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Review Article

MUSCULAR FAILURE TRAINING IN CONDITIONINIG NEUROMUSCULAR PROGRAMS

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ABSTRACT

Many recommendations for designing of resistance training programs are suggested training all the sets to perform until voluntary fatigue with a maximum load selected, situation known as muscular failure. However, recent evidence has emerged that suggest caution in the prescription of training to failure in both, healthy and performance perspective. This review has addressed to this issue and made a collection of literature and a qualitative analysis of this topic. Final conclusion of this study suggest that implementation of the muscular failure resistance training is not recommended in subjects who trained with healthy goals, because it breaks the acceptable risk-benefit ratio in healthy training. However, athletes or advanced practitioners can be applied wishing to exceed a "plateau", only if planned and does not interfere with the production of specific strength.

***Key words*:** muscular fatigue, resistance training, recovery.

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INTRODUCTION

Conditioning neuromuscular programs have proven beneficial for the health of those who practice it (Kelly, 2001; NSCA, 2001; Rodriguez, 2008; ACSM, 2009). Benefits are a result of the adaptations leaded by stimulation of muscular effort and the responses generated by it. Under this consideration, the dose-response is necessary to optimize the results of the stimulus (Kelly et al., 2001; Rhea et al., 2003).

Thus, institutions and organizations concerning the field of Sports Science, as the American College of Sports Medicine (ACSM) and the National Strength & Conditioning (NSCA), among others, have published recommendations and position stands about the characteristics of healthy neuromuscular conditioning programs (Conley & Rozenek, 2001; Kraemer & Ratames, 2004; ACSM, 2009).

These reference documents are the criteria for progression of training and how to manipulate the variables in order to obtain the best results, minimizing the risks. Among the many variables that setting the resistance training, the application of repetitions to muscular failure brought to a relative load (% 1RM) is a variable applied in the practical field but with little scientific support (Tan, 1999; Shimano et al., 2006; Willardson, 2006, 2007).

Despite the lack of studies addressing this aspect of training there is scientific evidence rejecting their application among recreational practitioners. As a starting point in this discussion, Sandow, considered a pioneer of resistance training health-oriented in 1904 expressed the need to train until slight muscular pain but never reached the point where they feel totally exhausted or fatigued (Zimmerman, 2004). The purpose of this review is to collect data about the effects of training to muscular failure and their usefulness in the field of healthy neuromuscular conditioning training healthy.

METHOD

Has there been conducted a systematic review of the literature in order to analyze the recent literature which reports the application of maximum voluntary fatigue in conditioning neuromuscular programs. To this end, a literature search was conducted in MedLine and SportsDiscus apply the combination of the following key words: failure, resistance training, maximal effort delivery, muscular fatigue. Papers written in Spanish and English were considered for this review. This search yielded 29 specific articles. After selecting texts, were obtained from the Faculty of Medicine and the Faculty of Science of Physical Activity and Sport at the University of Valencia. Review was extended by manual searching to specific strength training texts. All the information it obtained and was analyzed qualitatively based on the information provided by research to be specific and was related to the acute and / or chronic training to muscular failure.

 ISSN 1988-5202

BACKGROUND

To focus of the current topic that will be developed in this paper is muscular failure training, we first make a definition of training to muscular failure, and then be exposed to possible explanations that have informed the inclusion of this unique training methodology. Similarly, exposed the risks associated with the muscular failure methodology. Analyzed the theoretical basis proposes a strategy for implementing training to muscle failure for athletes. Finally, there are several future lines of research proposals which increase the body of knowledge related to training to muscular failure and its implementation.

Definition of muscle failure

In the available literature we find several meanings relating to the training concept well suited to muscular failure, which refer to different aspects in the production of muscle strength. Some definitions refer to functional disability or reduced/impaired capacity to perform one repetition maximum filling full range of motion (Hunter et al., 2004; Izquierdo et al., 2006a). Other meanings materialize that inability to a point in the range of motion, which coincides with the lower mechanical efficiency (Willardson, 2007). Some definitions suggest a multivariable cause because that will interfere with the ability to maintain the power / muscle work expected (Fitts, 1994). Finally, there are assertions that indicate fatigue of all motor units as the main cause for reduction in functional conditioning neuromuscular program (Willardson, 2007).

A possible standard definition of training to muscular failure could be defined as the point during an exercise against resistance in which the activated muscle group is unable to generate concentric work expected to complete a repetition with a full range of motion due to fatigue.

Justification for the application of muscle failure

Prescription of neuromuscular conditioning programs based on the percentage of one repetition maximum (RM%) often carry implicit finding muscle failure estimated the number of repetitions for the selected load (Stone et at., 1996), this would imply a maximum stress (12 repetitions (12RM)). This form of training leads structural damage of the muscular system (Kibler et al., 1996). These damages have been understood as necessary, though not as single factor to trigger adaptive neuronal responses and, mainly, morphological adaptations (Calderon et al., 2004). From a biological perspective, damage is attributed to the stimulus that triggers muscle regeneration and muscle adaptation due to muscle plasticity afforded by the polynuclear structure of muscle fibers (Close et al., 2005). However, at present paper not discern the mechanism explaining the adaptation of the neuromuscular system (Folland et al., 2002), co-existing scenarios that suggest various conjectures about what might be the trigger mechanism of muscular adaptations, highlighting the assumptions of the mechanical stimulus (Stone et al., 1996), metabolic stimulation (Crewther et al., 2006a) or hormonal stimulation (Kraemer & Ratamess, 2005; Crewther et al., 2006b).

