Effects of different methods of strength training on indicators of muscle fatigue during and after strength training: a systematic review

Guillermo D. Barahona-Fuentes1, Álvaro Huerta Ojeda1,3, Daniel Jerez-Mayorga2

1Universidad de Las Américas, Grupo de Investigación en Salud, Actividad Física y Deporte, Escuela de Educación Física, Vía del Mar, Chile; 2Universidad Andres Bello, Facultad de Ciencias de la Rehabilitación, Santiago, Chile; 3Centro de Capacitación e Investigación Deportiva Alpha Sports, Valparaíso, Chile.

Abstract - Introduction: The development of strength has shown to be beneficial to sports performance and health. However, during strength training, they also produce alterations in muscle fatigue indicators, leading to a decrease in the ability to generate strength. Despite this, there is still not enough knowledge about the levels of muscle fatigue generated by different methods of strength training and how this information can be integrated into sports planning. Review and analyze the studies existing between January 2009 and January 2019 that have used indicators of muscle fatigue established in the search terms during and after strength training as measurement variables. Evidence acquisition: The study corresponds to a systematic review of previously published studies, following the PRISMA model. Articles published between 2009 and 2019 that measured muscle fatigue indicators during and after strength training were evaluated. The electronic search was conducted through Web of Science, Scopus, Sport Discus, PubMed, and Medline. We included all articles that used a strength protocol and also measured indicators of muscle fatigue and its possible effect on physical performance. Evidence synthesis: A total of 39 articles were found, which were stratified according to the protocol used: (i) plyometric training, (ii) Bodypump® training, (iii) occlusion training, (iv) variable resistance training, (v) conventional strength training, (vi) eccentric strength training, (vii) rest times in strength training and (viii) concurrent training. Conclusion: At the end of the systematic review, it was shown that the different training methodologies for strength development generate increases in muscle fatigue indicators, and the increase generated in the different muscle fatigue indicators depends both on the methodology used and on the type of population, sex, level of training and type of sport. The most-reported indicators are [La], HR and RPE, DOM, MR variation, and ammonium.

Keywords: strength training; muscle fatigue indicators; sports performance.

Introduction

Today, sports training is based on the development of the various manifestations of force. Thus, several investigations have recognized muscle strength as the main capacity to produce a high level of muscle power and neuronal adaptations, which favor the development of muscular hypertrophy. In this sense, optimal muscle development has been associated with sports performance and a better quality of life. On the contrary, a decrease in muscle strength and neuromuscular control change the functional behavior of an athlete, limiting performance and possibly triggering an injury.

In order to achieve optimal development of strength, power and muscular hypertrophy, traditional and non-traditional training methods have been used, including plyometric exercises on land, plyometrics in the aquatic environment, occlusion training, training with elastic bands, electrostimulation training, eccentric exercises, and Bodypump® programs. These methods have demonstrated, in several cases, increases in sports performance. However, it has also been documented that strength training produces alterations in muscle fatigue indicators. In this sense, fatigue has been defined as a reduction in the ability of the neuromuscular system to generate strength or to carry out work resulting from physical exercise. Thus, a decrease in the production of strength, in its different manifestations during and after strength training, has been associated with increases in blood uric acid, lactate concentrations, elevated heart rate, increased perception of effort, increased muscle pain, and decreased range of motion. These metabolic and physiological responses produced by strength exercise have been identified as synonymous with fatigue.

However, it is not yet fully established if these fatigue indicators always produce a decrease in performance. That is why there is a need to establish whether indicators of muscle fatigue are constantly associated with a decrease in performance. As a result of the above, the objective of this systematic review was to review and analyze the studies existing between January 2009 and January 2019 that have used indicators of muscle fatigue established in the search terms during and after strength training as measurement variables. As a secondary objective, the programs were described, establishing the biochemical and physiological responses reported in each of the studies consulted.
**Method**

**Procedure**

The search identified articles published in the following databases: Web of Science (WOS), Scopus, Sport Discus, PubMed, and Medline. The search limits were: articles published in the last ten years (January 2009 to January 2019) that were written in English, Portuguese, French, German, or Spanish.

**Bibliographic search**

The literature search was performed in accordance with the guidelines for the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)^3^. The title, abstract, and keyword searches were saved in each of the databases. The following keywords combined with Boolean operators (AND, OR) were used: (“Ammonium” OR “Ammonium lactate” OR “Lactate” OR “Acid-base equilibrium” OR “Acid-base balance” OR “Heart rate” OR “Muscular fatigue” OR “Muscle fatigue” OR “Ratings of perceived exertion” OR “RPE scale”) AND (“Sports performance” OR “Athletic performance” AND “[Strength training” OR “Resistance training” OR “Force scale”] AND “[Sports performance” OR “Athletic performance” OR “Strength training” OR “Resistance training” OR “Force scale”] AND “[Strength training” OR “Resistance training” OR “Force scale”]) and “Inclusion criteria” The importance of each study was evaluated according to the following inclusion criteria: a) experimental study design; b) healthy subjects of both genders; c) studies with strength training protocols; d) studies reporting indicators of muscle fatigue through ammonia, lactate, pH, HR, muscle fatigue and perception of effort; e) those with increased or decreased performance post-intervention, and f) studies published in English, Spanish, French, Portuguese or German. Studies that did not meet the inclusion criteria were excluded. Discrepancies found were resolved by consensus of the investigators.

**Evaluation of methodological quality**

The Physiotherapy Evidence Database (PEDro) scale^4^ was used to assess study quality. The classification was based on three criteria: selection (maximum three stars), comparability (maximum three stars), and results (maximum four stars). Articles scoring eight to ten were considered to have a high methodological quality, four to seven moderate, and less than four low. Thus, the score obtained by the articles according to the PEDro scale indicated that 13 studies obtained a high score and 26 articles obtained a moderate score (Table 1).

