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REVISIÓN / REVIEW

EFFECTS OF INERTIAL OVERLOAD RESISTANCE TRAINING ON MUSCLE FUNCTION

EFFECTOS DEL ENTRENAMIENTO CON SOBRECARGAS ISOINERCIALES SOBRE LA FUNCIÓN MUSCULAR

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ABSTRACT

Resistance training should be included in all exercise programs that improve health and quality of life. These programs have been focusing on both concentric-eccentric contractions, however, a new type of resistance training based on eccentric contractions provided by inertial overload is being carried out. Therefore, the aim of the present study is to prove the effects of this kind of training based on eccentric contractions by inertial overload. Databases utilized to carry out information research were *Web of Science*, *Pubmed*, *Medline*, *Dialnet* and *Scielo*. Results would suggest that inertial training based on inertial overload produces maximal EMG and an earlier muscular hypertrophy compared to conventional resistance training, besides the fact it could be successful on muscle-tendon injuries.

KEYWORDS: eccentric, flywheel inertial loading, inertial resistance, resistance training, strength.

RESUMEN

El entrenamiento de fuerza debe incluirse en todos los programas de ejercicio encaminados a mejorar la salud y la calidad de vida. Los programas de entrenamiento de fuerza han priorizado los regímenes de contracción concéntricos a los excéntricos, sin embargo, actualmente se está realizando un tipo de entrenamiento de fuerza basado en contracciones excéntricas mediante sobrecargas de tipo inercial. Por tanto, el objetivo del presente trabajo de revisión bibliográfica ha sido comprobar los efectos de este tipo de entrenamiento basado en contracciones excéntricas mediante sobrecargas de tipo inercial sobre la función muscular. Para ello se realizó una búsqueda bibliográfica en las bases de datos *Web of Science*, *Pubmed*, *Medline*, *Dialnet* y *Scielo*. Los resultados de nuestra revisión sugieren que este tipo de entrenamiento da lugar a una mayor actividad electromiográfica e hipertrofia muscular con respecto a programas de entrenamiento convencionales, al tiempo que podrían ser efectivos en la recuperación de lesiones músculo-tendinosas.

PALABRAS CLAVE: excéntrico, volante carga inercial, resistencia inercial, entrenamiento fuerza, fuerza.

INTRODUCTION

Resistance training induces both neural and structural adaptations (Crewter, Cronin, and Keogh, 2006; Hunter, McCarty and Bamman, 2004; Young et al., 2005), involving hypertrophy, muscle strength and power improvements (Smith et al., 2014). Such adaptations have caused that this kind of exercise is used by athletes of almost all kind of modalities to improve performance (Basset and Howley, 2000; Young et al., 2005). The effects of resistance training on the mass (Chung et al., 2013) and muscle quality (Brooks et al., 2007), too, have been positively associated with factors such as insulin sensitivity and negatively with neuromuscular diseases, as could be Parkinson's disease (Schilling et al., 2009). Therefore, resistance training should be included in all those exercise programs aimed at improving health and quality of life (Ratamess et al., 2009).

Resistance training based on concentric contractions has been the most frequently used, because eccentric contractions have been associated with delayed muscle pain and functional impairment of muscle fiber, which is accompanied by a transient decrease in maximum strength levels, muscular power and sports gesture economy (Braun and Dutto, 2003; Cheung, Hume and Maxwell, 2003; Moysi et al., 2005; Yu et al., 2003). Muscle damage caused by eccentric contractions is also accentuated by the increasing speed of contraction (Chapman et al., 2008), the degree of amplitude, intensity and its duration (Cheung et al., 2003; Moysi et al., 2005; Nosaka, Newton and Sacco, 2002). However, a new type of resistance training with high speed and intensity eccentric contractions provided by inertial overload is becoming very popular nowadays.

Machines which apply eccentric inertial overloads are based on a rotating disc fixed to a support structure with a strap acting at a distance from the axis of rotation, where pulling movements are carried out (Chiu and Salem, 2006). Thus, after pulling the strap through a concentric action, the wheel keeps rotating due to inertia, until the muscle must slow down all the kinetic energy previously generated at the end of the eccentric phase, in a fast way (Tesch, Ekberg and Trieschmann, 2004). Thus, the lowest angular displacement at this stage is responsible for the increased load on the eccentric action of the movement (Tous, 2010).

