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Review

Skeletal muscle functional and structural adaptations after eccentric overload flywheel resistance training: a systematic review and meta-analysis

Sergio Maroto-Izquierdo[a,*], David García-López[b], Rodrigo Fernandez-Gonzalo[c], Osvaldo C. Moreira[a], Javier González-Gallego[a], José A. de Paz[a]

[a] Institute of Biomedicine (IBIOMED), University of León, Spain
[b] Department of Health Sciences, European University Miguel de Cervantes, Spain
[c] Department of Physiology & Pharmacology, Karolinska Institutet, Sweden

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ABSTRACT

Objectives: The purpose of this meta-analysis was to examine the effect of flywheel (FW) resistance training with Eccentric Overload (FW-EOT) on muscle size and functional capacities (i.e. strength and power) in athletes and healthy subjects, and to compare FW-induced adaptations with those triggered by traditional resistance exercise interventions.
Design: A systematic review and meta-analysis of randomised controlled trials.
Methods: A search of electronic databases [PubMed, MEDLINE (SportDiscus), Web of Science, Scopus and PEDro] was conducted to identify all publications employing FW-EOT up to April 30, 2016. Outcomes were analyzed as continuous outcomes using a random effects model to calculate a standardized mean difference (SMD) and 95% CI. A total of 9 studies with 276 subjects and 92 effect sizes met the inclusion criteria and were included in the statistical analyses.
Results: The overall pooled estimate from the main effects analysis was 0.63 (95% CI 0.49–0.76) with a significant ($p < 0.001$) Z overall effect of 9.17. No significant heterogeneity (p value = 0.78) was found. The meta-analysis showed significant differences between FW-EOT vs. conventional resistance training in concentric and eccentric strength, muscle power, muscle hypertrophy, vertical jump height and running speed, favoring FW-EOT.
Conclusions: This meta-analysis provides evidence supporting the superiority of FW-EOT, compared with traditional weight-stack exercise, to promote skeletal muscle adaptations in terms of strength, power and size in healthy subjects and athletes.

1. Introduction

Eccentric (ECC) training has been extensively studied in the scientific literature.[1] In comparison with concentric (CON) exercise, isolated ECC actions are characterized by producing higher peaks of force[2] with lower muscle activation[3,4] and metabolic cost,[5] as well as higher solicitation of Type IIx fibers,[6] increased cross-education effect[7] and greater cortical activity.[8] Furthermore, despite producing high levels of muscle damage and soreness after the initial bout,[9] ECC-based resistance exercise training has been associated with effective muscle damage prevention mechanisms,[10–12] earlier increments in muscle mass when compared with CON[13,14] and improved jumping performance.[10,15] Thereby, ECC actions seem to optimize the efficacy of training.[16,17]

The ability to produce force in the CON phase limits the load/weight to be used during training. As a result, and given the higher force production capacity of skeletal muscle during ECC actions, the loads used during traditional free weights or weight-stack exercise are sub-optimal during the ECC phase of the movement.[2,18] However, optimization of resistance training using a strictly ECC regime is rather complex and technically difficult to apply.[19] In addition, ECC actions are rarely isolated in real-life situations, and usually appear during the stretch-shortening cycle, inducing a greater contribution of the elastic components in the muscle-tendon unit; the stretch-shortening cycle increases the potential to produce force in the subsequent CON action due

* Corresponding author.
E-mail address: smaroi@unileon.es (S. Maroto-Izquierdo).

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to increased storage and use of elastic energy.[17] Several methods have been designed and proposed to offer an eccentric overload (EO) during resistance training, such as (1) controlling and adjusting the time/velocity of CON and ECC movement during resistance training[20,21]; (2) using third-party assistance or devices for moving/rising the load during the CON phase[10–12]; and (3) employing isokinetic dynamometers.[22]

Devices created to isolate or overload the ECC phase of the muscle action have emerged as an alternative method that may produce greater muscle adaptations, and therefore have been developed and/or tested for rehabilitation and performance purposes. The iso-inertial devices were originally designed by Berg & Tesch[23] in 1994 to counteract the deleterious effect of microgravity on skeletal muscle. Such technology presents one of the most-used exercise paradigms to produce EO during resistance training. The iso-inertial devices more frequently employed are "The Flywheel Exercise Device",[23,24] "VersaPulley",[25] and "Inertial Training and Measurement System".[26] These iso-inertial devices use the flywheel (FW) principle to produce unlimited resistance during the entire range of motion. During the CON phase the force applied unwinds a cord/strap connected to the shaft with the FW, which starts to rotate and store energy. Kinetic energy will increase as a function of the rotational speed. Once the CON action is completed, the cord/strap rewinds and the trainee must resist the pull of the FW by performing a braking, ECC muscle action. By using appropriate technique, i.e. resisting the inertial force gently during the first third of the ECC action, and then applying maximal effort to stop the movement at the end of the range of motion, EO can be produced in force/power values.[24,27] Then, the next CON action is immediately initiated.