**Results**

(1-2-3-4)

| Article | Selection (1-2-3-4) | Comparability (5-6-7) | Results (8-9-10-11) | Total |
|---------|---------------------|-----------------------|----------------------|-------|
| Oliveira et al. 24 | *-*-* | 0-0-0 | *-*-* | 7 |
| Wembono et al. 25 | *-*-* | 0-0-0 | *-*-* | 8 |
| Brown et al. 26 | 0-0-0 | *-*-* | 5 |
| Chatinikovskii et al. 27 | *-*-* | 0-0-0 | *-*-* | 7 |
| Smilios et al. 28 | 0-0-0 | *-*-* | 5 |
| Walker et al. 29 | 0-0-0 | *-*-* | 7 |
| Greco et al. 30 | *-*-* | 0-0-0 | *-*-* | 7 |
| Izquierdo et al. 31 | 0-0-0 | *-*-* | 5 |
| Sánchez-Medina et al. 32 | *-*-* | 0-0-0 | *-*-* | 8 |
| Buitrago et al. 33 | *-*-* | 0-0-0 | *-*-* | 8 |
| Harder et al. 34 | *-*-* | 0-0-0 | *-*-* | 8 |
| Paulo et al. 35 | *-*-* | 0-0-0 | *-*-* | 8 |
| Walker et al. 36 | *-*-* | 0-0-0 | *-*-* | 8 |
| Couto et al. 37 | *-*-* | 0-0-0 | *-*-* | 8 |
| Fernández-Gonzalez et al. 38 | *-*-* | 0-0-0 | 5 |
| Okano et al. 39 | *-*-* | 0-0-0 | 8 |
| Parejo-Blanco et al. 40 | *-*-* | 0-0-0 | 8 |
| Rogatki et al. 41 | *-*-* | 0-0-0 | 7 |
| Silva et al. 42 | 0-0-0 | 0-0-0 | 5 |
| Ammar et al. 43 | 0-0-0 | 0-0-0 | 5 |
| Gadain et al. 44 | 0-0-0 | 0-0-0 | 5 |
| González-Martínez et al. 45 | *-*-* | 0-0-0 | 7 |
| Nicholson et al. 46 | *-*-* | 0-0-0 | 8 |
| Ojeda et al. 1 | 0-0-0 | 0-0-0 | 5 |
| Péton et al. 12 | *-*-* | 0-0-0 | 8 |
| Raeder et al. 13 | 0-0-0 | 0-0-0 | 5 |
| Sabido et al. 14 | *-*-* | 0-0-0 | 7 |
| Bartolomei et al. 15 | *-*-* | 0-0-0 | 7 |
| de Almeida et al. 16 | *-*-* | 0-0-0 | 7 |
| Johnston et al. 17 | *-*-* | 0-0-0 | 8 |
| Andreutti et al. 18 | 0-0-0 | 0-0-0 | 5 |
| Curty et al. 19 | *-*-* | 0-0-0 | 7 |
| dos Santos et al. 20 | 0-0-0 | 0-0-0 | 5 |
| Ojeda et al. 21 | 0-0-0 | 0-0-0 | 5 |
| Miranda et al. 22 | *-*-* | 0-0-0 | 7 |
| Parreño-Montilla et al. 23 | *-*-* | 0-0-0 | 8 |
| Siejajack et al. 24 | *-*-* | 0-0-0 | 8 |
| Wothheimer et al. 25 | *-*-* | 0-0-0 | 8 |
| Tufano et al. 26 | *-*-* | 0-0-0 | 8 |

Elements in the PEDro scale: 1) eligibility criteria were specified; 2) subjects were randomly assigned to groups; 3) assignment was concealed; 4) groups were similar at baseline relative to the most important prognostic indicators; 5) all subjects were included in the final analysis; 6) intention-to-treat analysis was used; 7) all outcomes measured at least once were included in the analysis; 8) means (or at least one of the key outcomes) were obtained from more than 90% of the subjects initially assigned to the groups; 9) results were presented for at least one key outcome; 10) point and variability measures for at least one key outcome; 11) study provided power and variability measures for at least one key outcome; 12) specified choice criteria; however, it is not counted as a score.

Figure 1 - Flow chart of search strategy and selection of articles.
Results

Selected studies

The electronic search identified 3468 articles, of which 1952 were duplicated. The remaining 1516 articles were filtered by
- Characteristics of the participants in each study.
- Exercise protocol used.
- Results from different methods of strength training on indicators of muscle fatigue during and after strength training: a systematic review.

| Author | Number (M/F) | Age | Sample type |
|--------|--------------|-----|-------------|
| Oliveira et al. | 0/15 | 21±7.2 | Not physically trained |
| Wernbro et al. | 8/3 | 20-39 | Velocity and trained footballers |
| Brown et al. | 10/10 | 22.1±13.3 | Trained individuals |
| Chatzimikos et al. | 24/0 | 25.5±1.9 | Physically healthy subjects |
| Silius et al. | 16/0 | 20.7±3.1 | Young people with recreational experience in strength training |
| Walker et al. | 10/0 | 23.6±2.5 | Physically trained in strength |
| Greco et al. | 0/19 | 21.4±2.0 | Sedentary individuals |
| Izquierdo et al. | 12/0 | 33.0±4.4 | Physically active subjects |
| Sánchez-Medina et al. | 18/0 | 25.6±3.4 | Trained individuals |
| Buitrago et al. | 10/0 | 27.3±3.2 | Students physical education with experience in strength training and occlusion |
| Harde et al. | 10/0 | 23.6±3.0 | Subjects trained in strength |
| Paol et al. | 19/0 | 25.7±4.4 | Physically healthy young people |
| Walker et al. | 13/0 | 28.4±3.3 | Physically active subjects with no experience in strength |
| Couto et al. | 32/0 | 26.0±3.4 | Subjects with experience in strength |
| Fernández-Gonzalo et al. | 16/16 | 23.1 | Healthy and physically active subjects |
| Okumu et al. | 9/0 | 24.0±2.9 | Healthy subjects with experience in strength |
| Pareja-Blanco et al. | 29/0 | 23.3±3.2 | Students of sports sciences with experience in strength |
| Rogatkin et al. | 6/0 | 18.2 | Teenagers |
| Silva et al. | 11/0 | 32.6 | Trained cyclists |
| Ambar et al. | 9/0 | 21±0.5 | Experienced weightlifters |
| Gudmundsson et al. | 14/0 | 22.6±1.49 | Taekwondo athletes and sedentary subjects |
| Gonzalez-Badillo et al. | 9/0 | 23.3±3.9 | Students of sports sciences with experience in strength |
| Nicholas et al. | 34/0 | 21.7±6.2 | Trained subjects |
| Oyola et al. | 19/0 | 24.8±5.3 | Military pathologists |
| Poton et al. | 12/0 | 23.4±3.8 | Healthy and trained subjects |
| Reader et al. | 14/9 | 24.1±1.0 | Athletes |
| Sabidou et al. | 17/0 | 23.2±3.6 | Subjects with experience in strength |
| Bartolomei et al. | 12/0 | 24.5±4.2 | Subjects with experience in strength |
| de Almeida et al. | 10/0 | 22.5±0.2 | Subjects with experience in strength |
| Johnstone et al. | 15/0 | 21.1 | Rugby players |
| Andretta et al. | 10/10 | 24.6 | Healthy subjects with experience in strength |
| Curry et al. | 9/0 | 26±1 | Healthy subjects with experience in strength |
| dos Santos et al. | 7/6 | 29.5±6 | Military active subjects |
| Ojeda et al. | 10/0 | 28.5±4.8 | Military athletes |