Without going into the adaptive processes of muscle training (target exceeds the scope of this paper), can find several justifications for the inclusion of muscle failure within a neuromuscular conditioning program:

 ISSN 1988-5202

a) Ability to generate greater motor recruitment, and thereby increase muscle activation (Stone et al., 1996; Tan 1999; Naclerio, 2005; Drinkwater et al., 2005; Rooney et al., 1994; Lambert & Flynn, 2002; Willardson, 2007). The effort generated will require greater involvement of additional motor units when the first were fatigued. According to size principle, the units possess mainly type IIx fibers (Sale, 1987), a situation that will stimulate strength gains and stimulate muscle trophic responses (Rooney et al., 1994; Drinkwater et al., 2005; Willardson, 2007).

b) Ability to generate more damage by mechanical stress, facilitating subsequent adaptations (Stone et al., 1996). This situation would be based on the pioneering theory promulgated by Engerhard in 1932. This theory deals with the degradation / synthesis as a possible biological mechanism of adaptation, suggesting a link between the previous process of protein degradation and increased activity of the genetic apparatus (Calderon et al., 2004). In addition, muscle damage has been identified as a stimulus for the growth and activity of satellite cells to repair damaged myofibers. This repair process would lead the hypertrophic adaptation (Antonio & Gonyea, 1993; Close et al., 2005). Despite these indications be satisfied, there is a consensus conclusion on the need to harm muscular fiber to trigger muscle adaptations for building muscle by the action of satellite cells. In this regard, Close et al. (2005) state that there is a possibility they happen processes of proliferation and migration of satellite cells without the presence of muscle damage (Close et al., 2005). In the same line is evidenced by Spiering et al (2008), who note that many of the biological responses of strength training they start thanks to mechanical deformation of the muscle fiber generated by the concentric-eccentric actions, and therefore without structurally damaging the muscle.

c) Increase anabolic hormone levels. Hormonal factors induced by neuromuscular conditioning programs play an important role in adaptive processes (Kraemer & Ratamess, 2005; Crewther et al., 2006b). Goto et al. (2004) reported the acute effects of adding less load repetitions to muscle fatigue immediately after the series with a high in the knee extension machine. The result of this training protocol led to an increase in strength and hypertrophy of the subjects, according with the authors, these results can be attributed to increased growth hormone that caused the intervention methodology.

d) Transitional fibers. Fry (2004) informed in his review paper, a critical factor in the possible transition of the fibers in the direction IIA → IIB is in the completion of the repetitions to muscle failure or nearby. This hypothetical conversion is focus on justifying fast fibers increase strength and muscle size.

CURRENT STATUS OF TOPIC

Sports Application

In the narrative review by Willardson (2007), it is shown that the implementation of muscular failure training should be implemented for those with an advanced level in resistance training who wish to exceed state of blockage or "plateaus " on performance neuromuscular. Table 1 shows the different effects of training to muscle failure in sports populations, compiled by the major studios.

 ISSN 1988-5202

In 1994, Rooney et al. (1994) suggested the need to fatigue the muscle to optimize the strength training stimulus. In this line, some studies with athletes have reported increases in strength by the application of muscle failure in conditioning neuromuscular programs (Goto et al., 2007; Drinkwater et al., 2005). In this sense, performance in young athletes was measured by Drinkwater et al. (2005) who found greater improvements for the test 6RM test (6 repetition maximum) and power for the bench press in the group that carried out the sets to muscular failure, with the group that did not reach muscle failure.

Among athletes there is also evidence that similar effects with muscular failure conditions and conditions not to muscular failure. In this sense, the data published by Drinkwater et al. (2007) show that similar effectiveness of a resistance training program without reaching muscle failure and another that forced repetitions to reach volitional fatigue because post-training tests did not show significant differences in neuromuscular status among young basketball players.

In highly trained subjects has been suggested that the inclusion of training to muscle failure could also interfere with the final performance due to a reduction in specific production force (Byrne et al., 2004; Close et al., 2005). In this line, an experimental study led by PhD. Izquierdo et al. (2006a), showed how training using sets made to muscle failure led a decline in execution speed of the repetition-execution among basketball players. The authors attribute that this decrease in speed of execution was the result of fatigue induced by the method of training. The same study provided evidence to show how the method in which it was reached muscle failure leads to a reduction in the number of repetitions average (Izquierdo et al., 2006a).

When comparing two different training programs only differential by variable of muscular failure removes a significant difference to performance. Implementation of training to muscle failure leads a significant increase in local muscle endurance, while training without reaching muscle failure generates higher power outputs and a hormone balance best for specific sports performance (Izquierdo et al, 2006a, 2006b.).

Although the application of this method may mean a new stimulus for optimizing the gain in strength (Goto et al., 2004; Drinkwater et al., 2005; Willardson, 2007) its application should not exceed the seven weeks to avoid the overtraining risk and injuries (Stone et al., 1996; Tan, 1999).

So added must take into consideration that the effectiveness of strategy training to muscle failure must be accompanied by a sufficient training intensity (Stone et al., 1996; Campos et al., 2002; Izquierdo et al., 2006a). Without the necessary level of intensity, the effectiveness of training will be reduced, moving away from training areas (Campos et al., 2002), and compromising athletic performance (Izquierdo et al., 2006a, 2006b).

Finally, Drinkwater et al. (2004) suggest that the ability to reach muscle failure must be combined with other variables such as duration of the sets and the rest in order to optimize the magnitude of strength gains, these variables must be added the order of exercises (Drinkwater et al., 2004), which can affect the number of repetitions performed to failure for the same muscle group at 80% 1RM, as has been demonstrated in previous research (Simao et al., 2007).