Eccentric inertial training has been proposed as an appropriate stimulus, not only to improve strength and power levels in healthy population (Norrbrand et al., 2008, 2010) but also it could be an optimal training system to avoid sarcopenic states (Reeves et al., 2005) and even prevent the occurrence of injuries and facilitate their recovery time (Romero-Rodriguez, Gual and Tesch, 2011). Therefore, the objective of the present review was to test the effectiveness of eccentric training on the inertial force production capacity and muscle power, as well as making changes at connective and musculoskeletal tissues.

MATERIAL AND METHODS

In order to meet the objectives of the work, a review in which all inertial overload training interventions that have assessed the adjustments on the muscle-tendon function has been carried out. The bibliographic search in the databases *Web of Science*, *PubMed*, *Medline*, *Dialnet* and *Scielo* was performed using keywords included in the *Medical Subject Headings (MeSH)* developed by the *U.S National Library of Medicine*. The terms used were "*eccentric overload*", "*eccentric muscle actions*", "*inertial training*" and *flywheel*, in combination with "*resistance training*" and *strength*.

A total number of 626 results responded to the search strategy, however, a filter which delimited the work published to a period between 2005 and 1 January 2015 was applied. The 235 resulting abstracts published in that period were read by two researchers. Furthermore, all works which met the following criteria were eliminated by researchers: those works published in a language other than Spanish, English, French or Portuguese (n : 3), intervention works - patents (n : 98), conference abstracts (n : 24) or bibliographic reviews and meta-analysis (n : 5) - or intervention works focused on analyzing not only answers and adaptations (n : 7). Out of the 59 articles including exercise interventions, those which conducted a workout without including inertial overloads (n : 42) or without valuing muscle function (n : 3) were removed. Out of the 14 articles that met the inclusion criteria proposed by researchers, a total of 9 items were finally used for the present work (see Figure 1). The reason was the inability to access the full text of 5 articles, which is the main limitation of this review.

