry as a training method for amateur long distance runners. To prescribe the training, the authors used the following periodization:

Table 1 - 6-week periodization of pliometric training for runners

Week/session	Squat jump	Split scissor jump	Double leg bound	Alternate leg bound	Single leg forward hop	Depth jump	Double leg hurdle jump	Single leg hurdle hop	Total contacts
1/1	2×10	2×10	2×10						60
1/2	2×10	2×10	2×10						60
2/1	2×10	2×10	2×10	2×10					100
2/2	2×10	2×10	2×10	2×10					100
3/1		2×12	2×12	2×12	2×10				136
3/2		2×12	2×12	2×12	2×10				136
4/1			3×10	3×10	2×12	2×6			150
4/2			3×10	3×10	2×12	2×6			150
4/3			3×10	2×15	3×10	2×8			156
5/1				2×15		2×8	2×10	2×10	136
5/2				3×15		2×10	2×10	2×10	170
5/3				3×15		2×10	2×10	2×10	170
6/1					3×10	3×10	3×10	3×10	180
6/2					2×15	3×10	3×10	3×10	180
6/3					2×15	3×10	3×10	3×10	180

(SPURRS, MURPHY AND WATSFORD, 2003. P. 2)

The effects of this 6-week periodization have been tabulated in the following table:

Table 2 - Comparative data between the experimental group and control group from the pre-intervention and post-intervention period with pliometric training.

Variable	Experimental group ($n=8$)		Control group ($n=9$)	
	Pre	Post	Pre	Post
BM (kg)	74.74 (2.94)	74.80 (2.85)	70.24 (6.47)	70.05 (6.65)
CMJ (m)	0.38 (0.06)	0.43 (0.08)*	0.33 (0.04)	0.32 (0.06)
5BT (m)	10.46 (0.76)	11.28 (0.73)*	10.23 (0.55)	10.33 (0.58)
Th_{la} (mmol l^{-1})	4.26 (1.18)	4.03 (1.42)	3.73 (1.08)	4.10 (0.73)
RE (ml kg^{-1} min^{-1})				
12 km h^{-1}	26.05 (4.11)	24.30 (3.68)*	24.08 (2.87)	24.21 (3.37)
14 km h^{-1}	33.35 (5.15)	31.23 (4.27)*	30.62 (3.29)	30.46 (3.98)
16 km h^{-1}	41.96 (6.14)	40.22 (5.43)*	38.64 (4.95)	38.85 (5.33)
$\dot{V}O_{2max}$ (ml kg^{-1} min^{-1})	57.6 (7.7)	59.5 (8.1)	57.8 (5.4)	61.5 (5.9)
3-km time (min)	10.28 (1.26)	10.12 (1.15)*	9.36 (0.57)	9.31 (0.52)

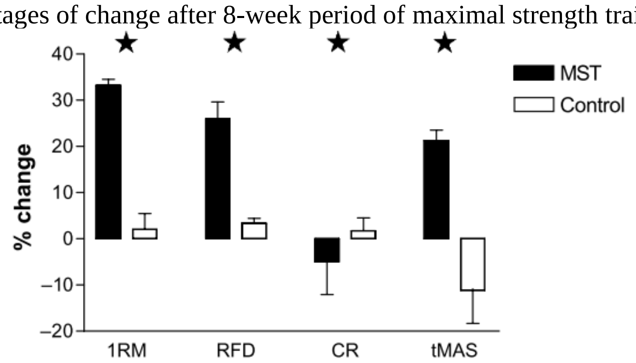
*Significant differences
(SPURRS, MURPHY AND WATSFORD, 2003. P. 4)

In the experimental group, after the 6-week training period, significant differences were found for: increased performance in vertical jump (CMJ); increased performance in horizontal jump (5BT quintuple jump); increased running economy at speeds of 12, 14 and 16 km/h and increased performance in the 3 km test. No significant difference was observed in the control group.

The increase in performance, especially in the factors that characterize the so-called running economy, are attributed to different adaptations: increase in tendon stiffness; improvement in the rate of force development and improvement in the muscle stretching and shortening cycle. Pliometry seems to be closely related to running performance, and is an effective means of improving performance, since running is simply characterized by a succession of jumps (SPURRS, MURPHY AND WATSFORD, 2003. P. 5 AND 6).

Similar positive increases in running economy have been reported by (STØREN *et al.*, 2008) when they subjected trained triathletes to an eight-week Maximum Strength Training protocol . [4]

Graph 7 - Percentages of change after 8-week period of maximal strength training in runners.



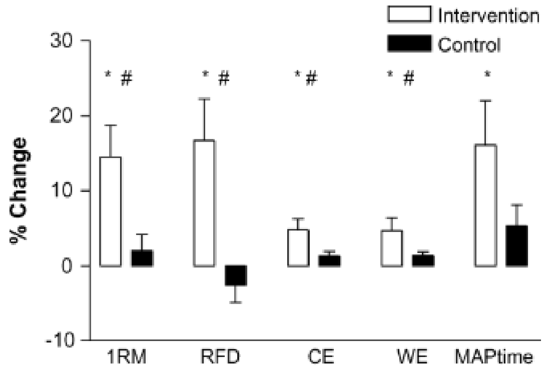
(STØREN *ET AL.*, 2008. P. 1090)

[4] Maximal strength training with high loads and few repetitions has been reported to be an effective means of promoting neural adaptations for increased strength at the expense of hypertrophy (HOFF ET AL, 2007).