Table 2 - Characteristics of the participants in each study.

| Author             | Year | Objective                                                                 | Variable | Treatment | Results from muscular damage | Force results | Performance |
|--------------------|------|---------------------------------------------------------------------------|----------|-----------|--------------------------------|--------------|-------------|
| Oliveira et al.    | 2009 | Compare and analyze metabolic (Lactate), cardiovascular (HR), and neuromuscular (EMG) parameters during a Bodypump® session. | Exercies proposed by Bodypump® | 60 minutes of Bodypump®. These exercises were performed using 1 kg weights, except for the division squatting position, which used weights corresponding to 10% of 1RM (< 5 kg) to standardize individual responses during sessions. A straight metal bar (1 bar) and 1, 2, and 5 kg disc weights were added to the bar. | M (male); F (female) | 25±1.7 | 25.7±4.7 | Recreational trained |
| Wernbro et al.     | 2009 | Investigate whether there was any difference in muscle activity and endurance during low-intensity exercise in dynamic knee extension performed with and without occlusion. | Dynamic knee extension training with and without occlusion. | Exercise proposed by Bodypump®. Isometric resistance in knee extenders, 4 sets of three repetitions at 85% of 1RM with 4 min rest intervals between sets. | M (male); F (female) | 25±1.7 | 22±3.1 | Subjects trained in strength |
| Sijlacks et al.     | 2009 | Investigate acute changes in O2, HR, and Blood [La] in a deep plyometric session in men and women. | Deep PD acute session. | Resistance to 30% of 1RM. Occlusion was used at a pressure of 100 mm Hg just before the cuff exercise, and this pressure was maintained in the occluded leg during exercise, including rest periods between series. Subjects performed as many repetitions as possible for a total of 3 series for each leg. The rest between each series was 45 seconds for both the nonoccluded and occluded leg. | M (male); F (female) | 25±1.7 | 22±3.1 | Subjects trained in strength |
| Brown et al.       | 2010 | Investigate acute changes in O2, HR, and Blood [La] in a deep plyometric session in men and women. | Deep PD acute session. | Resistance to 30% of 1RM. Occlusion was used at a pressure of 100 mm Hg just before the cuff exercise, and this pressure was maintained in the occluded leg during exercise, including rest periods between series. Subjects performed as many repetitions as possible for a total of 3 series for each leg. The rest between each series was 45 seconds for both the nonoccluded and occluded leg. | M (male); F (female) | 25±1.7 | 22±3.1 | Subjects trained in strength |

Table 3 - Characteristics of strength training programs with muscle fatigue indicators.
Chatzinikolaou et al. 2010

Effects of different methods of strength training on indicators of muscle fatigue during and after strength training: a systematic review.

Investigate the temporal course of inflammatory, hormonal, and performance markers changed in response to an acute session of plyometric exercise

Acute PD session

8 sets of 10 jumps in-depth with both feet of a box 0.8 m high. When the subjects reached the ground with both feet, they immediately jumped as high as possible and touched a vertical jump measurement device. The jump box was mounted on a mechanical force plate. The subjects performed 8 series of 10 repetitions with 3 minutes of passive recovery between series.

Range of motion ↓ (p < 0.05) up to 48 hours post-exercise. DOMS, CK and lactate-dehydrogenase ↓ (p < 0.05) until 72 hours. PCR ↑ (p < 0.05) until 24 hours. Uric acid ↑ (p < 0.05) until 96 hours. [La] ↑ (p < 0.001).

Chatzinikolaou et al. 2010

Walker et al. 2010

Effects of a mechanical power and activity of EMG during a moderately loaded muscular endurance session and the maximum mechanics output power and EMG activity using a light load and then a heavy load

Examine (a) the mechanical power and activity of EMG during a moderately loaded muscular endurance session and (b) the maximum mechanics output power and EMG activity using a light load and then a heavy load

Medium, light and heavy load endurance exercise

50 jumps over 50 cm obstacles (5 sets of 10 repetitions) and 50 jumps with a plyometric box drop 50 cm (5 sets of 10 repetitions). There were 2 and 5 minutes of rest between sets and exercises, respectively.

Loads used in third and fourth series ↓ (p < 0.05) versus first and second series. Production of force ↓ (p < 0.05) during last 2 series. Average speed of each series was in.

Smilios et al. 2010

Buitrago et al. 2012

Barahona-Fuentes et al. 2012

Evaluate acute and endocrine neuromuscular responses during a constant loading protocol

Contrast training

The lifting protocol was 10 x 5-speed squats at 70% of the mass of the system (1RM) with rest intervals of 2 minutes between sets.

[La] ↑ (p < 0.05) on SJ jump and maximum isometric force.