 ISSN 1988-5202

Table 1. Studies applying muscular failure in athletes

AUTHORS	SUBJECTS	TRAINING	MAIN RESULTS
Izquierdo-Gabarren et al., 2009	43 highly level rowers	4 FM 4 exercise achieving muscular failure 4 NFM 4 exercises no muscular failure 2 NFM 2 exercises no muscular failure	4NFM ↑RM 4.6 % bench press ↑Power 6.4%
Drinkwater et al., 2007	Elite athletes	6 weeks a)4x6 b)8x3 c)12 x 3	No significant differences in strength and power performance in the groups that carried out the largest number of forced repetitions.
Drinkwater et al., 2005	Sportsman	Bench press 3 days/week 6 weeks 24 repetitions (80-105%6RM) a)4x6 failure training b)8x3 without failure	The muscular failure group showing greater improvements -no significant- that the NFM group ↑7.3 kg in the 6RM bench press ↑40.8W power throwing of bench press
Brandenburg & Docherty, 2006	18 subjects with experience in resistance training	FM 3 x to muscular failure 77%RM NFM 1 to muscular failure + 2,3 decreasing the load	Similar increases strength
Benson et al., 2006	13 subjects with experience in resistance training	FM 3 x 10rep (10RM) NFM 1,2 x 10rep (90% 10RM) + 1 al 100%	Similar fatigue ↓MVCI y IEMG FM ↑ lactate levels

PANM: Conditioning Neuromuscular Program (resistance training). FM: muscular failure NFM: no muscular failure. RM: repetition maximum. W: vwatt. MCIV: maximum voluntary isometric. IEMG: Integrated Electromyography

ISSN 1988-5202

Application in healthy training

As has been discussed above, the appropriate application of muscular failure training can be justified for athletes who wish to change or enhance the training stimulus in order to improve their muscular performance.

However, within the field of healthy-training is not required to generate so intensity training for get health benefits, in this respect have published several authors (Nosaka et al., 2003; Izquierdo et al., 2006a; Colado & Chulvi, 2008; Izquierdo & González, 2008). These positions are substantiated by scientific evidence (Kramer, et al., 1997; Sanborn et al., 2000; Folland et al., 2001, 2002; Izquierdo et al., 2006b).

Results provided by Sanborn et al. (2000) show greater improvement on the maximal strength and explosive strength in young untrained women when performing resistance training without reaching muscle failure.

When comparing the performance of a set of 8-12 repetitions to muscle failure with three sets of 10 reps without reaching muscle failure results support the protocol without muscular failure as more effective in increasing maximal strength in the squat, thanks a favorable anabolic environment (Kramer et al., 1997). The improvements of the training protocol without reaching the failure attributed to a proper anabolic environment have been replicated in posterior research (Izquierdo et al., 2006b).

Muscle fatigue does not seem to be a necessary component to trigger adaptations to strength training. This statement is based on a research by Folland et al., (2002), these researchers compared two neuromuscular conditioning programs implemented during nine weeks in active subjects without experience in resistance training. One group conducted a training of high fatigue characterized by four sets of 10 repetitions to muscle failure with an intensity of 75% of one repetition maximum, allowing a 30 seconds rest between-sets. The second group performed a repetition an every 30 seconds to get 40 repetitions. The first result is striking is that the high fatigue group had to reduce the load during the protocol while the low fatigue group did not have that need. The second important finding of this study is that the maximum isometric strength gains, maximum dynamic force and maximum isokinetic strength were similar in both groups, although the low fatigue group improved more gradually (Folland et al., 2002). Table 2 shows the different effects of training to muscle failure in non-athletic populations, compiled by the major studies.

 ISSN 1988-5202

Table 2. Studies applying the muscular failure training to people with no athletes (recreative)

AUTHORS	SUBJECTS	TRAINING	MAIN RESULTS
Sanborn et al., 2000	17 woman without experience in resistance training	3 days/week; 8 weeks a)1x8-12 to muscular failure b)3x45/75% no muscular failure	↑0,3% CMJ ↑24,2% 1RM multi-set without muscular failure ↑11,2% CMJ ↑34,7%1RM
Izquierdo et al., 2006	42 subjects healthy and active	11 weeks and 5 weeks for *peaking cycle* Group a) Muscular failure training in all exercises Group b) no muscular failure training	Muscular failure ↑23% 1RM bench press ↑22% squat ↑27%power bench press ↑26% 1RM leg extension ↑66% number of maximum repetitions In the peaking phase shows an increasing trend in the number of repetitions in the bench press
Folland et al., 2002	Without experience in resistance training	9 weeks a)4x10 (75% 1RM) muscular failure b) 1 rep every 30 seconds for a total of 40 reps	Similar improvements in the performance of isometric force, maximum dynamic and isokinetic. The group did not reach muscle failure was the more progressive improvements.

CMJ: counter movement jump (cm). 1RM: one repetition maximum (kg). Peaking: performance optimization phase.

 ISSN 1988-5202

Other considerations

In the papers reviewed before, training load was applied to failure depending on the 1RM (repetition maximum achieved on a voluntary effort). However, due to the variability of load that can cause this type of stimulus control has been suggested the rating perceived effort as a control parameter for resistance training. Under this limitation and design philosophy of neuromuscular conditioning programs highlight the scale of perceived exertion of Robertson et al. (2003), or González-Badillo' line of research about the perceived effort (Gonzalez & Ribas, 2002). The use of the scale of perceived exertion did not support the idea of muscular failure as no recommended maximum perceived exertion of maximum effort or character or supramaximal (González & Ribas, 2002; Izquierdo & González-Badillo, 2008). Remarkable is the contribution of Zimmerman (2004) who believes that you must always leave three repetitions in the reserve would be the right choice.