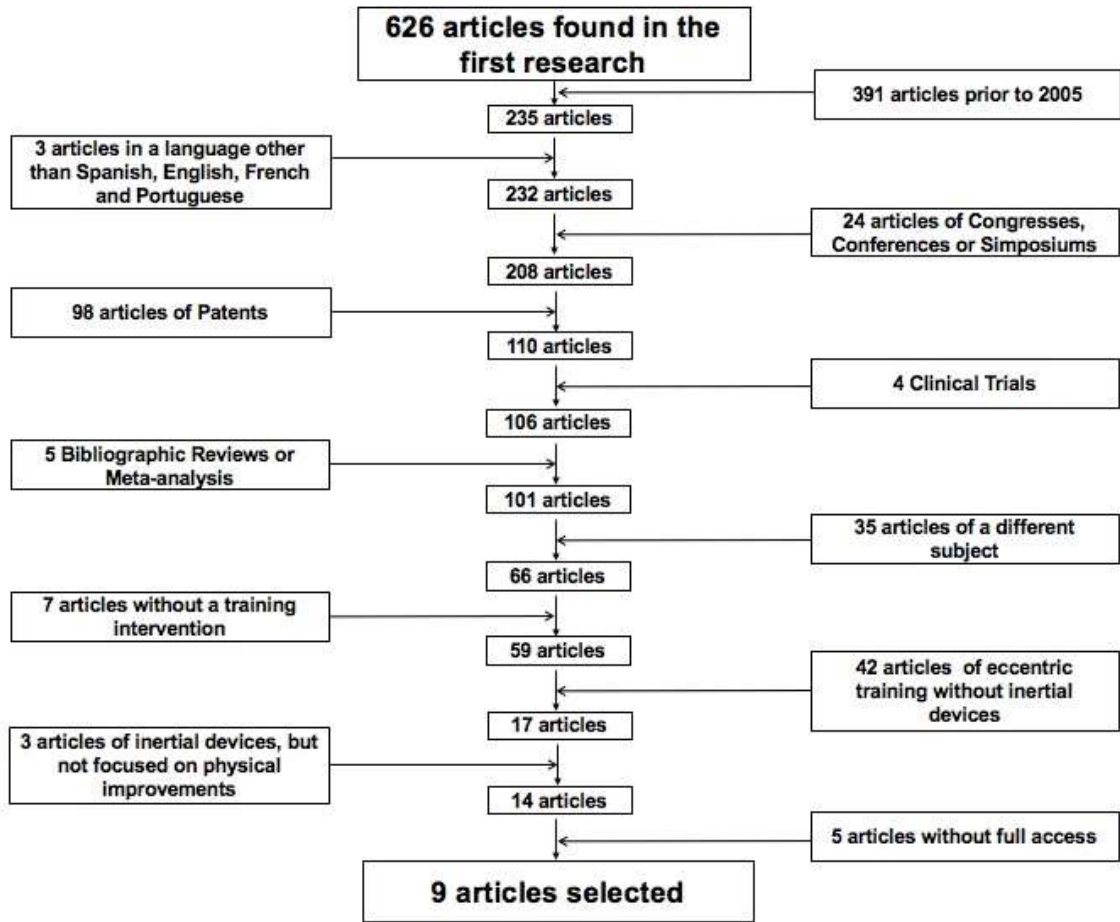


Figure 1. Exclusion criteria followed when selecting the studies analyzed in the investigation.

Table 1. Summary of studies that have evaluated the effects of eccentric isoinertial overload training

Reference	Sample	Duration	Method	Assessment	Results
Brzenczek-Owczarzak et al. (2013)	Elderly women (n: 45): GE0kg (n: 18) GE5kg (n: 17) GC (n: 10)	4 w (12 sessions)	GE0kg: 4 x 20 sec x 3 shoulder exercises without additional load. R: 2 min GE5kg: idem, but with a 5kg additional load	- Shoulder Abduction Force - Shoulder Abduction Power	Force: improved in GE0kg (21.9%) and GE5kg (6.9%). Statistically greater improvement in GE0kg vs GE5kg Power: improved in GE0kg (34.3%) and GE5kg (9.8%). Statistically greater improvement in GE0kg vs GE5kg
Fernández-Gonzalo et al. (2014)	People who had a Stroke (n: 20)	8 w (16 sessions)	GE: 4 x 7 x knee extension in the affected leg. R: 3 min	- Concentric P _{peak} Knee Extension - Isometric Leg Extension Force - BBS - 6MWT - TUG - 30CST - Modified Ashworth Scale - SIS	Concentric P _{peak} Knee Extension: increased on the affected leg (34%) and non-affected leg (25%). Statistically greater improvements in affected leg vs non-affected leg Eccentric P _{peak} Knee Extension: increased on the affected leg (44%) and non-affected leg (34%). Statistically greater improvements in eccentric P _{peak} vs concentric P _{peak} Increase in Force of bilateral isometric extension on the affected leg (17%) and unilateral isometric extension (20%). Statistically greater improvements in affected leg vs non-affected leg BBS: improved (7%) 6MWT: improved (17%) TUG: improved (15%) 30 CST: improved (17%)
Norrbrand et al. (2008)	Strength-trained	5 w (12 sessions).	GE: 4 x 7 x leg extension CCG: 4 x 7 RM x leg extension	- CVM Knee Extension - CSA Quadriceps	CVM: improved in GE and CCG. Statistically greater improvement in GE vs CCG

	adults (n: 15): GE (n: 7) GEC (n: 8)				CSA quadriceps: improved in GE (6.2%) and CCG (3.0%). Statistically greater improvement in GE vs CCG
Norrbrand et al. (2010)	Strength-trained adults (n: 17): GE (n: 9) GEC (n: 8)	5 w (12 sessions).	GE: 4 x 7 x leg extension CCG: 4 x 7 RM x leg extension	- MVC Knee Extension - RFD	MVC knee extension: improved in GE (8.1%) and in CCG (4.8%). Statistically greater improvement in GE vs CCG
Onambélé et al. (2008)	Elderly people (n: 24): GE (n: 12) GEC (n: 12)	12 w (66 sessions)	GE: 1-4 x 8-12 x leg extension. R: 5 min CCG: 1-4 x 8-12 (80% of 1RM) x leg extension. R: 5 min	- MVC Knee Extension - Postural Balance (posturography) - Stiffness of Achilles Tendon	MVC knee extension: Force improved in GE (28%) and in GEC (4%). Statistically greater improvement in GE vs CCG Postural Balance improved in GE (from 24.3 to 35.2 sec). Statistical differences in GE vs CCG Stiffness of Achilles Tendon: mejora en GE (136%) y CCG (54%). Statistically greater improvement in GE vs CCG
Romero-Rodríguez et al. (2011)	Deportistas de élite con tendinopatía rotuliana crónica (n: 10)	6 w (12 sessions)	GE: 4 x 10 x knee extension. R: 2 min.	- MVC - CMJ - Concentric and Eccentric F _{max} Knee Extension - VAS - VISA	Eccentric F _{max} knee extension: 90% improved VAS: 60% decreased VISA: 86% improved
Reeves et al. (2005)	Active and healthy bedridden men (n: 18) GE (n: 9) GC (n: 9)	13 w (38 sessions)	GE: 4 x 7 x hip extension + knee and ankle extension. R: 2 min inter-series y 5 min inter-exercises	- CSA of Achilles Tendon - Isometric Force Plantar Flexion - Deformation of Gastrocnemius Tendon	Deformation of gastrocnemius tendon: 16% increased in GE and 26% in GC. Statistically greater difference in GC vs GE Stiffness of Achilles Tendon: decreased in GE (37%) and GC (58%). Statistically greater difference in GC vs GE

