

Variation in resistance training load: So much to explain

Variação na carga de treinamento de força: Ainda há muito para se explicar

Variación en la carga de entrenamiento de fuerza: todavía hay mucho que explicar

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Abstract

The periodic variations in the resistance training load are more efficient for promoting muscle strength in comparison to training that does not vary the load over time. This variation occurs by manipulation of the variables presented in a resistance training program, such as the intensity, volume, muscle action speed, and exercise order. Although the pieces of evidence point to the superiority of the varied training, it's not clear how the processes that influence the force production are affected when the training is performed with load variation through the time. Knowing the mechanics triggered by the load variation along the time could lead to training more specific to the goals desired. Thus, we aimed to discuss the central and peripheral mechanisms that influence the process of force production and to generate insights for new investigations that aim to compare the strength development between the varied and non-varied resistance training programs.

Key Words: Resistance Training; Muscle Strength; Adaptation Biological

Resumo

Estudos demonstraram que as variações periódicas na carga de treinamento de força são mais eficientes para promover força muscular em comparação a treinamentos que não variam a carga ao longo do tempo. Essa variação ocorre pela manipulação das variáveis de um programa de treinamento, como a intensidade, volume, velocidade das ações musculares e ordem dos exercícios. Embora as evidências apontem a superioridade do treinamento variado, não está claro como os processos que influenciam a produção de força são afetados quando o treinamento é realizado com variação de carga. Conhecer os mecanismos desencadeados pela variação da carga ao longo do tempo pode levar a treinamentos mais específicos aos objetivos desejados. Assim, objetivamos discutir os mecanismos centrais e periféricos que influenciam o processo de produção de força e gerar insights para novas investigações que visem comparar o desenvolvimento da força entre os variados e não variados programas de treinamento de força.

Palavras-chave: Treinamento de Resistência; Força Muscular; Adaptação Biológica

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Resumen

Estudios han demostrado que las variaciones periódicas en la carga del entrenamiento de son más efectivas para promover la fuerza muscular en comparación con el entrenamiento que no varía la carga con el tiempo. Esta variación se produce al manipular las variables de un programa de entrenamiento, como la intensidad, el volumen, la velocidad de las acciones musculares y el orden de los ejercicios. Aunque la evidencia apunta a la superioridad del entrenamiento variado, no está claro cómo los procesos que influyen en la producción de fuerza se ven afectados cuando el entrenamiento se realiza con cargas variables. Conocer los mecanismos desencadenados por la variación de la carga puede conducir a un entrenamiento más específico hacia los objetivos deseados. Nuestro objetivo es discutir los mecanismos centrales y periféricos que influyen en el proceso de producción de fuerza y generar conocimientos para nuevas investigaciones que tienen como objetivo comparar el desarrollo de la fuerza entre los programas de entrenamiento de fuerza variados y no variados.

Palabras clave: Entrenamiento de Resistencia; Fuerza Muscular; Adaptación Biológica

1 Introduction

The variability represents one of the sports training principles, being characterized by a periodic change in training stimulus (ACSM, 2009). Its conception is based on the General Adaptation Syndrome (SEYLE, 1950), which suggests that when the body is exposed to a stimulus capable of stressing the biological system, physiological changes may occur resulting in adaptations (CUNANAN et al., 2018). In sports training, the continuous and unchanged execution of the same stimulus (training load) is accomplished of neuromuscular adaptations that lead to an increase of muscle strength (KRAEMER et al., 2003). However, keep practicing the same stimulus over a long period may lead to stagnation in the neuromuscular system's ability to produce force (KRAEMER et al., 2003), as well as it turns into a demotivating factor for the athlete (POLIQUIM, 1998), and it may cause overtraining and injuries (FOSTER 1998; MEESUEN et al., 2013). To maximize physical performance, sports coaches opt for training periodization, which offers a variation in the training load capable of providing an adequate sports performance for competition (CUNANAN et al., 2018).

In resistance training, periodization represents a variation in the training load over time (POLIQUIM, 1998; EBBEN et al., 2004; ZOURDOS et al., 2016; WILLIAM et al., 2017) without the need for specific physical performance at a given competition, and it will be treated in the present study as variability. The resistance training variability refers to a systemic process of changing the training load variables configuration over time. This keeps the stimulus challenging and effective in providing adaptations that match with the previous objectives determined (FLECK, 1999). Given the human biological system's ability to adapt quickly to a stimulus, changes in the training load are necessary for the continuity of the expected responses (FLECK, 1999). In this sense, studies have been investigating the effects of variation of intensity, volume, and exercises over the months, weeks, or days, in an attempt to



increase neuromuscular adaptations (RHEA et al., 2002; FONSECA et al., 2014; ZOURDOS et al., 2016). However, there is no consensus regarding the ideal periodicity in which the training load should be varied in order to provide the greatest increases in muscle strength (BUFORD et al., 2007, HARRIES; LUBAN; CALLISTER, 2016; CALDAS et al., 2016).