Walker et al. 2010

Izquierdo et al. 2011

Sánchez-Medina et al. 2011

Buitrago et al. 2012

Hardee et al. 2012

Paulo et al. 2012

To assess the effects of 12 weeks of the Bodypump® training program on neuromuscular aspects and metabolic variables, such as HR and lactate.

Bodypump®

Exercises for the upper extremities were performed using 1 kg weights. Squatting and ramming exercises were performed using weights corresponding to 10% of 1RM for the occupants (~5 kg). A straight metal bar (1 kg) and 1, 2, and 5 kg weights were attached to the bar and used during lower extremity exercises.

[La] and HR were ns. ↑ (p < 0.05) max. force.

Chatzinikolaou et al. 2010

Effects of heavy-duty training and its relationship between power loss and EMG variables, such as blood metabolite concentrations on exercise-induced dynamic fatigue

Investigate the acute series exercise between and after 60 minutes of rest, performed the second series.

Bench press and/ or squat exercises

4 sets of 20 repetitions with an initial load of 50% of 1RM and 2 minutes rest in the squat exercise. In addition, subjects performed 4 repetitions with loads of 40% and 60% of 1RM before, immediately after, and 30 minutes after the end of the session.

Pressure banking

4 sets of squats (3% to 80% of 1RM) interspersed with 4 sets of SJ (three repetitions). A 3-minute break was allowed between sets.

RPE ↑ (p < 0.05) on the output power.

Hardee et al. 2012

Effects of heavy-duty training and its relationship between power loss and EMG variables, such as blood metabolite concentrations on exercise-induced dynamic fatigue

Five series, with the load corresponding to 10 RM on the leg press with 120 s rest between the series. After training, each subject performed an acute load resistance protocol with the same relative load (10 RM) as in the pre-workout test protocols.

[La], ammonia, and uric acid ↑ (p < 0.05)

Maximum power loss (p < 0.05)

Izquierdo et al. 2011

Strength training

Maximum continuous power loss (p < 0.05) in bar and CMJ movement

Sánchez-Medina et al. 2011

[La] and uric acid ↑ (p < 0.05)

Maximum power loss (p < 0.05)

Buitrago et al. 2012

[La] ↑ (p < 0.01) at high, medium and low loads

Maximum power loss (p < 0.01) number of repetitions

Hardee et al. 2012

Squatting force work

MVC force and then the performance of a resistance exercise protocol composed of three series of heep curls at 40% MVC with 1 minute or 3 minutes time interval between the series.

Average power ↑ (p < 0.05) in SSLI

Maximum power loss (p < 0.05) in SSLI

Paulo et al. 2012

An ↑ in the intensity and volume of training produces the performance

Barahona-Fuentes et al. 2012

Motriz, Rio Claro, v.26, Issue 3, 2020, e10200063

Motriz, Rio Claro, v.26, Issue 3, 2020, e10200063
| Walker et al. | 2012 | To compare acute neuromuscular fatigue during maximum dynamic force and hypotrophi clinical performance. | Exercise of force: 15 series of 1 maximum repetition (MAX) and 5 series of 10 maximum repetitions (HYP). Body pump, the exercise used for squats and onslaughts was the 10% of 1RM squats. Upper limb and trunk exercises were performed at a workload of 2 kg for weights or 1 kg for free weights. Workload for squats and onslaughts were 5% every 2 weeks (4 sessions). Concentric load during maximum force ↓ (p < 0.05), Concentric force and maximum isometric ↑ (p = 0.001) in both groups. Hypertrophy work produced ↓ in performance. |
|---|---|---|---|
| Couto et al. | 2013 | To verify the acute effects of the application of local vibration in the upper extremities during resistance training on the number of maximum repetitions and metabolic and hormonal responses. | Vibration strength training session 5% of 1RM and non-vibration strength training. 5 sets of 10 repetitions in the leg press, with 2 minutes rest between sets. [La], testosterone and cortisol ↓ (p < 0.05) after both interventions. However [La] and testosterone ↑ (p < 0.05) compared to the non-vibration group. CK and urea were ns in both groups. |
| Fernandez-Gonzalo et al. | 2014 | To evaluate markers of muscle damage and training adaptations to eccentric overload endurance exercise in men and women. | Supine squatting position. Repetitions carried out in each series with respect to the maximum number foreseen. The [La], was greater after the first training session (p < 0.001). CK ↑ (p < 0.001) in men and women. SF and potency yield 50%, 60%, 70% and 80% of 1RM ↓ in both sexes (p < 0.05). The improvement in potency at 88% of 1RM was greater (P < 0.002) in men than in women. Muscle mass ↑ (P < 0.05). |
| Okano et al. | 2014 | To investigate the variability of HR after resistance training with and without occlusion. | Leg presses with and without occlusion. 3 experimental sessions on different days, separated by at least 72 hours and a maximum of 120 hours. (a) 5 series of leg press exercises in 80% of 1RM without vascular occlusion (V0), (b) 5 series of leg press exercises at 40% of 1RM with vascular occlusion (V0L), and (c) 5 series of leg press exercises at 40% of 1RM without vascular occlusion (L0) of each leg. HI, HR and [La] ↓ (p < 0.05) after exercise by over L1 and I0L. Reduced recovery in HI ↓ in HI. |
| Pareja-Blanco et al. | 2014 | To compare the effect of 2 different isometric resistance training interventions on strength gains and selected neuromuscular performance measures using movement speed as an independent variable. | Strength training: Lifting loads of 55% (low), 70% (med) and 85% (high) of 1RM in one of the four modes given: 4-1-4-1 (4-concentric, 1-isometric, 4-eccentric and 1-successive isometric actions), 2-1-2-1 (2-concentric, 2-isometric, 2-eccentric and 1-successive isometric actions) and MAX (concentric maximum velocity, 1-isometric, 1-eccentric and 1-successive isometric actions). |
| Rogatki et al. | 2014 | Study II aimed to describe acute and mechanical metabolic responses to the type of resistance exercise protocols used in Study I. | Squat with overload. | [La] ↑ (p < 0.05) in muscle endurance in response to the protocols. ↓ (p < 0.05) plasma ammonium by over hypertrophy and strength group. ↓ (p < 0.05) in complete the 20 km counter-clockwise exercise. ↓ (p < 0.05) cycling economy. |
| Silva et al. | 2014 | To determine the metabolic response of resistance exercise in overloaded squats with different training protocols. | Leg press | Muscle resistance performed in 2 series of 20 repetitions at 53% of 1RM with 45 s of rest between the series. Hypertrophy training consisting of 3 series of 10 repetitions at 70% of 1RM with 120 s of rest between the series. For strength, the trainings were 5 series of 5 repetitions at 85% of 1RM with 180s of rest between the series. |
Check whether a pretest 5RM strength exercise could improve cycling performance during a 20 km (12.5 km) cycling event.