				<ul style="list-style-type: none"> - Stiffness of Achilles Tendon - Young's Module of Achilles Tendon - Length of Achilles Tendon - Force of Gastrocnemius Tendon - Tension of Gastrocnemius Tendon - Stress of Gastrocnemius Tendon 	<p>Young's Module of Achilles tendon: decreased in GE (38%) and in GC (57%). Statistically greater difference in GC vs GE</p> <p>Force of gastrocnemius tendon: decreased in GE (14%) and in GC (28%). Statistically greater difference in GC vs GE</p> <p>Tension of gastrocnemius tendon: increased in GE (17%) and in GC (27%). Statistically greater difference in GC vs GE</p> <p>Stress of gastrocnemius tendon: decreased in GE (14%) and in GC (27%). Statistically greater difference in GC vs GE</p>
Rittweger et al. (2007)	<p>Young bedridden men (n: 25):</p> <p>GE (n: 9) GC (n: 16)</p>	13 w (38 sessions)	GE: 4 x 7 x hip extension + knee and 4 x 14 x ankle extension. R: 2 min inter-series y 5min inter-exercises	- CMJ (H, P _{peak} and A _{peak})	<p>H: decreased in GE (10.4%) and in GC (29.5%). Statistically greater difference in GC vs GE.</p> <p>H Recovery Time: less in GE (72 days) vs GC (163 days). Statistically greater difference in GC vs GE</p> <p>P_{peak}: decreased in GE (6.1%) and in GC (25.8%). Statistically greater difference in GC vs GE</p> <p>P_{peak}: GE shows efectivity (76%) to maintain it. Statistical differences in GE vs GEC</p> <p>P_{peak} Recovery Time: less in GE (18 days) vs GC (140 days). Statistically greater difference in GC vs GE</p> <p>A_{peak}: decreased in GE (5.4%) and in GC (15.7%). Statistically greater difference in GC vs GE</p>

					A_{peak} Recovery Time: less in GE (15 days) vs GC (71 days). Statistically greater difference in GC vs GE
Seynnes et al. (2007)	Young-trained people (n: 13): GE (n: 7) GC (n: 6)	5 w (15 sessions)	4 x 7 x knee extension. R: 2 min	- MVC Knee Extension - CSA Quadriceps - Muscle Architecture of VL	MVC in knee extension: improved in GE (38.9%) along with increased electromyography activity (34.8%). Statistically greater differences in GE vs GEC CSA quadriceps: improved in GE (13.8%). Statistically greater differences in GE vs GEC Muscle Architecture of VL: pennation angle improved in GE (7.7%). Statistically greater differences in GE vs GEC

30CST: 30-Second Chair Stand Test; 6MWT: 6 minute Walking Test; A_{peak} : Peak Acceleration; BBS: Berg Balance Scale; CCG: Concentric Contractions Training Group; CG: Control Group; CMJ: Countermovement Jump; CSA: Cross-sectional Area; DJ: Drop Jump; FJP: Four-consecutive Jump Test; F_{max} : Maximal Force; GE0kg: Eccentric Isoinertial Overload without Additional Load Training Group; GE5kg: Eccentric Isoinertial Overload with Additional 5kg-load Training Group; GE: Eccentric Isoinertial Overloads Training Group H: Flying Height; IF_{max} : Maximal Isometric Force; min: Minute; MVC: Maximal Voluntary Contraction; P_{peak} : Peak Power; R: Recovery; RFD: Rate of Force Development; sec: Seconds; SIS: Stroke Impact Scale; TUG: Timed Up and Go Test; VAS: Visual Analog Scale; VISA: Patellar Tendinopathy Questionnaire; VL: Vastus Lateralis; w: Week.

