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Resistance training exercise selection: efficiency, safety and comfort analysis method

Seleção do exercício no treinamento resistido: método de análise eficiência, segurança e conforto

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Abstract - Manipulation of resistance training variables has been shown to have a substantial effect on muscular adaptations. A major variable in this process is exercise selection. In addition to the effectiveness of a given exercise to recruit the target muscle groups, safety considerations and individual comfort during execution of a lift should be considered. The correct biomechanics of the chosen exercise will assist in promoting desired muscle adaptations, while proper safety procedures will reduce risk of injury. Lifting comfort will facilitate enjoyment and foster adherence to the program. Therefore, the purpose of this paper was to offer guidelines for selection of resistance training exercises based on the Efficiency, Safety, and Comfort Analysis Method (ESCAM).

Key words: Physical Education and training; Muscle skeletal; Resistance training.

Resumo - *A manipulação das variáveis do treinamento resistido demonstraram ter um efeito substancial nas adaptações musculares. Uma variável importante neste processo é a seleção de exercícios. Além da eficácia de um determinado exercício para recrutar os grupos musculares-alvo, as considerações de segurança e conforto individual durante a execução de um levantamento devem ser considerados. A biomecânica correta do exercício escolhido ajudará a promover as adaptações musculares desejadas, enquanto os procedimentos de segurança adequados reduzirão o risco de lesões. O conforto no levantamento facilitará o prazer e promoverá a adesão ao programa. Portanto, o objetivo deste artigo é oferecer orientações para a seleção de exercícios no treinamento resistido com base no Método de Análise de Eficiência, Segurança e Conforto (ESCAM).*

Palavras-chave: *Educação Física e treinamento; Músculo esquelético; Treinamento de força.*

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INTRODUCTION

Resistance Training (RT) has been used to promote general health and sports performance for some time, as well as to enhance physique aesthetics. From a muscle hypertrophy standpoint, it has been proposed that manipulation of training variables plays an important role in achieving maximum muscular development. Major variables for achieving success include training volume, intensity, recovery between sets, and exercise order[1,2]. An often overlooked factor for optimizing hypertrophic adaptations is the proper selection of exercises that comprise the training routine[3]. Current guidelines typically fail to indicate which exercises should be included in the routine and which muscles should be prioritized when designing the training program[1]. Most recommendations only indicate that individuals should perform single- and multi-joint exercises sequenced from larger to smaller muscle groups on both machines and free weights, without adequate guidelines as to which exercises should be performed first and which muscles should be prioritized. Furthermore, there is usually little mention of safety issues that should be associated with specific exercises.

There are a wide range of basic RT exercises from which to choose, and variations of each movement make selection options virtually unlimited. One of the main factors used to prescribe any exercise is the effectiveness of that exercise to activate a target muscle, which is often determined by surface electromyography (sEMG) analysis and kinematic modelling, or longitudinal studies verifying efficiency of a given exercise in promoting improvements in strength and hypertrophy outcomes. However, decision-making should also consider any potential injury risk of a given exercise, as well as the comfort of movement execution, as these factors play a role in both safety and exercise program adherence. For example, it is possible that a given exercise (or variation) produces maximal activation of a muscle group but, at the same time, increases the risk of soft-tissue injury. In this case, would the risk outweigh the benefit? Similarly, including an exercise that the trainee feels uncomfortable performing may ultimately have a negative influence on long-term adherence to the exercise program. The present paper endeavors to propose a decision-making method for exercise selection based on the proposed Efficiency, Safety, and Comfort Analysis Method (ESCAM).

DEVELOPMENT EFFICIENCY, SAFETY AND COMFORT ANALYSIS METHOD (ESCAM)

ESCAM is a simple strategy to prescribe exercises for a given individual. A particular exercise should not be included simply because it involves the target muscle group to be strengthened without first considering the joint structures directly stressed by the movement (cartilage, capsule, ligament, bursas, etc.). This may also lead to consideration of the comfort of the exercise including individual limitations during the exercise execution as well as personal preference which is likely to facilitate RT adherence. The following sections will address these factors as they relate to exercise selection.