Harries et al. (2015) conducted a systematic review and meta-analysis comparing the strength performance between training programs that varied monthly, and daily the training load. The results of this study pointed to a similar effect on strength development between these two training programs. In the systematic review and meta-analysis conducted by Caldas et al. (2016), the results of training programs that varied daily and weekly the training load were superior for increasing the maximum strength in relation to the monthly variations. However, besides analyzing the strength performance this review included studies that also evaluated the muscle hypertrophy, what reduced the number of investigations in comparison to the Harries et al. (2015). Although there is no consensus regarding what is the best variation strategy for increasing strength performance, there is an agreement by both researchers and coaches about the superiority of training programs that vary the training load over time against programs that do not vary the load regarding the muscle strength performance (EBBEN et al., 2004, RHEA and ALDERMAN, 2004, ACSM, 2009, WILLIAM et al., 2017).

In the systematic review and meta-analysis performed by Rhea and Alderman (2004), the strength performance was compared between varied and non-varied training programs. This investigation included studies with men and women. In addition, individuals with different training status and age were analyzed. The result shows the varied programs were considered more efficient by promoting the greater increase in maximal force development compared to non-varied programs. However, other studies were conducted after 2004, and in some cases, the superiority of the varied programs for strength development was not evidenced over the non-varied programs (HOFFMAN et al., 2009; SOUZA et al., 2014). Thus, William et al. (2017) performed a systematic review and meta-analysis comparing the development of maximum strength in leg press, bench press and squat exercises between varied and non-varied programs. The results of this investigation corroborate with the initial findings of Rhea and Alderman (2004), by proposing that varied programs are superior to non-varied programs when the maximum strength performance is desired.

However, despite the consensus regarding the use of varied programs for promoting strength development, little explanation has been given concerning the physiological mechanisms that support the use of these models. In addition, the methodologies applied in the previous studies aimed for testing only the strength pre and post-intervention. Rarely was thought in testing the mechanistic biological processes



involved by the change in the training load over time (BAKER, WILSON, CALYON, 1994; KRAEMER et al., 2003; ULLRICH et al., 2015) that would aid to explain and support the results of Rhea and Aldermen (2004) and Williams et al. (2017). Understanding the impact of variability under the physiological scope can provide information that justifies the manipulation of the variables over time in resistance training programs. In this perspective, the present study has as objective to discuss the central and peripheral mechanisms that influence the process of strength production and thus, to generate scientific subsidy directed to new studies that aiming at the comparison of strength development between the varied and non-varied training programs.

2 Central factors

The physical movement takes place on the organizational process that occurs in the cortex (KOLB; WHISHAW, 2009). There are guidelines that suppose the movement planning as well as its sequencing derive from the conjunct action of the dorsolateral prefrontal cortex and the pre-motor cortex with the supplemental motor area, respectively (VOLLMANN et al., 2013). In addition, the primary motor cortex is responsible for specific elements such as the organization of the direction and contraction force that generates the movements (ROLAND, 1980). In this sense, different parts of the cortex organize the planning and execution of a given motion. Thus, the definition and command of the motor units that will be recruited, as well as the magnitude and frequency of the electrochemical signal to be sent to the muscular junction, begin in the cortex with synaptic transmission to the spinal column by means of motor neurons network (CHENEY, 1985). This excitatory process also understood as corticospinal excitability (CHENEY, 1955, ROSSINI et al., 1994, NUZZO et al., 2016, MASON et al., 2017) reflects, at least in part, the synaptic transmission demand (CHENEY, 1985).