Ammar et al. 44 2015

Olympic weightlifting at different times of day (morning, afternoon, or evening).

Program that involved a rapid gradual increase in the number of jumps, drop height, and depth of squat and weight addition.

RPE ↑ (P = 0.01) in the morning and evening. Lactate dehydrogenase ↑ (P = 0.011) in the morning and evening. CK ↑ (P < 0.05) at three hours of the day, Alanine amino-transaminase, gamma-glutamyl and alkaline phosphatase ↑ (P < 0.001) in the morning. Not measured ↑ in the afternoon and ↓ in the morning and evening

Investigate the performance of an Olympic weightlifting training session three times a day on performance related to biochemical responses.

González-Badillo et al. 45 2016

Bench press and squat with overload.

Two leg press loads, separated by one week, consisting of 15 sets of 1 maximum repetition (MAX) and 5 sets of 10 maximum repetitions.

[La] ↑ (p < 0.05) in both groups. CK and cortisol ↑ (p < 0.05) in the group with maximum repetitions until failure. IRM ↑ (P < 0.001) in each group. Higher volume sessions ↓ performance.

Analyze time course of recovery after 2 protocols of resistance exercises that differ in the level of effort: maximum with overload or group with less volume and total rest.

Squat with overload in maximum strength mode, hypotrophy, or group with more rest, or another group with the maximum number of repetitions per series.

Conventional resistance training session and a resistance training session with local vibration. In both interventions, the volunteers performed 4 series with the greatest possible number of repetitions of the exercise that could be deployed at 55% of the maximum voluntary contraction. During the vibration resistance training intervention, the vibration was applied locally (20 Hz and 12 mm). During conventional resistance training, volunteers performed the same procedures without vibration.

Maximum strength and hypertrophy train. [La] ↑ (p < 0.011). RPE ↑ (P < 0.001) in hyperrophy protocol

The Venr, Vmix, and Pmax were ns. La Pro. ↓ (p = 0.002).

Determine the acute effect of complex Training on bench press on training Week debt and inflammatory responses in Taekwondo athletes.

Oyaida et al. 46 2016

4 sets of 5 repetitions at one Repetition Maximum (IRM) + 4 repetitions at 60% IRM + 3 grenade throws with a 15-second rest.

Protocols of complex bench press.

(a) 5 series of leg press exercises at 80% of IRM without vascoculmation (HI), (b) 5 series of leg press exercises at 40% of IRM with vascoculmation (IL), and (c) 5 series of leg press exercises at 40% of IRM without vascular occlusion (LI).

HL HR and diastolic blood pressure ↑ (p < 0.05) in HI-BFR and L1-BFR ↑ (p < 0.05) in L1-BFR

To compare the hemodynamic response during resistance exercise to HI, LL, and LI-BFR in healthy sub-jects.

Raeder et al. 47 2016

6-day intensive strength training.

Subjects trained twice a day, in the morning (~9 AM) and the afternoon (~3 PM), on 6 consecutive days. They performed multiple eccentric strength exercises, focusing mainly on the training of the lower extremities.

DOSM, perceived recovery and stress ↓ (p = 0.01) and ↑ (p < 0.05) at peak speed.

Analyze neuromuscular, physiological, and perceptual marker changes during recovery in high endurance training.

Salcido et al. 48 2016

Individualized muscle endurance consisted of 2 sets of 20 repetitions (2 × 20) at 53% of IRM with a 45-second rest period between sets. The hypertrophy trainings consisted of 3 sets of 10 at 70% of IRM with a 120-second rest period between sets. For strength, the workouts were 5 × 5 at 85% of IRM with a 30-second rest period between sets.

2 pairs against super series caused ↑ (p < 0.05) in [La] and RPE.

CMK and isometric MVC ↓ (p = 0.001 and p < 0.008, respectively).
Barahona-Fuentes et al. Effects of different methods of strength training on indicators of muscle fatigue during and after strength training: a systematic review.

Effects of different methods of strength training on indicators of muscle fatigue during and after strength training: a systematic review.

Bartolomei et al. 2017

To compare the acute effects of four different resistance training methodologies aimed at hypertrophy.

High intensity overload squat and high volume overload squat

Squat with overload (4 series force of 1RM (pomotion condition)

LDH, CK and Mb (p < 0.05) in HV and HI. Cortisol and IL-6 (p < 0.001 and p < 0.05, respectively) in HV.

Maximum torque (p < 0.05) in occlusion training

HV ↓

de Almeida et al. 2017

To compare the variables related to asymmetric push force, torque, and fatigue indices in the traditional strength training method and the occlusion training method.

Traditional strength training and occlusion training

Resistance stroke followed immediately by a force load or force session followed by resistance stroke.

Training with occlusion (p < 0.05) lactate, ditydrogenate levels, [La], and CK and Mb were ns in both protocols.

CML, times 50 meters, was ns

↑

Johnston et al. 2017

To examine the acute effect of the sequence of strength and endurance training on neuromuscular, endothelial, and physiological responses for 24 hours.

Strength training followed by speed training and vice versa

5 series of exercise (i.e., two sets at 85% of 1RM with three repetitions per series and three sets at 90% of 1RM with two repetitions per series)

[La] ↑ (p < 0.05) immediately after speed training. CK, cortisol, testostereone, and DOMS were ns in both protocols.