Efficiency

Efficiency is related to the capacity of a given exercise in strengthening and/or promoting hypertrophy of a target muscle. The most appropriate way to assess the efficiency of a given exercise is by analyzing the longitudinal studies that examined the exercise capacity to promote strength and muscle hypertrophy. That is, analyze pre- and post-training scores of a group of participants who trained the exercise for at least a few months. However, this type of research is more difficult to be conducted, and thus limited in the literature. Alternatively, sEMG is the most common technique used to determine the magnitude of muscle activity in a specific exercise. However, several points must be considered when using sEMG including: (a) comparison of exercises in different planes and muscle lengths; (b) technique of signal capture (e.g., electrode diameter, distance between poles, etc.), processing and analysis of signal amplitude (i.e., mean rectified value, moving average, linear envelope, median frequency, and root mean square)[4], and; (c) standardization to a parameter (e.g., maximum isometric voluntary contraction). It is important to note that although there is an association between hypertrophy and muscle activation[5], hypertrophy is a multifactorial phenomenon[2] and is influenced by more than simply neuromuscular activation; thus, greater electromyography responses does not necessarily translate to greater muscle hypertrophy[6].

Another factor to be considered is the type of stimulation generated by an exercise in the target muscle. Muscle hypertrophy is theorized to occur through mechanical tension, metabolic stress, and repair of muscle damage[2,7]. In certain exercises, peak tension occurs when a muscle is stretched, which favors greater muscle damage; alternatively, peak tension occurs in other exercises when the muscle is shortened, thus favoring a greater accumulation of metabolites. For example, peak quadriceps tension during squatting occurs when the muscle is stretched; thus, the hypertrophic advantage of squatting for the quadriceps would be achieved at higher degrees of knee flexion, which hypothetically would induce greater muscle damage. On the other hand, peak quadriceps tension in the knee extension exercise occurs when the muscle is shortened, near the point of full knee extension[8], thus favoring greater metabolite accumulation. It is important to emphasize that these stimuli are not necessarily exclusive or redundant, so the combination of the two aforementioned exercises may be synergistic in optimizing muscular development. This hypothesis is warranted in future experiments.

Another consideration with respect to selecting exercises is whether to include single-joint exercises. Controversy on the topic surrounds the fact that compound exercises naturally involve the recruitment of more muscles compared to single-joint exercises. Recently, some authors have postulated that single-joint exercises are not required to optimize muscle hypertrophy[9]; however, other authors have challenged this viewpoint[10].

Although compound exercises can be considered essential movements in a resistance-training program, a case can be made that single-joint exercises are complementary and perhaps additive from a hypertrophy standpoint. For example, squatting is a compound exercise that elicits substantial hypertrophy of the quadriceps and *gluteus maximus*[11]. However, the activity of the *vastus lateralis* or *medialis* is considerably greater than the *rectus femoris* during squats[12], conceivably due to the bi-articular nature of the *rectus femoris* is not fully activated when the hip is flexed. Thus, during performance of the squat, this lower degree of strength production, may ultimately result in a suboptimal development of the *rectus femoris*. Earp et al. [13] observed that after 8 weeks of squat training there was a significant increase in Cross-Sectional Area

(CSA) of the *vastus lateralis* (13.5%), *vastus intermedius* (18.0%), and *vastus medialis* (17.1%), but no statistically significant change was observed for the *rectus femoris* (1.0%). Kubo et al.[11] also did not observe significant change in *rectus femoris* CSA after 10 weeks of full and half squat training. On the other hand, the *rectus femoris* showed greater activation during single-joint knee extension exercise[14,15]. Accordingly, Ema et al.[14] observed that twelve weeks of knee extension training produced greater *rectus femoris* hypertrophy (~22%) compared to the vasti muscles (≤10%)

The hamstrings present similar issues with respect to exercise selection. Although the hamstring muscles are activated in the squat, their EMG amplitude is only approximately half that achieved when performing single-joint exercises such as the stiff-leg deadlift and knee curl[16]. As with the *rectus femoris*, the attenuated activation of the hamstrings during squatting occurs due to the bi-articular nature of the muscle complex, whereby its length remains relatively constant during exercise performance. Therefore, it follows that there should be less development of the hamstring muscles in relation to the quadriceps. In support of this supposition, Illera-Domínguez et al.[17] observed an increase of approximately 10% in the quadriceps after four (4) weeks of squat training, with no statistically significant increase for the semitendinosus, semimembranosus, and short head of *biceps femoris*. Similar findings were reported by Kubo et al.[11], who observed no hypertrophy in the hamstrings after 10 weeks of squat training.