All results presented reflect only those with statistically significant differences ($p < 0.05$)

EFFECTS OF ECCENTRIC TRAINING WITH INERTIAL OVERLOADS ON MUSCULAR STRENGTH AND POWER

Muscle mechanical properties enable it to generate higher force levels when contracting in lengthening (eccentric actions) compared to shortening (concentric actions) (Komi and Buskirk, 1972). When a concentric contraction is preceded by an eccentric action and a short coupling period between contractions, known as stored elastic energy (SSE), the eccentric action may enhance subsequent concentric action (Norrbrand et al., 2008). For this is why the combination of eccentric and concentric contractions within a training program lead to greater improvements in strength and power levels than those only focused on a exclusive muscle contraction system (Hruda et al., 2003).

At conventional strength training, based on concentric contractions, the maximal activation of the eccentric phase is prevented by the load (Moritani, Muramatsu and Wall, 1987). For instance, within a typical conventional strength training exercise, such as knee-extension exercise machine, the maximum EMG activity is achieved during the initial phase of contraction, coinciding with 170-180° knee angle and a minimum fascial stretching (Onambélé et al., 2004). By contrast, during the execution of a knee extension exercise inertial machine, EMG maximum levels occur at 90-100° angulation (Norrbrand et al., 2008), coinciding with peak fascial stretching moments, (Onambélé et al., 2008). Furthermore, due to inertial machines have to stop inertia generated on the axis of rotation within a very small movement range, it consequently leads the eccentric force peak to reach much higher levels compared to other types of eccentric training performed at a lower speed (Norrbrand et al., 2008). Concerning concentric phases in such machines, it results a maximum degree of muscle activation throughout the range of motion (Tesch et al., 2004), due to the absence of phase *mechanical disadvantage* observed during concentric phases while training with conventional loads.

Therefore, the eccentric inertial systems that generate overloads result in high degrees of muscle activation throughout the concentric and eccentric phase of the movement, especially in the final part of the later. Thus, this type of overload has the possibility to produce optimal overloads to induce improvements in the highest levels of muscle contraction and force production, especially in SSE muscle actions (Norrbrand et al., 2010). Consequently, it was found that both 12-week training program in elderly population (Onambélé et al., 2008) and a 5-week program in resistance-trained adults (Norrbrand et al., 2008, 2010) based on inertial eccentric overload, led to a greater EMG activity and higher levels of strength compared to conventional strength training.

Eccentric and SSE actions must be prioritized in rehabilitation programs of people who suffered stroke, due to their favorable difference in maximal voluntary concentric contraction relative to the eccentric, compared to healthy subjects (Clark, Condlife and Patten, 2006; Hedlund et al, 2012;. Ryan et al., 2011). Fernández-González et al. (2014) found that an 8-weeks training program (frequency of 2 sessions per week) consisting of 4 sets of 7 reps of knee extension on the affected side, induces significant improvements in both affected legs (trained) compared to the untrained in maximum isometric

contraction force of the knee, and in both the eccentric and concentric peak power of both legs. However, what is really remarkable is that these improvements were accompanied by an increased functional test performance related to quality of life such as the Berg Balance Scale, the 30 seconds Sit and Go Test, the Time and Go Test and 6-Minute Walking Test.

Improving strength and muscle power levels is a target for the entire adult population. A greater strength is related to a better profile of cardiometabolic risk factors and a reduced risk of cardiovascular events (Ratamess et al., 2009). Since aging is accompanied by a loss of muscle mass levels as well as deterioration of contractile capacity and strength production, elderly population should conduct training programs aimed at improving muscular strength levels. Previously, we have mentioned the study carried out by Onambélé et al. (2008) who found that eccentric inertial training program was not only effective to lead to improvements in the force levels but also had a higher effect than a concentric training. In order to identify whether this population group should add additional loads on an eccentric inertial training, the effect on the levels of strength and power in shoulder abduction was observed in a group of elderly women who exercised for a total of 12 sessions, performing this kind of training with or without 5kg extra-weight overload (Brzenczek-Owczarzak et al., 2013). The results of the study showed that as well as both types of training induced significant improvements on strength and power at trained muscles, the non-added overload exercise group showed greater improvements.