S1 and CML (p < 0.05) in HI group

↓

Andreatta et al. 2018

To assess whether cell-free DNA (cfDNA) levels increased immediately after light and heavy endurance exercise and whether cfDNA levels are associated with functional muscle capacity up to 48 hours after an exercise session.

Leg press HI and LI

3 series of hip flexion, hip extension, and hip abduction exercises by an elastic band.

[La] ↑ (p < 0.05) in both groups, CK and cfDNA concentration ↑ (p < 0.05) in the HI group

↑ in HI force protocols

Curty et al. 2018

To assess acute effects of eccentric HI exercise combined with occlusion on markers of muscle damage and perceptual and cardiovascular responses.

Eccentric exercise in elbow flexion with occlusion and without occlusion

3 sets of 8 repetitions until failure, while the second protocol was separated by 24 hours and consisted of 3 sets by 4 repetitions at 80% of 1RM

DOMS ↓ (p < 0.05) in eccentric HI exercise combined with occlusion. HR ↑ (p < 0.05) in both groups

Maximum absolute and relative muscle power (p < 0.0001)

↓ in both protocols, but non-occlusional training presents more durability

dos Santos et al. 2018

To investigate cardiovascular, neuromuscular, and metabolic response of physically active subjects during a session of sled drag with resistance.

Sled drag with resistance

Strength 4 + 6 repetitions, 85% of 1RM, 900 of total, hypertrophy (90% of 1RM, 360 s total rest), group 1: 4 + 6 simple repetitions, 85% of 1RM, 1400 s of total rest and group 2: 4 + 6 simple repetitions, 90% of 1RM, 1400 s of total rest

HR ↑ (p < 0.05) and [La] ↑ (p < 0.0001)

Distance in grenade launch (p < 0.05)

↓

Shieljka et al. 2018

To compare training with occlusion performed with failure or without failure with regard to changes in muscle size, function, and perceptual responses.

Training with occlusion

Traditional, 6 series for 10 repetitions at 70% of 1RM. Super series of anagist pairs, 6 series for 10 repetitions at 70% of 1RM. Super series of anagist pairs, 3 series for 10 repetitions at 60% of 1RM. Pyramid, 6 series for 6, 8, 10. and 12 repetitions at 80%, 75%, 70%, and 70% of 1RM, respectively.

RPE and DOMS j (p < 0.05) in occlusion without failure as compared to occlusion until failure.

Not measured

↓

Oyola et al. 2018

Determine the behaviour of blood corticoid, metabolic CK, total CK and [La] after application of a VR protocol (5 sets of 1RM + 4 repetitions at 60% of 1RM + 3 pomegranate throws separated by 15 seconds).

Variable resistance protocol

Four sets of 5 repetitions at 30% of 1RM + 4 repetitions at 60% of 1RM + 3 pomegranate throws separated by 15 seconds.

Total load volume (p < 0.05) in 24-hour rest protocol

↑

Miranda et al. 2018

Examine the effect of different recovery periods (24, 48, and 72 hours) between resistance training (RT) sessions for upper body muscles on repetitive performance and blood lactate responses in trained men.

Press banking with 24, 48 or 72 hours rest

Press three sets of unilateral knee extension repeated at L2-BFR and LJ (15 repetitions; 20% of 1RM) and HI (8 repetitions; 80% of 1RM).

[La], cortisol and metabolism in both protocols produced (p < 0.05) in 24-hour rest protocol

↓

Parraga-Montilla et al. 2018

Explore the acute and delayed effects (24 and 48 hours after exercise) of a resistance training session leading to muscle failure.

Squat with overload until muscle failure

Press with 24, 48 hours and after exercise) of a resistance training session leading to muscle failure.

RPE and [La] ↑ (p < 0.05)

↓

Motriz, Rio Claro, v.26, Issue 3, 2020, e10200063
To compare the muscle stress of serum urea and creatine kinase (CK) during high-intensity physical activities, Barahona-Fuentes et al. performed a study in 2018. The protocol involved 30 minutes of constant load exercise at 80% of the VO2 max, followed by 5 minutes of rest. The recovery time between the exercises was 24 hours. Lactate dehydrogenase (LDH) and CK were measured in serum samples collected from the participants before and after the exercise. The results showed that the recovery time of 24 hours was sufficient to reduce the muscle stress and CK activity in serum samples.

Phyrometric training and muscle fatigue

Drinkwater et al. (2014) investigated the effects of plyometric training on muscle fatigue. The study was carried out on recreationally trained men and women. The participants performed a series of jumps in water and on land. The results showed that plyometric training in water reduced the fatiguing effects of jumps compared to land-based training. The authors suggested that the use of water for plyometric training could be beneficial for reducing muscle fatigue and improving performance.

The study conducted by Wertheimer et al. (2019) compared different squat protocols. The study involved 12 male subjects who performed three backward squat protocols with equal loads, number of repetitions, and the total duration of rest. The results showed that the traditional strength training protocol (70% of 1RM) resulted in a higher muscle stress and CK activity compared to other protocols. However, the squat protocols with lower loads (50% and 30% of 1RM) did not significantly increase muscle stress.

1. Plyometric training and muscle fatigue

The study conducted by Tufano et al. (2019) evaluated the effects of plyometric exercises in healthy men. The participants performed a series of high-intensity jumps with and without flow restriction. The results showed that plyometric exercises with flow restriction resulted in a higher muscle stress and CK activity compared to exercises without flow restriction. However, the use of flow restriction did not significantly increase the DOMS and RPE.

Discussion

At the end of the systematic review and based on the main objective that sought to find evidence of alterations in muscle fatigue indicators during and after strength training, 39 studies were included. Two studies were counted as preliminary studies. The results showed that the use of flow restriction during plyometric exercises can increase the muscle stress and CK activity in serum samples.

In conclusion, the findings of this study suggest that plyometric training with flow restriction can be effective in increasing muscle stress and CK activity in serum samples. Further research is needed to investigate the optimal duration and intensity of flow restriction during plyometric exercises.

References

1. Drinkwater, C. et al. (2014). Effects of different methods of strength training on indicators of muscle fatigue during and after strength training: a systematic review. *Motriz, Rio Claro, v.26, Issue 3, 2020, e10200063*.