The training protocol was able to produce significant changes in maximal strength (1 RM), rate of force development (RFD) and increase time to exhaustion (tMAS), in parallel the cost of running (CR) decreased, such changes occurred without significant change in body weight or VO2max. The study also identified a positive correlation between increased maximal strength and rate of force development and improved running economy, which can be explained by a greater ability of the central nervous system to coordinate the action of motoneurons, which has been called in the literature as improved "neural *drive"* (GANDEVIA, 2001).

Maximum strength training has also been reported to be effective for improving economy of motion in trained cyclists (*Cycling Economy*) (SUNDE ET AL., 2010). The reasons for this improvement do not seem to differ from those reported previously.

Graph 8 - Percentages of change after 8-week period of maximal strength training in cyclists.



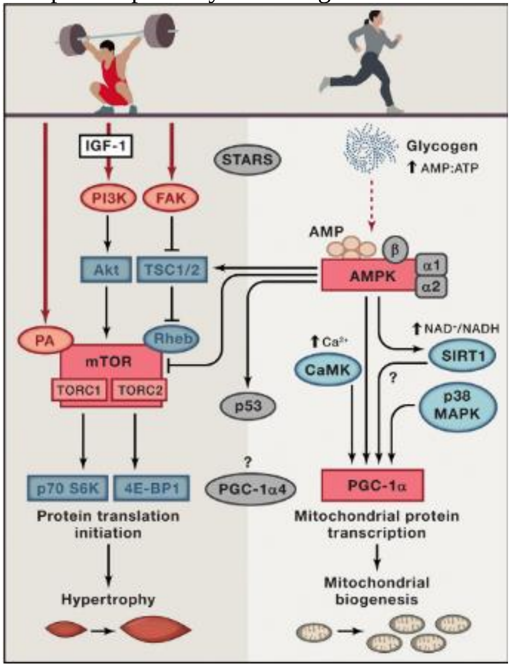
(SUNDE ET AL., 2010. P, 2161)

Like (StØren *et al*., 2008), this study also identified significant improvement in maximal strength (1RM), rate of force development, and time to exhaustion (MAPtime), as well as improvements in economy of movement (CE - *Cycling Ecnonomy)* and Work Efficiency[5] (WE - *Work Efficience*) in the intervention group when compared to the control group.

The idea of concurrent training deserves to be contextualized, and it makes little sense to talk about concurrent training and much more sense to talk about combined training. The term concurrent training may be described as the moment in which different capacities or adaptations are induced during some moment of the training periodization. Although the expression is usually used to refer to the supposed competition between *endurance* and strength adaptations, it is possible to contextualize the competition of different adaptation pathways in several physical capacities (FYFE, BISHOP, & STEPTO, 2014).

[5] Recent literature on Endurance training has used the term economy of motion to refer to the cost over VO2max of work, however, the term *Work Efficiency* (energy cost of mechanical work) is more usual in work on cycling.

Image 7 - Adaptation pathways to strength and *endurance* training.



(HAWLEY *ET AL*., 2014. P. 744)

The competition between the adaptive pathways would occur, firstly, because the activity of the AMPK enzyme supposedly inhibits the mTOR factor, impairing muscle hypertrophy. In second plan, an increase in muscle hypertrophy seems not to be beneficial to *Endurance* athletes since it generates a decrease in mitochondrial density, a determining factor for the performance of *Endurance* sports (FYFE, BISHOP and STEPTO, 2014), (HAWLEY *ET AL*., 2014.)

4 FINAL CONSIDERATIONS

From this study, we can safely say that *Endurance* performance is determined by factors such as VO2max, oxygen utilization fraction, and economy of motion.

Increases in VO2max can be induced by continuous light-to-moderate intensity and high-intensity interval training, although the time spent in the light intensity zones has been considerably higher in recent years.

Economy of motion finds correspondence in different *Endurance* modalities such as running economy, cycling economy, and swimming economy and is determined by training, environmental, physiological, biomechanical, and anthropometric factors.

In this sense, strength and power training has a positive relation with the improvement of *Endurance* performance, especially considering pliometric and maximal strength training, since adjusted to individual capacity and training specificities. The reasons for this improvement seem to be related to both neural and morphological adaptations, such as the increase in maximum force, the increase in the rate of force development, the improvement of the shortening-stretching cycle, the greater capacity to react to the ground, and a greater capacity to store elastic energy.

Thus, it is recommended that runners and cyclists who seek improvements in their performance include maximal strength and pliometric training in their training programs, since this performance is strongly influenced by neuromuscular adaptations that are induced from these trainings. One can consider that the increment of strength training in the training routine is important not only for *Endurance athletes* but also for other segments of the population, especially the elderly, culminating with improvements in the functionality of the neuromuscular system and the so-called "neural *drive*".

The concern about "competing training" does not show itself relevant when training programs are organized based on meeting specific demands of *Endurance* sport performance, especially resistance training with low volume and high percentage of maximum strength. On the contrary, the morphological ones as hypertrophy can bring damages to *Endurance* performance, especially by the decrease of mitochondrial density and the increment in body mass.

Therefore, it is recommended that trainers and other professionals involved in the care of *Endurance sports* have the physical evaluation and the specificities of the sport as the central point of the prescription they intend to make.

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