The calf muscles are another region that can benefit from single-joint exercise. For example, the force exerted at the ankle joint during the squat is substantially inferior to that produced by the hip and knee[18], thus resulting in suboptimal activation of the soleus and gastrocnemius muscles. In addition, squatting does not allow a large range of motion of the ankle joint consequently minimizing involvement of the calf muscles during exercise performance. Considering the aforementioned information, it will be necessary to complement multi-joint lower body training with single-joint exercises that target the *rectus femoris*, hamstrings and calf musculature.

Regarding the upper limbs, compound exercises such as the bench press, row, lat-pulldown, and military press will activate both the trunk and upper-limb muscles, which may induce some degree of hypertrophy in upper limb muscles (biceps and triceps)[9]. However, recent studies indicate that adding isolated exercises to a workout routine may allow for a greater increase in arm circumference. Barbalho et al.[19] investigated untrained men who underwent eight (8) weeks of resistance training in two conditions: a routine including only compound exercises (bench press, military press, lat pulldown, and seated cable row) or a routine in which isolated exercises (cable triceps and barbell biceps curl). Their results indicated that the group that added the isolated exercises had a greater increase in arm circumference (+5.2%) in comparison to the group that only trained with compound exercises (+4.0%). In another study employing a similar design in female participants, results also indicated that both groups increased arm circumference, but the gain was higher in the group that added the isolated exercises compared to the group that trained only with compound movements (+4.4% vs +3.5%, respectively)[20]. In a study performed with previously trained individuals, França et al.[21] observed that resistance-trained men who added single-joint exercises had more than double the muscle growth compared to the group that trained only with compound exercises (+3.2% vs. +1.3%, respectively), although differences between conditions did not rise to statistical significance. More recently, Mannarino et al.[22] investigated the hypertrophic effects on 10 subjects who performed only the unilateral row (multi-joint exercise) on one side of the body, while the other side of the body performed only the unilateral arm curl (single-joint exercise). After eight (8) weeks results showed that the side that trained with single-joint exercise had higher elbow flexor hypertrophy compared to the side that performed the multi-joint exercise (+11% vs. +5%, respectively). These results indicated that while it was possible to achieve upper limb hypertrophy using multi-joint exercises, single-joint exercises may confer additional muscle hypertrophy.

This section highlights the importance of taking muscle action into account when selecting exercises for a given RT program. The selection also should consider the objectives and needs of the trainee.

Safety and comfort

Safety is related to the soft-tissue joint structures involved in exercise performance (e.g., cartilage, joint capsule, ligament, bursas). Some movements may expose the soft tissues to an increased risk for injury. For example, when shoulder abduction exceeds 90º during performance of the lateral raise, the head of the *humerus* will tend to have greater contact with the acromioclavicular joint, which in turn can lead to impingement of the supraspinatus[23]. A strategy to reduce the potential impingement would be to perform the lateral raise in the scapular plane (full can, Figure 1a-c). However, such strategy may reduce the activation of middle deltoid head[24]. Therefore, if the target is maximal activation of all deltoid's components, the pronated position of the forearm (empty can) can be adopted at the beginning of the movement until the range of motion approaches 90º (Figure 1d-e). Conversely, a range of motion beyond 90º generally should be avoided to decreased stress of the acromioclavicular joint[23] (Figure 1f).