EFFECTS OF ECCENTRIC TRAINING WITH INERTIAL OVERLOADS ON MUSCULAR HYPERTROPHY

Muscle hypertrophy reflects a positive nitrogen balance in which protein synthesis exceeds degradation of nitrogen compounds (King Ramos and Dominguez, 2014). Classically, it has been proposed that muscle hypertrophy is a late adaptation to strength training (Sale, 1988), considering that the minimum time for hypertrophy degree detention should be at least 8-12 weeks (Akima et al., 1999; Hubal et al, 2005), and the first improvements in levels of muscle strength and power should be exclusively due to neural factors (Moritani and deVries 1979).

Muscle damage which occurs after resistance training appears to be the main factor leading to the proliferation of satellite cells and thus the protein synthesis (Hawke, 2005), a correlation between the magnitude of hypertrophy and damage caused to myofibrillar level (Norrbrand et al., 2008). Thus, hypertrophic responses occur at later training phases (Moore et al, 2005; Woolstenhulme et al, 2006) and that "late" consideration could have been originated within commonly employed hypertrophy detention methods, including ultrasound, computed tomography or magnetic resonance imaging (Seynnes et al., 2007).

The greater electromyographic activity (maximal at both concentric and eccentric phase) observed during resistance training based on eccentric inertial overload contractions (Norrbrand et al., 2008, 2010) as well as an increased mechanical stress imposed at the end of the eccentric contraction, lead this type of overload to a greater muscle damage compared to other kinds of

training (Yu et al., 2003). Furthermore, this type of overloads could increase hypertrophy due to the ability to increase the synthesis of factor similar to Insulin Like-Growth Factor (IGF-1) (Bamman et al., 2001) and an increase of the sarcomeres in series and parallel due to increased fascial length (Wickiewicz et al., 1983) that occurs during such muscle contraction (see figure 2).

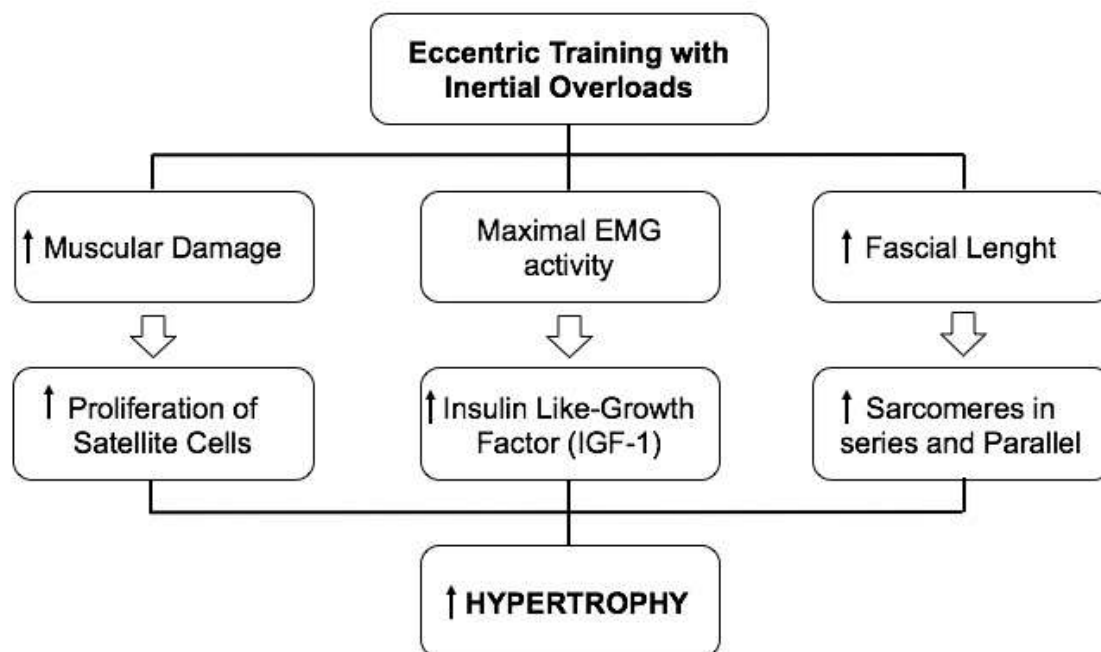


Figure 2. Factors which the inertial eccentric overload training increases muscle hypertrophy.