Nowadays is proliferating the implementation of the partial occlusion during strength training, obtaining very positive results in this regard (Loenneke & Pujol, 2009). This methodology applies low relative loads (approximately 20-30% 1RM) for a high number of repetitions (> 20, reaching volitional fatigue), divided into 3-5 series, while applying an occlusion of low intensity (50 -100 mmHg) (Loenneke & Pujol, 2009). Recently, Wernbom et al. (2009) compared the application of this particular training method. The study generated two groups, one group was applied partial occlusion while the other group received no occlusion, both groups trained at 30% 1RM. Our results allow the authors to conclude that no significant differences in the EMG record, while no partial occlusion group performed more repetitions in the series and led all major post-exertional muscle pain. Therefore, pending further investigation, the application of muscle failure combined with partial occlusion, does not seem to generate greater effects with regard to implementation without partial occlusion.

Risks associated with training to muscle failure

In addition to the scale on the effectiveness of the method, there are some risks associated with training to muscle failure that may involve risk and commitment for those who use it (Table 3):

Negative effects on the adjustments in the neuromuscular system

Regular application of this form of training where is repeated the muscular damage induced by neuromuscular training may lead responses that reduce the effectiveness, or training adaptations delayed by several weeks (Kibler et al., 1992; Folland et al., 2001). In this sense is known that, the reduction on the level of neuromuscular system function can be extended in time and thereby affect the development of activities of daily living (Behm et al., 2001).

Similarly, the inflammatory responses generated by muscle damage is characterized by an increase of cytokines, which can be reduced and/or suppress testosterone anabolic functions (Clarkson & Newman, 1995; Ruiz et al., 2002) and even favour an atrophic process (Bruunsgaard et al., 2004; Roubenoff et al., 1997).

 ISSN 1988-5202

Risk of injury and overtraining in muscular failure training

In general, it is known that exercise causes muscle pain post-effort and discomfort that leads increases in muscle enzymes in blood flow caused by muscle damage, it generates a state of inflammation (Clarkson & Newman, 1995; Folland et al., 2001).

Associated with maximum efforts are a notable risk, the possibility of encouraging compromise breathing Valsalva maneuver (Zimmerman, 2004), with the health risk associated with it.

A significant aspect of this methodology is its ability to increase blood pressure values with magnitude greater than the methods that do not involve muscular failure (Zimmerman, 2004; Stone et al., 1996), leading an increase of heart effort (Zimmerman, 2004).

By taking the muscle to total fatigue may be shortcomings in the implementation correct exercise technique, raising the risk of compensatory movements (Zimmerman, 2004; Duffey & Challis, 2007). With reference to the safe during execution of the exercises, Rozzi et al. (1999) added that the training to muscular failure reduces the effectiveness of joint proprioceptive, leading to an increased risk of injury.

Although there is little objective evidence in this regard, this approach may increase the risk of injury in skeletal muscle, among others, Kibler et al. (1992) suggest reduction of elasticity, muscle weakness and muscle imbalances, as the most significant musculoskeletal risks.

For his part, Stone et al. (1996) highlighted the increased risk of entering a state of overtraining when you hold the training program to muscle failure.

The application of this methodology may involve a loss of motivation (Zimmerman, 2004) and very high state of discomfort (Kravitz, 2007), caused mainly by the large increase in lactate levels (Zimmerman, 2004). Therefore, states should be reserved for high motivation toward training.

Finally, it should be noted that the implementation of sets to muscle failure should be restricted to certain body regions such as lumbar spinal erectors, where it reduces the effectiveness of training. In this specific case, the training to muscle failure increases the involvement of synergistic muscles like the gluteus maximus or hamstring. For this reason, several authors support the implementation of 8-12 repetitions without reaching muscle failure for lumbar paraspinal strengthening (Graves et al., 1999; Carpenter et al., 1991; Clark et al., 2002; Hongo et al., 2005; Mayer et al., 2005).

 ISSN 1988-5202

Table 3. Risk of muscular failure training

Possible negative effects	Authors
Structural muscle damage	Kibler et al., 1992; Folland et al., 2001
↑ Inflammatory response	Clarkson and Newman 1995; Ruíz et al., 2002
Valsalva maneuver favors	Zimmerman, 2004
↑ Blood pressure	Stone et al., 1996; Zimmerman, 2004
↑ Risk of compensatory movements	Duffey and Challis, 2007
↓ Proprioceptive ability	Rozzi et al., 1999
↑ Lactate	Benson et al., 2006; Zimmerman, 2004
It requires strong motivation	Kravitz, 2007
↑ Overtraining risk	Stone et al., 1996; Willardson, 2007

CONCLUSIONS

The referenced literature suggests that sets can be applied to muscular failure, occasionally, in highly experienced athletes in resistance training that seeking to improve their performance in plateaus periods. However, the application of this form of training must be planned and not exceed seven weeks to avoid overtraining. Moreover, the application must be subject to avoid such training does not interfere on sports such as specific performance, power and even the maximum force, therefore, be interesting to establish a threshold of repetitions and intensity to ensure proper execution speed. A final important aspect of applying the training to muscle failure involves the motivation of the practitioner, since because of discomfort levels generated by the training require high values of motivation.