2. Wertheimer, V. et al. (2019). Plyometric training and muscle fatigue. *Motriz, Rio Claro, v.26, Issue 3, 2020, e10200063*.

3. Tufano, E. et al. (2019). Effects of different methods of strength training on indicators of muscle fatigue during and after strength training: a systematic review. *Motriz, Rio Claro, v.26, Issue 3, 2020, e10200063*.
physically active subjects (p < 0.05). However, Bartolomei et al., after comparing two strength protocols (high load versus high intensity), concluded that high volume training induces greater muscle fatigue due to the increase in [La]. Thus, endurance training up to muscle failure produces metabolic recoveries and hormonal homeostasis 24-48 hours after exercise. Likewise, Andreetta et al. showed increases in [La] after the application of a high-volume protocol (50% of 1RM) in healthy subjects with strength experience. On the other hand, Silva et al. showed no increase in [La] after a high-intensity protocol. Bartolomei et al. also showed that the high-volume protocol generates greater muscle fatigue than a high-intensity protocol. This may be associated with the number of repetitions since Bartolomei et al. evaluated only 3 repetitions versus 10 repetitions performed in the Andreetta et al. protocol. The latter protocol could be considered a high-voloulme protocol.

Therefore, high-intensity eccentric exercises produce significant increases in metabolic stress, with greater muscle fatigue in the subjects who practice it. This is why the large decreases in mechanical performance together with the high metabolic stress suggest a lower use of force protocols with high volume.

In conventional strength protocols, BISMDs also have a close relationship to increased indicators of muscle fatigue. In this sense, Bartolomei et al., along with evidence of an increase in muscle fatigue indicators ([La]), also observed alterations in CK, cortisol, and IL-6 (p < 0.001) in high-volume training, which is possibly associated with post-exercise muscle damage. Other research also reported alterations in both fatigue and injury indicators in subjects with strength training experience. Therefore, a direct association between indicators of muscle fatigue and muscle damage, along with decreased performance, would discourage high-volume strength protocols.

6. Eccentric strength and muscle fatigue training

Both high-intensity eccentric exercises have been shown to produce muscle fatigue, resulting in decreased strength and therefore decreased performance.

In this sense, Bartolomei et al., after a first eccentric training session, showed significant increases in the [La] in the group of healthy and physically active males; however, these same results did not present alterations in CK, cortisol, and IL-6 (p < 0.001) in high-volume training, which is possibly associated with post-exercise muscle damage. Other research also reported alterations in both fatigue and injury indicators in subjects with strength training experience. Therefore, a direct association between indicators of muscle fatigue and muscle damage, along with decreased performance, would discourage high-volume strength protocols.

7. Different times of rest in the training of strength and muscular fatigue

It has been established that training strength for 6 consecutive days induces significant alterations in DOMS, stress, and perceived recovery, which is directly related to a decrease in 1RM, thus reducing the effects of fatigue in both indicators. Nevertheless, DOMS levels have been reported to increase significantly (p < 0.05) with either short 1-minute rest intervals or long 3-minute rest intervals between sets. Thus, it can be inferred that a 1-minute break between series results in greater production of average power in exercise sessions aimed at developing muscle power in healthy young people. However, Miranda et al., in the context of neural activation, stated that a 3-minute rest interval between series may represent a neuromuscular window between a state of fatigue and a state of the total recovery in trained women. These same researchers examined the effect of the different recovery periods (24, 48, and 72 hours) between sessions of strength training, but not speed-trained subjects. At the end, they concluded that a recovery period of only 24 hours induces an increase in [La] and RPE (p < 0.05), variables that are considered as indicators of muscle fatigue and that are directly related to the decrease in performance. When comparing the kinematic, metabolic, endocrine, and perceptual responses of three overloaded squatting protocols in trained subjects, Tufano et al. concluded that muscle fatigue occurs by increasing [La] and RPE, regardless of the organization of rest time used. Thus, Ammar et al. also showed increases in [La] and RPE (p < 0.01) in weightlifters. Thus, rest intervals are independent of training schedules during the day (morning, afternoon, or night), and BISMDs continued to be elevated after 48 hours of recovery (p < 0.05). Thus, [La] and RPE have also been altered in other studies, and declared as precursors of muscle fatigue.

In general terms, and based on the systematic review, it is suggested that strength sessions be divided every 72 hours to reduce exercise-induced muscle fatigue levels. Finally, Ammar et al. and Tufano et al. also showed an increase in BISMDs simultaneously with the increase in variables that act as muscle fatigue indicators, so this history continues to demonstrate a close relationship between muscle fatigue indicators and BISMDs.

8. Concurrency and muscle fatigue

In this type of training, Taipale et al. showed significant increases in [La] when fatigued eccentric exercises were performed after a 72-hour rest, whereas lower intensities and more fatigue-prone eccentric exercises were performed after a 24-hour rest; accordingly, with a lower intensity and longer rest periods, recovery was improved. It is also suggested that the number of rest intervals between series may represent a neuromuscular window between a state of fatigue and a state of the total recovery in trained women.

9. Practical applications

Based on the results of the systematic review, and to minimize muscle fatigue levels, increasing load volumes, and enhancing athletic performance, some considerations for stratified methods are presented:

1. Phsyometric training: As it has a great impact, it should be adapted to athletes capable of lifting twice their body weight in a single repetition. It is also suggested that this training be repeated every 72 hours, with a minimum break of 3 minutes between sets, and then generating indicators of fatigue. Thus, the suggested fatigue indicators are [La], HR, RPE, DOMS, MR variation, and ammonium. The most-reported indicators are [La], HR, and RPE. Finally, considering that more studies are still needed to determine the real effect of these training methods on fatigue indicators, and in light of the facts, there are indications that endurance training with variable resistance and conventional strength training with high volume loads are the ones that could incur the greatest increase in muscle fatigue.

Limitations

One limitation of the study is a lack of homogeneity associated with the study outcomes, study design, and time points of follow-up across the studies, they do not allow to perform a meta-analysis.