Thus, it has been found that improvements in this type of training reach statistical significance quickly, achieving significant increases in pennation angle (7.7%) and the cross-sectional area of the quadriceps (13.8%) in just 5 weeks of knee extension training with an eccentric training with inertial overloads (Seynnes et al., 2007).

In situations where there is a rapid sarcopenia, as in people who are bedridden where important states of muscle atrophy are observed in periods of only 10 days (Berg and Testch, 1996), it has been found that a training program focused on leg extensor muscles, based on eccentric inertial contractions, is able to preserve their muscle mass levels and minimize the loss of muscle volume of plantar flexors up to 15% (Reeves et al., 2005).

EFFECTS OF ECCENTRIC TRAINING WITH INERTIAL OVERLOADS ON CONNECTIVE TISSUE

The mechanical properties of tendon adapt to different loads to which it is subjected (Reeves et al., 2005). The arrangement, thickness and crosslinking of the collagen fibers may be affected by physical inactivity (Woo et al., 1975) or weightlessness (Narici et al., 2003), reducing the stiffness of such structures, increasing the degree of deformation under the same load (Woo et al., 1982)

(considering walking or the mobilization of body weight as the minimum threshold for preserving the mechanical properties of the tendon). By contrast, exposure to repeated loads, such as the one caused by resistance training, are effective in increasing the degree of tendon stiffness (Reeves, Maganaris and Narici, 2003).

In situations involving significant changes in the mechanical properties of the tendon, such as being bedridden for a period of 13 weeks, in which significant reductions in stiffness (58%) and Young's modulus (57%) of Achilles' tendon are observed, as well as increases in deformation of gastrocnemius tendon (28%), it has been proved that carrying out 4 sets of 7 repetitions of ankle-hip-knee extension through eccentric inertial overloads (frequency of 3 sessions per week) significantly reduced -nearly the half- negative effects of physical inactivity on the tendon properties (Reeves et al., 2005).

In addition to positive effects when maintaining the mechanical properties of the tendon after following this type of training in bedridden people (Reeves et al., 2005), it has been found that the time for restoring performance in a vertical jump is significantly lower when following an eccentric inertial training program at bedridden period (Rittweger et al., 2007). Thus, while the loss of kinematic parameters in performing a vertical jump such as flying height (10.4% vs 29.5%), peak power (6.1% vs 25.8%) and peak acceleration (5.4% vs 15.7%) were statistically lower in the eccentric inertial exercise contractions group, and the recovery time of performance prior bedridden period was much earlier in the training group compared to the control group (72 vs 163 days for flying height, 18 days vs 140 days for peak power and 15 days vs 71 days in the peak acceleration) (Rittweger et al., 2007).

In the field of injuries recovery, we must consider that eccentric training is the most recommended (LaStayo et al., 2003). By applying this type of training, based on eccentric inertial contractions, a training program for athletes with patellar tendinopathy has been found, which consisted in 12 weeks of training including 4 sets of 10 repetitions of knee extension, besides producing significant improvements in maximum levels of eccentric strength in knee extension (90%) resulted in significant improvements in self-reported pain (Romero-Rodriguez et al., 2007). Similarly, results provided by Rittweger et al. (2007) prompt that this type of training can greatly reduce performance recovery periods after an immobilization period, suggest that this type of training can be effective to facilitate the rapid return to sports.

CONCLUSIONS

The conclusions of the present review are summarized as followed:

- Resistance training with eccentric inertial overloads is a training method superior to others, as conventional training based on concentric contractions, in order to improve strength and power levels, due to the maximum EMG activity produced at both eccentric and concentric phases.

- Resistance training based on eccentric actions through inertial resistance is a training method which, due to the increased EMG activity produced, the largest muscle damage they cause and their ability to induce major overloads in situations of maximum fascial stretching, result in significant levels of hypertrophy in periods of only 5 weeks of training.

- Resistance training based on eccentric actions through inertial resistance may impose an optimal load for the connective tissue, also capable of maintaining mechanical properties in situations with negative affecting capacity, as well as it could facilitate recovery from injury.

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