Implementation to healthy-training and practitioners with a low / medium status, and special populations, appears to be no substantiated because protocols comparing the effects of training and training to failure without reaching failure, have not found significant differences. In an aggregate, this form of training entails risks for the performance and functional capacity if, as increasing the risk of injury.

If you want to apply the training to muscular failure as a different stimulus (following the principle of variation) and planned (according to the principle of progression) in athletes or highly trained users who want to maximize both neural and hypertrophic adaptations should address the following considerations:

1) Application shall be planned; including sets with 8-12 repetitions near volitional fatigue, this range of repetition is used because it is based as a dose that can cause synergistic increases in strength, muscle endurance and hypertrophy in a healthy way (Hass et al., 2001). Number of sets should not be too high, since the benefits are very similar to small volumes and large volumes (Gonzalez-Badillo et al., 2006). Additionally, you must assume the existence of a large variability in the responses, depending on the adaptive capacity of each person (Humburg et al., 2007). It seems that may be a suitable alternative for those practitioners who do not have time to

 ISSN 1988-5202

implement a multi-series, and even generate better results than multi-series program without planning in subjects with experience in resistance training (Hass et al., 2000).

2) Application of muscular failure should be used in one or two exercises per muscle group, preferably in the last sets. These exercises should be located at the beginning of the session.

3) Inclusion of training to muscle failure can cause interference on the proper technique of the exercise, so it is recommended to apply when performing exercises on guided-machines (Willardson, 2007).

4) Time of rest between sets will be crucial if you apply muscular failure training, these two variables significantly affect the changes in hormonal and metabolic systems (for further review go to Willardson (2006). When you want to keep the number of repetitions for the methodology to muscle failure requires at least four minutes of rest between sets. Apply less recovery time will mean a loss in execution speed, increased fatigue and a decrease in training load (Richmond & Godard, 2004; García-López et al., 2007).

5) For a given training session should alternate between different muscle groups to prevent cumulative fatigue (Miranda et al., 2007).

6) Implementation of training to muscular failure should not exceed 7-week to avoid the risk of injury and / or overtraining interfering therefore attempts to optimize the neuromuscular system (Stone et al., 1996).

7) After the application microcycle based in muscular failure should apply a discharge microcycle (Naclerio, 2005).

As a final summary, it has designed a table (Table 4) depending on the objectives and the status of fitness that includes the positioning of the ACSM (2009) and the possible application of training reaching muscle failure.

Table 4. Inclusion to muscular failure at the various stages of training status according to the ACSM (2009).

	STRENGTH TRAINING	**MUSCLE HYPERTROPHY**	**MUSCLE POWER**	**LOCAL MUSCULAR ENDURANCE**	**MOTOR PERFORMANCE**	**OLDER ADULTS**
NOVICE	Do not apply	Do not apply	Do not apply	Do not apply	Do not apply	Do not apply
INTERMEDIATE	Do not apply	Ability to use as a stimulus different (<3 weeks)	Do not apply	Possibility to apply included in the planning	Do not apply	Do not apply
ADVANCED	Apply if there is plateau (≤ 7 weeks) and different stimuli.	Apply if there is plateau (≤ 7 weeks) and different stimuli.	Do not apply	Possibility to apply (≤ 7 weeks) included in the planning	Do not apply	Do not apply

 ISSN 1988-5202

FUTURE RESEARCH

Compare the effects obtained by reach muscular failure by the number of repetitions and through time maintaining muscle tension. As has been suggested previously (Tran & Docherty, 2006), when designing a neuromuscular conditioning program should attend the training volume, but only after the number of sets and reps but at the time of muscle tension, however, it is an issue which requires further investigation.

Carry out intervention work with periods of longer duration and frequency by placing short inter-tests in order to observe the progression in performance, especially if the volumes of the experimental protocols are not matched.

Compare acute and chronic effects of a conditioning neuromuscular program led to the failure by controlling the maximal repetition rate, the scale of perceived exertion and / or by the nature of effort.

Compare the morphological effects on the muscle cross-sectional area, program progressive resistance training led to failure without reaching maximum volitional fatigue.

Quantify the effects achieved by reaching the muscle failure during resistance training with new technologies such as electrical stimulation and / or neuromuscular vibrations.

Performing a meta-analytic review of the effectiveness of training to muscle failure compared with no training to muscle failure.

REFERENCES

1. ANTONIO J, GONYEA W. Skeletal muscle fiber hyperplasia. *Med Sci Sports Exerc.* 1993; 25:1333-1345. [Abstract] [Back to text]
2. BEHM DG, BAKER KM, KELLAND R, LOMOND J. The effect of muscle damage on strength and fatigue deficits. *J Strength Cond Res*. 2001; 15:255-263. [Abstract] [Back to text]
3. BENSON C, DOCHERTY D, BRANDENBURG J. Acute neuromuscular responses to resistance training performed at different loads. *J Sci Med Sport.* 2006; 9:135-142. [Abstract] [Back to text]
4. BRANDENBURG J, DOCHERTY D. The effect of training volume on the acute responses and adaptations to resistance training. *Int J Sports Physiol Perform.* 2006; 1:108-121. [Abstract] [Back to text]
5. BRUUNSGAARD H, BJERREGAARD E, SCHROLL M, PEDERSEN BK. Muscle strength after resistance training is inversely correlated with baseline levels of soluble tumor necrosis factor receptors in the oldest old. *J Am Geriatr Soci.* 2004; 52:237-241. [Abstract] [Back to text]
6. BYRNE CH, TWIST C, ESTON R. Neuromuscular function after exercise-induced muscle damage. Theoretical and applied implications. *Sports Med.* 2004; 34:49-69. [Abstract] [Back to text]
7. CALDERÓN FJ, GARCÍA A, BENITO PJ, LEGIDO J. Adaptación biológica al entrenamiento de resistencia. *Arch Med Dep.* 2004; 20:317-327. [Back to text]