The effects of inertial training using FW devices have been extensively investigated over the past 20 years. The majority of studies assessed the effects of eccentric overload training (EOT) on lower body muscle mass in healthy and active subjects. These studies employed a mean workload of 4 sets of 7 maximum repetitions during 5–15 weeks. Results indicate that EOT employing FW technology induce gains of 5–13% in muscle mass,[28–31] 11–39% in maximal voluntary contraction,[28–30] 12–25% in 1 repetition maximum (1 RM),[31,32] 21–90% in ECC force,[19,23,33] 10–33% in muscle power,[32,34] 6–15% in jump ability,[32,34,35] 2–10% in running speed[32,35,36] and up to 35% in electromyography activity.[29,37,38] Despite EOT being associated with a high magnitude of muscle damage and inflammatory responses during the initial phase of training, a significant attenuation of these processes occur shortly after,[31] indicating no counterproductive effects on muscle. Additionally, these devices have been shown very effective in counteracting the decrements in muscle mass and strength during weightlessness,[39–41] as well as improving muscle function, balance, gait and functional performance in elderly[42,43] and stroke patients.[44,45]

While there has been an increase use of these technology and a significant amount of research comparing the effectiveness of eccentric overload flywheel resistance training (FW-EOT) with traditional weight-stack exercise programs, there is no systematic review that summarizes the results of such studies, and adequately assess their scientific rigor. When confronting with a task of this magnitude, there are inherent methodological limitations, such as the difficulty to isolate or enhance the ECC phase from the CON,[1] and the diversity of devices employed to generate EO. To circumvent these limitations, we performed a systematic review including only training studies using FW technology to generate the EO vs. traditional free-weight or weight-stack training. Therefore, the purpose of the current review and meta-analysis was to systematically review the literature on randomised clinical trials examining the effects of FW-EOT, and how the intervention affects functional and structural muscle adaptations among athletes and healthy subjects, and to perform a quantitatively comparison of FW-EOT vs. traditional resistance exercise training in inducing gains in muscle mass, force and power.

2. Methods

This systematic review was designed following the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Protocols (PRISMA-P).[46,47] The PRISMA-P statement includes 26 points, grouped in 17 kinds of items checklist and it is designed to be used as a basis for reporting systematic review of randomised trials. A review protocol was not registered for this review.

A systematic, computerized search of the literature in PubMed, Web of Science (including Web of Science and MEDLINE results), Scopus, SportDiscus and PEDro was conducted by an independent researcher with controlled vocabulary and keywords related to eccentric training, eccentric overload training and flywheel training. Our search time frame was restricted to 22 years (1 January 1994 to 30 April 2016); 1994 was chosen because research on FW technology began that year.[23] We developed our search strategy based on the lack of reviews and meta-analysis about FW-EOT.[1,48] To do this, the search strategy used by previous reviews in the field of resistance training was employed.[48] The search language was restricted to English, and a filter containing Medical Subject Headings (MeSH) terms was applied. First, a general search including the terms "eccentric training", "eccentric exercise", "negative work" was performed. A more specific search included the terms of "eccentric-overload", "eccentric-overload training", "inertial training", "inertial exercise", "isoinertial training", "flywheel", "flywheel resistance", "gravity-independent" and "enhanced-eccentric". These terms were chosen because they have been traditionally used to describe this training methodology. The results of this specific search were then combined with the following terms: "device", "strength", "force", "power", "hypertrophy" and "muscle mass".

The reference list of all selected publications was verified to retrieve relevant publications that were not identified by the computerized search. References of selected and included original articles, abstracts and available conference proceedings were also searched, including publications, posters, abstracts or conference proceedings. To identify relevant articles, titles and abstracts of all selected publication after the first search were analyzed looking for training methods where the ECC phase was overloaded or reinforced. In the specific search, in addition to the identified citations of the first search, titles and abstracts of all recognized publications were examined in detail. Full-text papers were recovered if the abstract provided insufficient information to establish eligibility or if the article abstract had passed the first eligibility review.

All articles examining FW-EOT were eligible for full-text review. An article was eligible for study inclusion if it met all of the following criteria:

1. The original article was a randomised controlled trial (RCT) or clinical controlled trial (CCT) published in peer-reviewed journals.
2. The article reported on athletes or physical active subjects of either sex who had completed an EOT protocol during at least 4 weeks with a minimum training frequency of 2 days per week.
3. The study described healthy subjects without a history of injury in the trained limb.
4. The manuscript included a FW-EOT intervention and a control or alternative intervention group, comparing training adaptations in strength and/or power, and/or muscle mass.

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