Additionally, the influence of strength exercises on corticospinal excitability level has already been investigated acutely (NUZZO et al., 2016; LATELLA et al., 2017; MASON et al., 2017) chronically (CARROL et al., 2002; JENSEN; MASTRAND; NIELSEN, 2005; KIDGELL, PEARCE, 2010). In an acute effect analysis, Nuzzo et al. (2016) identified that a single resistance training session was able to increase the corticospinal excitability, meaning an increased efficacy of corticospinal-motoneuronal synapses or increased motoneuron excitability, which, according to the authors, could represent the initial neural adaptations to the training. In the study by Carroll et al. (2002), reductions of electromyographic activity and cortical excitability for the same absolute intensity (measured pre- and post-training) was observed after 4 weeks of resistance training. According to the authors, these results show that resistance training can increase the efficiency of electrochemical signal transmission in the corticospinal synaptic



network. In this sense, the improvement in synaptic transmission due to resistance training would reduce the need for recruiting higher threshold motor units to accomplish the same absolute stimulus (i.e. to lift the same weight pre and post-training period). Because of the activation of a lower percentage of motor units of lower threshold would already be enough to produce the necessary force. Thus, with a smaller number of higher threshold motor units activated it is possible to carry out the same absolute training load, and other higher threshold motor units would probably be available to perform a training load in greater magnitude (i.e. intensity) than would be possible at the pre-training.

In this way, perhaps the varied resistance training programs could be able to induce greater corticospinal excitability than the non-varied training over time which would result in greater improvement in synaptic transmission and force production. This reasoning is reinforced by the results found in Kraemer et al. (2003), in which, after 9 months of training, the women tennis player that trained with daily variations presented the greater improvement in force than the women tennis players that kept constant the training load over time. However, no study was found concerning to compare the corticospinal excitability over time between varied and non-varied training programs.

Complementary, studies have demonstrated that performing a strength exercise may increase the synchronism level among motor units (DUTTA et al., 2015). In addition, the level of synchronism seems to depend on the individual's experience, fatigue level, and exercise intensity (FLING, CHRISTIE; KAMEN, 2009). Moreover, higher threshold motor units exhibit greater synchronization capacity than lower threshold motor units (DeFREITAS et al., 2014). Thus, increased muscle synchronization may augment the strength production (SEMMLER, 2012). In this understanding, the synchronized generation of intra and intermuscular action potentials, illustrate an improvement in the coordinating capacity and, consequently, in the force production.

In the study of Dutta et al. (2017), the effect of anodal transcranial direct current stimulation was used to measure and compare the motor unit synchronization from the biceps brachii during the isometric exercise at intensities of 12.5%, 25, 37.5%, and 50% of maximal voluntary contraction force. The results show that greater force productions at higher intensities were accomplished by the greatest increase in motor units' synchronization in comparison to the lower intensities. However, no study was found comparing the level motor unit's synchronism between varied and non-varied resistance training programs over time. In the Motor Learning field, studies show the varied practice represents an efficient alternative to increase brain network synchronism (SONG et al., 2015). Despite the wide limitations, an approach between the resistance training varied programs and the varied practice from Motor Learning allows being hypothesized that the variability in resistance training, perhaps, represents a better



alternative to optimize the mechanisms related to inter and intramuscular synchronization and, consequently, help to explain the greater increase in force production over time by the varied resistance training programs (Williams et al., 2017). However, this reasoning needs to be investigated.

In addition, a decrease in co-activation (antagonist muscle activation) represents a neuromuscular adaptation that may occur due to resistance training and it is associated with increased force production (CORMIE; MCGUIGAN; NEWTON, 2011). Co-activation of the antagonist muscle is a neuromuscular response that contributes to the stabilization of the joint in motion (BARATTA et al., 1998). However, the excess of co-activation can negatively affect strength performance, especially in movements that require maximum or explosive force production (OSTERING et al., 1984). However, the change at the co-activation has not yet been compared between the varied training and the non-varied training. The result of this comparison could contribute to the understanding of the effect of varied and non-varied training on the level of co-activation over time.

3 Peripheral factors

In addition to the neural factors, the force production capacity is influenced by as fiber type (PYKA et al., 1994) and architectural aspects of the skeletal musculature (AAGAARD et al., 2001; BLAZEVIK et al., 2003). The muscle architectural composition takes into account, mainly, the fiber pennation angle, the fascicle length, and the muscle cross-sectional area (BLAZEVIK et al., 2003; EMA et al., 2016). Studies have been demonstrated the resistance training can modify any of the above-mentioned aspects that compose the muscle architecture and fiber type, benefiting the process of production and transmission of muscular strength (BLAZEVIK et al., 2003, 2007; AAGAARD et al., 2001, STARON et al., 1990).