 ISSN 1988-5202

8. CAMPOS GE, LUECKE TJ, WENDELH HK, TOMA K, HAGERMAN FC, MURRAY TF, RAGG KE, RATAMESS NA, KRAEMER WJ, STARON RS. Muscular adaptations in response to three different resistance-training regimens: specificity of repetition maximun training zones. *Eur J Appl Physiol.* 2002; 88:50-60. [Abstract] [Back to text]
9. CARPENTER DM, GRAVES JE, POLLOCK ML, LEGGET SH, FOSTER D, HOLMES B, FULTON MN. Effect of 12 and 20 weeks of resistance training on lumbar extension torque production. *Phys Ther.* 1991; 71:580-588. [Full text] [Back to text]
10. CLARK BC, MANINI TM, MAYER SM, PLOUTZ-SNYDER LL, GRAVES JE. Electromyographic Activity of the lumbar and hip extensors during dynamic trunk extension exercise. *Arch Phys Med Rehab.* 2002; 83:1547-1552. [Abstract] [Back to text]
11. CLARKSON PM, NEWHAM DJ. Associations between muscle soreness, damage, and fatigue. *Adv Exp Med Biol.* 1995; 384:457-469. [Abstract] [Back to text]
12. CLOSE G, KAYANI A, VASILAKI A, MCARDLE A. Skeletal muscle damage with exercise and aging. *Sports Med*. 2005; 35:413-427. [Abstract] [Back to text]
13. COLADO JC, CHULVI I. Criterios para la planificación y el desarrollo de programas de acondicionamiento muscular en el ámbito de la salud en Rodríguez PL editor. *Ejercicio físico en salas de acondicionamiento muscular. Bases científico-médicas para una práctica segura y saludable.* Madrid: Panamericana; 2008. pp. 91-127. [Abstract] [Back to text]
14. CONLEY MS, ROZENEK R. Health aspects of resistance exercise and training. *Strength Cond J*. 2001; 23:9-23. [Abstract] [Back to text]
15. CREWTHER B, CRONIN J, KEOGH J. Possible stimuli for strength and power adaptation. Acute metabolic responses*. Sports Med.* 2006a; 36:65-78. [Abstract] [Back to text]
16. CREWTHER B, KEOGH J, CRONIN J, COOK CH. Possible stimuli for strength and power adaptation. Acute hormonal responses. *Sports Med.* 2006b; 36:215-238. [Abstract] [Back to text]
17. DRINKWATER E, LAWTON TW, LINDSELL RP, PYNE DB, HUNT PH, MCKENNA MJ. Repetition failure is a key determinant of strength development in resistance training. *Med Sci Sports Exerc.* 2004; 36:S53. [Abstract] [Back to text]
18. DRINKWATER EJ, LAWTON TW, LINDSELL RP, PYNE DB, HUNT PH, MCKENNA MJ. Training leading to repetition failure enhances bench press strength gains in elite junior athletes. *J Strength Cond Res.* 2005; 19:382-388. [Abstract] [Back to text]
19. DRINKWATER EJ, LAWTON TW, MCKENNA MJ, LINDSELL RP, HUNT PH, PYNE DB. Increased number of forced repetitions does not enhance strength development with resistance training. *J Strength Cond Res.* 2007; 21:841-847. [Abstract] [Back to text]
20. DUFFEY MJ, CHALLIS JH. Fatigue effects on bar kinematics during the bench press. *J Strength Cond Res.* 2007; 21:556-560. [Abstract] [Back to text]
21. ENOKA RM, DUCHATEAU J. Muscle fatigue, what and how in influences muscle function. *J Physiol.* 2007; 586: 11-23. [Abstract] [Back to text]
22. FERNÁNDEZ- GARCÍA B, TERRADOS N. *La fatiga del deportista*. Madrid: Gymnos; 2004. [Abstract] [Back to text]
23. FITTS RH. Cellular mechanisms of muscle fatigue. *Physiol Rev.* 1994; 74: 49-94. [Abstract] [Back to text]