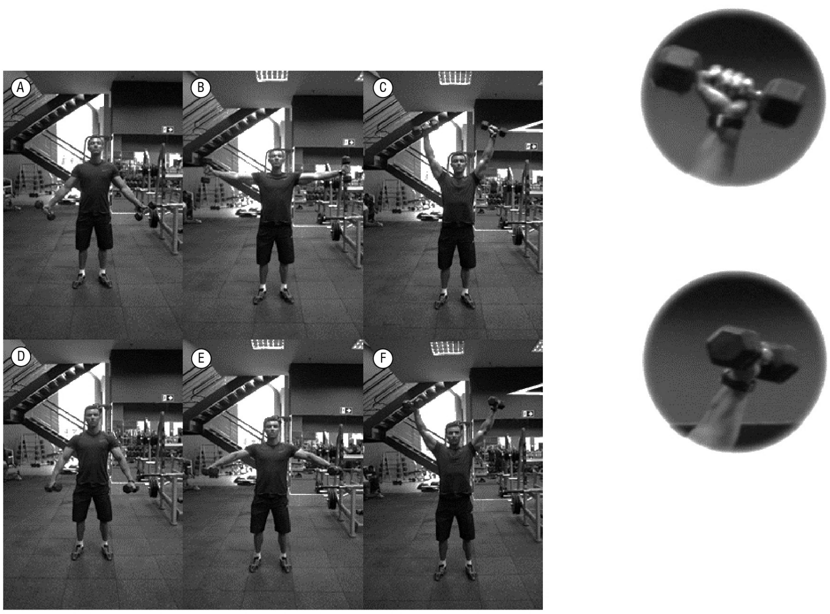

Figure 1. Lateral raise exercise executed with different shoulder positions. The details in balloons show shoulder position. Sequence A-C (lateral rotation of shoulder or full can); and sequence D-F (internal rotation of shoulder or empty can).

Safety also can be a consideration when performing the squat. Safe execution in the free-bar squat involves a variety of considerations such as hip and ankle mobility, balance and coordination, and proportionality of relative length between the trunk and lower limbs. Individual alterations in these factors may adversely affect exercise technique, increasing the risk of injury. In cases when a person is unable to perform the squat with proper form, it is advisable to substitute a variation that reduces degrees of freedom while providing comparable benefits. A viable alternative in this regard may be to perform the squat on a Smith machine, which limits movement in three-dimensional space, thereby making the movement easier and potentially safer than the free-bar squat while eliciting similar gains in strength and muscle mass[25]. The hack squat is another potentially viable alternative exercise, as the spine is supported by the backrest of the machine. In cases where compressive loading of the spine needs to be minimized, such as with frail individuals and/or those with a history of spinal injury or marked postural deviation, the use of dumbbells and/or kettlebells can be employed during squatting. The leg press is another exercise that also effectively activates the quadriceps and *gluteus maximus*[26-28], while placing minimal load on the spine.

Proper equipment adjustment must also be taken into account from a safety standpoint. For instance, during exercise performance on the wide-grip seated row machine, the seat must be elevated to the proper height and the frontal pad support correctly adjusted to avoid the shoulder joint going into hyperextension during execution. This helps to prevent the head of the *humerus* producing greater stress in the articular capsule[29]. Figure 2 illustrates the proper adjustment of seat height and front pad support (knee and hip joint approximately 90° of flexion). Furthermore, to execute exercises in the seated position (e.g., seated leg press, hack machine, seated leg curl, etc.), practitioner should keep the back flat against the seat. Another important point to be considered during performance of the leg extension and knee curl is the proper placement of the resistance pad, which should be aligned just above the ankle because when the pad is closer of the knee joint, smaller will be resistance arm moment.

Figure 2. Sequence of the wide-grip seated row machine exercise (A-C). The white arrow (figure C) details anatomical position that causes the *humerus* head to be projected anteriorly leading to greater stress in the articular capsule.

Similar logic can be applied to the spine where exercises can be performed in the seated or standing position (e.g., shoulder press, biceps curl, and lateral raise). If each physiological curvature of the spine and lower limb joint works as a distribution point during the standing position, the practitioner will have more force distribution points (spine + lower limb joint) compared to seated position (only the spine)[30]. As a consequence, the upright seated position presents a concentrated shear force (i.e., load applied transversely to the axis of the segment presenting opposing forces at different points of application) that has the greatest potential for risk of spinal injury[14]. The stress to the lumbar region can be substantially alleviated by inclining the seat backrest support by approximately 30º[31] (Figure 3b and 3d). However, this can change muscular recruitment, so consideration must be given to the tradeoff between safety and the adaptive response.

Figure 3. Change on angle of trunk during different backrest inclination on seated shoulder press exercise (A and C = 20° and B and D = 35°). The arrow indicates anterior displacement of the spine in the lumbar region during the same condition (C and D).

Furthermore, when choosing the exercise position (sitting or standing) consideration should always be given to the correct exercise technique and load. For instance, performing exercises with high load, in the seated position the backrest may avoid trunk oscillation. Conversely, when lifting moderate loads, the standing position may be more appropriate due to more distribution points of the external force. This example applies to shoulder press and is considering a sport application (i.e., Olympic weight lifting). Another point of interest is orientation of the feet for the support base which is formed by the position of the foot relative to the projection of the body's center of gravity. In particular, performing the standing shoulder press exercise with lateral displacement of the feet to hip width apart might cause anterior displacement of the spine, which would increase the possibility of discomfort in the lumbar muscles post-workout or, more seriously, acute lumbago. However, if the same exercise was performed with anteroposterior foot displacement of the same distance for the support base (hip width), the anterior displacement of the spine would be reduced since the support points (feet) would be better positioned to avoid anterior displacement of the spine[32] (Figure 4).