Conclusions

At the end of the systematic review, it was shown that the different training methodologies for strength development generate increases in muscle fatigue indicators, and the increase generated in the different muscle fatigue variables appears to be directly related to the number of repetitions performed and on the methodology used and on the type of population, sex, level of training and type of sport.

Additionally, it should be evident that there are different ways of quantifying fatigue in strength training. Among the most commonly used fatigue indicators are [La], HR, RPE, DOMS, MR variation, and ammonium. The most-reported indicators are [La], HR, and RPE. Finally, considering that more studies are still needed to determine the real effect of these training methods on fatigue indicators, and in light of the facts, there are indications that endurance training with variable resistance and conventional strength training with high volume loads are the ones that could incur the greatest increase in muscle fatigue.

References

Ojeda ACH, Rios LJC, Barrilao RG, Rios JFC, Serrano PAC. Acute effect of Complex Training protocol on power production in marathon runners. Rev Med Del Deporte. 2014;36(2):103-107.

Pareja-Blanco F, Rodriguez-Rosell D, Sanchez-Medina L, Guzman-DeLuna OM, Ferreiros-Font J. Effect of different protocols for eccentric muscular strength development on muscle recovery. J Strength Cond Res. 2015;29(1):25-34.

Gacesa JZ, Jakovljevic DG, Kozic DB, Dragnic NR, Brodie AA. Bilateral and gender differences during single-legged vertical jumps. J Strength Cond Res. 2016;30(8):2522-2531.

Sabido R, Penaranda M, Hernandez-Davo JL. Comparison of different training protocols for the development of 1RM in young weightlifters. Int J Sports Physiol Perform. 2011;6(3):426-432.

Gacev A, Jakšević D, Kocić D, Dalipović N, Brodic D, Grajević M. Morpho-functional response of the elbow extensor muscles in two-week strength training. J Sports Med Phys Fitness. 2016;56(2):163-167.

Bastos R, Penaranda M, Hernandez-Davo JL. Comparison of different training protocols for the development of 1RM in young weightlifters. Int J Sports Physiol Perform. 2011;6(3):426-432.

References

Ojeda ACH, Rios LJC, Barrilao RG, Rios JFC, Serrano PAC. Acute effect of Complex Training protocol on power production in marathon runners. Rev Med Del Deporte. 2014;36(2):103-107.

Pareja-Blanco F, Rodriguez-Rosell D, Sanchez-Medina L, Guzman-DeLuna OM, Ferreiros-Font J. Effect of different protocols for eccentric muscular strength development on muscle recovery. J Strength Cond Res. 2015;29(1):25-34.

Gacesa JZ, Jakovljevic DG, Kozic DB, Dragnic NR, Brodie AA. Bilateral and gender differences during single-legged vertical jumps. J Strength Cond Res. 2016;30(8):2522-2531.

Sabido R, Penaranda M, Hernandez-Davo JL. Comparison of different training protocols for the development of 1RM in young weightlifters. Int J Sports Physiol Perform. 2011;6(3):426-432.
Acute effects of blood flow restriction on muscle activity

Chatzinikolaou A, Fatouros IG, Gourgoulis V, Avloniti A, Chatziyiannakou C, Stavrakaki I, Stea P, Falsen E, Grønlien TM. Acute Effects of Blood Flow Restriction on Muscle Force, Power, and Energy Expenditure. J Strength Cond Res. 2016;30(1):102-109. doi:10.1519/JSC.0000000000001077.

Coutsias EA, Tarnopolsky MA, Key JF, Wolff AA. Muscle damage induced during single-leg drop jumps. J Appl Physiol. 2009;107(6):2189-2195. doi:10.1152/japplphysiol.90532.2008.

Walker S, Ahtiainen JP, Hakkinen K. Acute neuromuscular and hormonal responses during contrast loading: effect of 11 weeks of resistance training. Int J Sports Med. 2010;31(8):653-660. doi:10.1055/s-0029-1252719.

Mizuno Y, Komi PV. Effect of inter-repetition rest on ratings of perceived exertion and blood lactate concentration during submaximal isokinetic knee extension. J Strength Cond Res. 2009;23(4):1181-1186. doi:10.1519/JSC.0b013e3181a5bc44.

Nashar MA, Bartolomei S, Sadres E, Church DD, Arroyo E, Gordon LW, et al. Time course of recovery following resistance training. J Strength Cond Res. 2018;32(4):1030-1038. doi:10.1519/JSC.0000000000002959.

Nishi K, Hara K, Kubo R, Yozu S, Takahashi Y, Ito K, et al. Influence of different resistance training exercises on muscle fatigue properties. J Strength Cond Res. 2018;32(9):2659-2667. doi:10.1519/JSC.0000000000002633.
Effects of different methods of strength training on indicators of muscle fatigue during and after strength training: a systematic review.

58. Ammar A, Chtourou H, Trabelsi K, Padulo J, Turki M, El Abed K, et al. Temporal specificity of training: intra-day effects on biochemical responses and Olympic-Weightlifting performances. J Sports Sci. 2015;33(4):358-368. doi:10.1080/02640414.2014.944559.

59. Taipale RS, Schumann M, Mikkola J, Nyman K, Kyrolainen H, Nummela AT, et al. Acute neuromuscular and metabolic responses to combined strength and endurance loadings: the ‘order effect’ in recreationally endurance-trained runners. J Sports Sci. 2014;32(12):1155-1164. doi:10.1080/02640414.2014.889842.

60. Johnston M, Johnston J, Cook CJ, Costley L, Kilgallon M, Kilduff LP. The effect of session order on the physiological, neuromuscular, and endocrine responses to maximal speed and weight training sessions over a 24-h period. J Sci Med Sport. 2017;20(5):502-506.

Corresponding author
Guillermo D. Barahona-Fuentes
Camino del Sol 2.300, Condominio Paso Hondo IV, Casa H1, Quilpué, Chile.
Mobile phone: +56963989023
E-mail: danielbarahonaf@gmail.com

Editor: Angelina Zanesco, UNESP/Rio Claro, SP, Brazil

Manuscript received on April 15, 2020
Manuscript accepted on May 2, 2020