24. FOLLAND JP, CHONG J, COPEMAN EM, JONES DA. Acute muscle damage as a stimulus for training-induced gains in strength. *Med Sci Sports Exerc.* 2001; 22:1200-1205. [Abstract] [Back to text]
25. FOLLAND JP, IRISH CS, ROBERTS JC, TARR JE & JONES DA. Fatigue is not a necessary stimulus for strength gains during resistance training. *Br J Sports Med* 2002; 36:370-374. [Abstract] [Back to text]
26. FRY AC, KRAEMER WJ, VAN BORSELEN F, LYNCH JM, MARSIT JL, ROY EP, TRIPLETT NT, KNUTTGEN HG. Performance decrements with high-intensity resistance exercise overtraining. *Med Sci Sports Exerc.* 1994; 26:1165-1173. [Abstract] [Back to text]
27. FRY AC. The role of resistance exercise intensity on muscle fibre adaptations. *Sports Med.* 2004; 34:663-679. [Abstract] [Back to text]
28. GARCÍA-LÓPEZ D, DE PAZ JA, MONEO E, JIMÉNEZ-JIMÉNEZ R, BRESCIANI G, IZQUIERDO M. Effects of short vs long rest period between sets on elbow-flexor muscular endurance during resistance training to failure. *J Strength Cond Res.* 2007; 21:1320-1324. [Abstract] [Back to text]
29. GONZÁLEZ –BADILLO JJ, IZQUIERDO M, GOROSTIAGA EM. Moderate volume or high relative training intensity produces greater strength gains compared with low and high volumes in competitive weightlifters. *J Strength Cond Res.* 2006; 20:73-81. [Abstract] [Back to text]
30. GONZÁLEZ JM, RIBAS J. *Bases de la programación del entrenamiento de fuerza.* Barcelona: Inde; 2002. [Abstract] [Back to text]
31. GOTO K, NAGASAWA M, YANAGISAWA O, KIZUKA T, ISHII N, TAKAMATSU K. Muscular adaptations to combinations of high and low intensity resistance exercises. *J Strength Cond Res.* 2004; 18:730-737. [Abstract] [Back to text]
32. GRAVES JE, POLLOCK ML, FOSTER D, LEGGETT SH, CARPENTER DM, VUOSO R, JONES A. Effect of training frequency and specificity on isometric lumbar extension strength. *Spine*. 1990; 15:504-509. [Abstract] [Back to text]
33. HASS CJ, FEIGENBAUM MS, FRANKLIN BA. Prescription of resistance training for healthy populations. *Sports Med.* 2001; 31:953-964. [Abstract] [Back to text]
34. HASS CJ, GARZARELLA L, DE HOYOS D, POLLOCK ML. Single versus multiple sets in long-term recreational weigthlifters. *Med Sci Sports Exerc.* 2000; 32:235-242. [Abstract] [Back to text]
35. HONGO M, ITOI E, SINAKE M, SHIMADA Y, MIYAKOSHI N, OKADA K. Effects of reducing resistance, repetitions and frequency of back strengthening exercise in healthy Young women: a pilot study. *Arch Phys Med Rehabil.* 2005; 86:1299-303. [Abstract] [Back to text]
36. HUMBURG H, BAARS H, SCHRÖEDER J, REER R, BRAUMANN K-M. 1-set vs 3-set resistance training: a crossover study. *J Strength Cond Res.* 2007; 21:578-582. [Abstract] [Back to text]
37. HUNTER SK, DUCHATEAU J, ENOKA RM. Muscle fatigue and the mechanism of task failure. *Exerc Sports Sci Rev.* 2004; 32:44-49. [Abstract] [Back to text]
38. IZQUIERDO M, GONZÁELZ-BADILLO JJ, HÄKKINEN K, IBÁÑEZ J, KRAEMER WJ, ALTADILL A, ESLAVA J, GOROSTIAGA EM. Effect of loading on unintentional lifting velocity declines during single sets of repetitions to failure during upper and lower extremity muscle actions. *Int J Sports Med.* 2006a; 27:718-724. [Abstract] [Back to text]

 ISSN 1988-5202

39. IZQUIERDO M, GONZÁLEZ-BADILLO JJ. Prescripción del entrenamiento de fuerza en IZQUIERDO M. *Biomecánica y bases neuromusculares de la actividad física y el deporte*. Madrid: Editorial Médica Panamericana; 2008. pp. 663-675. [Abstract] [Back to text]
40. IZQUIERDO M, IBÁÑEZ J, GONZÁLEZ-BADILLO JJ, HÄKKINEN K, RATAMESS NA, KRAEMER WJ, FRENCH DN et al. Differential effects of strength training leading to failure versus not to failure on hormonal responses, strength, and muscle power gains. *J Appl Physiol.* 2006b; 100:1647-1656. [Full text] [Back to text]
41. IZQUIERDO-GABARREN M, GONZÁLEZ DE TXEBARRI R, GARCÍA-PALLARÉS J, SÁNCHEZ-MEDINA L, SÁEZ DE VILLARREAL ES, IZQUIERDO M. Concurrent endurance and strength training not to failure optimizes performance gains. *Med Sci Sports Exerc.* 2009 (in press). [Abstract] [Back to text]
42. KELL RT, GORDON B, QUINNEY A. Musculoskeletal fitness, health outcomes and quality of life. *Sports Med.* 2001; 31:863-873. [Full text] [Back to text]
43. KRAEMER WJ, RATAMESS MA. Hormonal responses and adaptations to resistance exercise and training. *Sports Med.* 2005; 35:339-361. [Abstract] [Back to text]
44. KRAEMER WJ, RATAMESS NA. Fundamentals of resistance training: Progression and exercise prescription. *Med Sci Sports Exerc*. 2004; 336:674-688. [Abstract] [Back to text]
45. KRAMER JB, STONE MH, O'BRYANT HS, CONLEY MS, JOHNSON RL, NIEMAN DC, HONEYCUTT DR et al. Effects of single vs multiple set of weight training: impact of volumen, intensity and variation. *J Strength Cond Res.* 1997; 11:143-147. [Abstract] [Back to text]
46. KRAVITZ L. Training to failure. *IDEA Fitness Journal.* 2007; 4:23-24. [Abstract] [Back to text]
47. LOENNEKE JP, PUJOL TJ. The use of occlusion training to produce muscle hypertrophy. *Strength Cond J.* 2009; 31:77-84. [Abstract] [Back to text]
48. MAYER JM, GRAVES JE, CLARK BC, FORMIKELL M, PLOUTZ-SNYDER LL. The use of magnetic resonance imaging to evaluate lumbar muscle activity during trunk extension exercise at varying intensities. *Spine.* 2005; 30:2556-63. [Abstract] [Back to text]
49. MCCULLY KK, FAULKNER JA. Injury to skeletal muscle fibers of mice following lengthening contractions. *J Appl Physiol.* 1985; 59:119-125. [Abstract] [Back to text]
50. MIRANDA H, FLECK SJ, SIMAO R, BARRETO AC, DANTAS EHM, NOVAES J. Effect of two different rest period lengths on the number of repetitions performed during resistance training. *J Strength Cond Res.* 2007; 21:1032-1036. [Abstract] [Back to text]
51. NACLERIO F. Entrenamiento de la fuerza y prescripción del ejercicio. En: JIMÉNEZ A. (ed.). *Entrenamiento perso*nal. Barcelona: Inde; 2005. pp 87-133. [Abstract] [Back to text]
52. NOSAKA K, LAVENDER A, NEWTON M, SACCO P. Muscle damage in resistance training- Is muscle damage necessary for strength gain and muscle hypertrophy?-. *Int J Sport Health Sci.* 2003; 1:1-8. [Full text] [Back to text]
53. RATAMESS N, ALVAR B, EVETOCH TK, HOUSCH TJ, KIBLER B, KRAEMER WJ, TRIPLETT NT. Progression models in resistance training for healthgy adults. *Med Sci Sports Exerc.* 2009; 41:687-708. [Abstract] [Back to text]