Relative to fiber type, studies have already shown that a muscle fiber type may be converted into other by training intervention (type IIa into type IIx or vice versa) (STARON et al., 1990; YUAN et al., 2011). Thus, if a training model may lead to a greater number of fiber conversions, from type IIa to type IIx, which is associated with greater force generation (MAFFIULETTI et al., 2016), perhaps the maximum strength performance would be improved if the muscle were enriched by a greater number of faster fiber type. As the adaptations derive from the stimulus overlaid (CUNANAN et al., 2018), perhaps the sort of intervention, such as the varied and non-varied resistance training may provoke different levels of fiber conversion over time. If one of these two training models provoke greater conversion of slower to faster fiber type, perhaps this training model was capable of inducing greater maximum muscle force



production. However, the comparison of the impact of strength programs that vary and non-vary the training load over time on the fiber conversion has yet to be done.

Concerning the architectural aspects of the skeletal musculature, the increased pennation angle and fascicle length have been accompanied by an augment in force production capacity (BLAZEVIK et al., 2003, 2007). Longer fascicle length is related to a greater number of contractile units arranged in series which may positively influence the force generation at a given shortening velocity due to a rightward shift in the isotonic force-velocity curve (LIEBER et al., 2010). In the study of Blazeovich et al. (2007), the fascicle length did not increase significantly from the fifth week until the tenth of training, as occurred during the first five weeks. It leaves in doubt whether the fascicle length could continue to increase if the training load were changed from the fifth week onwards. Besides, the study of Wells et al. (2014) presented an inhomogeneous increase in the fascicle length in the vastus lateralis muscle after 15 weeks of varied resistance training in women athletes. Moreover, the maximum strength was also increased after the intervention and this change presented a correlation to the fascicle length change. However, despite the fascicle length change signaled a structural adaptation that influences the force production (BLAZEVIK et al., 2003), the comparison of fascicle length change between varied and non-varied intervention has yet to be performed.

Regarding the pennation angle, studies have shown the pennation angle may increase due to resistance training (KAWAKAMI et al., 1993). Despite the increase in pennation angle may reduce force per muscle fiber (AAGAARD et al., 2001), it enables an increase of the contractile element in parallel and thus, a greater amount of force can be produced per muscle (FARUP et al., 2012). However, it was found no study that compared the change of pennation angle post interventions that vary and not vary the training load configurations over time. This analysis would give insights into how the varied and non-varied resistance training influences one of the factors that influence the force production such as the pennation angle (BLAZEVIK et al., 2003).

Among the factors that constitute the muscle architecture, at the best of our knowledge, only the cross-sectional area, or its indicator such as muscle thickness (FRANCHI et al., 2018), have already been compared between varied and non-varied resistance training programs as indicative of muscle hypertrophy. Taking into account the recent systematic review of Grgic et al. (2017) that compared the hypertrophic response between varying and non-varying resistance training, the training programs that proposed variation in training load over time demonstrated similar hypertrophic response than non-varied training programs. However, only three (in 12) studies used direct measures of hypertrophy (ultrasound or magnetic resonance imaging). Besides, most of the studies investigated non-strength trained men as



sample and the results found reflect only short-term interventions. In this case, more investigation is needed, especially with longer intervention and trained individuals. These observations are supported by Monteiro et al. (2009) that showed a decrease in lean body mass in trained men after 12 weeks with non-varied training. Besides, none of the studies included in Grgic et al. (2017) measured the hypertrophic response beyond one point (or region) in the muscle.

Since many studies have already shown that resistance training interventions may cause non-homogenous hypertrophy through the muscle (ANTONIO, 2000, BLOOMQUIST et al., 2013, EARP et al., 2015, MATA et al., 2017), it would be interesting if the muscle hypertrophy caused by the resistance training interventions with variations and non-variations were compared in more than one muscle site. However, the impacts of varying the training load on muscle hypertrophy in different regions along the muscle have not yet been investigated. According to the association between muscle size and muscle strength (BLAZEVICH et al., 2003), new studies could investigate and compare the effects of varying and not varying the training load on regional muscle hypertrophy and strength production.

Biochemical aspects that interfere in the muscle force production represent another source of variables that could be compared between variability x non-variability resistance training programs. Notwithstanding, although the biochemical variables have not been discussed in the present study, future investigations should take it into account during the comparisons between varied x non-varied training models in attempt to clarify what leads to the differentiation between this two training types on the strength performance.

In conclusion, resistance training variation seems to be an effective alternative to improve muscle strength. However, the pathways that underpin its utilization still need to be uncovered by new studies methodologies that aim to understand the central and peripheral mechanisms that take influence at the muscle strength production.

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