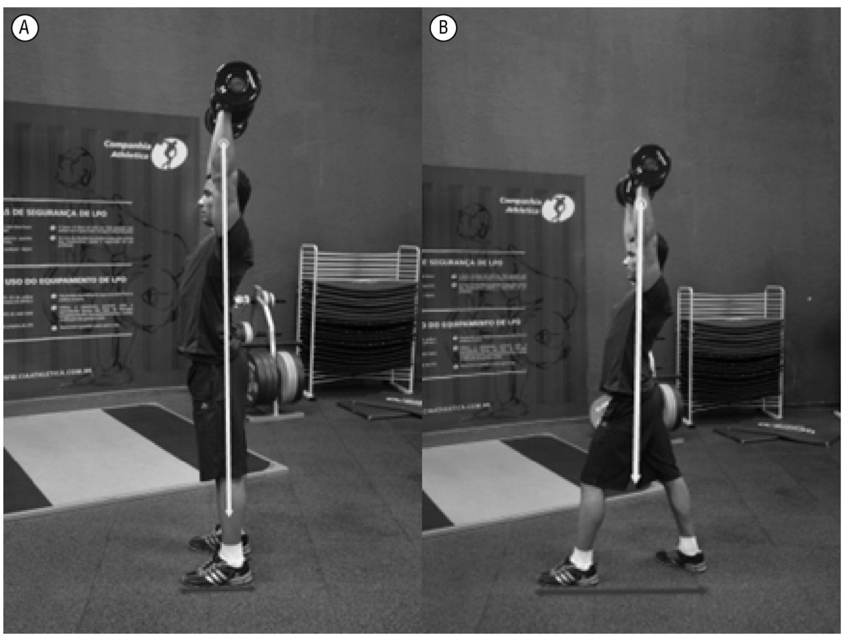

Figure 4. Arrow indicates the projection of the center of mass of the external resistance on support base (white arrow) during shoulder press exercise when performed with lateral displacement of the feet (hip width), figure A; and when performed with anteroposterior foot displacement on the same support base (hip width), figure B.

It is important to mention that a joint is not necessarily at a greater risk of injury simply because forces acting on a joint are increased from an exercise performance. Rather, it is necessary to observe if the compressive and shear forces are naturally increased and will still be within the physiological capacity of the supporting joint(s). For example, during the squat, the compressive forces increase in the greater degrees of knee flexion; however, the peak force is within the physiological capacity of the knee to support this increased force. Therefore, an analysis of each exercise and its pattern of performance should be made.

Another point to be considered when selecting exercises is the individual`s comfort during exercise performance. Comfort is a more subjective parameter and may vary among trainees. Some individuals may experience discomfort when performing exercises in machines, because in machines the trajectory is predetermined, limiting a more natural movement of the body thus creating discomfort for some individual. Moreover, some exercises will increase overload on the spine and may induce discomfort in the most fragile individuals and/or for those with a history of spinal injury or marked postural deviation. Furthermore, some practitioners may have difficulty performing free weight exercises, especially those with poor balance and/or coordination. They may feel more discomfort in exercises that require greater body awareness and may need to exert greater caution to avoid falls.

FINAL COMMENTS

Initially exercise selection should take into account three aspects: (1) purpose of the exercise; (2) target muscle; and (3) level of complexity of execution. Other demands may exist, but these three points represent the cornerstones of the selection process. Finally, all the points discussed herein should be included when selecting exercises. We believe that proper selection of exercises is an important factor to promote a successful program. When performing exercise selection, considerations regarding to muscle efficiency, spinal overload, and joint stress should be included.

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Ethical approval

The research was written in accordance with the standards set by the Declaration of Helsinki.

Conflict of interest statement

The authors have no conflict of interests to declare.

Author Contributions

Conceived and designed the experiments. Literature search: ESB, LBRO; Data organization: ESB, LBRO, ASR; Wrote the paper: ESB, BJS, LBRO, JLM, ASR; Final revision: ESB, JLM, ASR; English revision: BJS, JLM.

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