 ISSN 1988-5202

54. RHEA MR, ALVAR BA, BURKETT LN, BALL SD. A meta-analysis to determine the dose response for strength development. *Med Sci Sports Exerc*. 2003; 35:456-64. [Abstract] [Back to text]
55. RICHMOND SR, GODARD MP. The effects of varied rest periods between sets to failure using the bench press in recreationally trained men. *J Strength Cond Res.* 2004; 18:846-849. [Abstract] [Back to text]
56. ROBERTSON JR, GOSS FL, RUTKOWSKI J, LENZ D, DIXON C, TIMMER J. Concurrent validation of the OMNI Perceived Exertion Scale for Resistance Exercise. *Med Sci Sports Exerc.* 2003; 35:333-341. [Abstract] [Back to text]
57. ROUBENOFF R, FREEMAN LM, SMITH DE, ABAD LW, DINARELLO CA, KEHAYIAS JJ. Adjuvant arthritis as a model of inflammatory cachexia. *Arthritis Rheum.* 1997; 40:534-539. [Abstract] [Back to text]
58. ROZZI SL, LEPHART SM, FU FH. Effects of muscular fatigue on knee joint laxitiy and neuromuscular characteristics of male and female athletes. *J Athletic Training.* 1999; 34:106-114. [Abstract] [Back to text]
59. RUÍZ J, MULA FJ, MESA JL, GARZÓN MJ, GUTIÉRREZ A. Mejora de la fuerza por supercompensación tras sobrecarga y descanso activo. *Revista Entrenamiento Deportivo.* 2002; 16:6-12. [Back to text]
60. SALE DG. Influence of exercise and training on motor unit activation. *Exerc Sport Sci Rev*. 1987; 15:95-151. [Abstract] [Back to text]
61. SANBORN K, BOROS R, HRUBY J, SCHILLING B, O'BRYANT HS, JOHNSON RL, HOKE T, STONE ME, STONE MH. Short-term performance effects of weight training with multiple sets not to failure vs a single set to failure in women. *J Strength Cond Res.* 2000; 14:328-336. [Abstract] [Back to text]
62. SIMAO R, DE TARSO P, POLITO MD, VIVEIROS L, FLEXK SJ. Influence of exercise order on the number of repetitions performed and perceived exertion during resistance exercise in women. *J Strength Cond Res*. 2007; 21:23-28. [Abstract] [Back to text]
63. SPIERING BA, KRAEMER WJ, ANDERSON JM, ARMSTRONG LE, NINDL BL, VOLEK JS, MARESH, CM. Resistance exercise biology. Manipulation of resistance exercise programme variables determines the responses of celular and molecular signalling pathways. *Sports Med.* 2008; 31:863-873. [Abstract] [Back to text]
64. STONE MH, CHANDLER TJ, CONLEY MS, KRAEMER JB, STONE ME. Training to muscular failure: is it necessary? *Strength Cond J.* 1996; 18:44-48. [Abstract] [Back to text]
65. TAN B. Manipulating resistance training program variable to optimize maximum strength in men: A review. *J Strength Cond Res*. 1999; 13:289-304. [Abstract] [Back to text]
66. TRAN QT, DOCHERTY D. Dynamic training volume: a construct for both time under tension and volume load. *J Sports Sci Med.* 2006; 5:707-713. [Abstract] [Back to text]
67. WERNBOM M, JÁRREBRING R, ANDREASSON MA, AUGUSTSSON J. Acute effects of blood flow restriction on muscle activity and endurance during fatiguing dynamic knee extension at low load. *J Strength Cond Res*. 2009; 23:2389-2395. [Abstract] [Back to text]

 ISSN 1988-5202

68. WILLARDSON JM. A brief review: Factors affecting the length of the rest interval between resistance exercise sets. *J Strength Cond Res.* 2006; 20:978-989. [Abstract] [Back to text]
69. WILLARDSON JM. The application of training to failure in periodized multiple-set resistance exercise programs. *J Strength Cond Res.* 2007; 21:628-631. [Abstract] [Full text] [Back to text]
70. ZIMMERMAN K. *Entrenamiento muscular.* Barcelona: Paidotribo; 2004. [Abstract] [Back to text]

 ISSN 1988-5202