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Review Article

Resistance training variables on muscle hypertrophy: a systematic review

Short title: Resistance training variables and muscle hypertrophy

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ABSTRACT

Resistance training (RT) is a widely practised type of training, and the number of adherents of this type of physical exercise is increasing each year. Among the most sought objectives of those who initiate RT is muscle hypertrophy, although success in this process depends on a well-designed protocol and good manipulation of training variables. The present study aims to analyse, through a systematic review, the impact of the RT variables (such as intensity, volume, recovery interval, execution speed, and concentric muscle failure) relevant to muscle hypertrophy and if there is an ideal range for each training variable. The research was carried out in the PubMed, Web of Science, Scopus and Scielo databases from 2000 to 2020, using the terms "resistance training" and "hypertrophy" and "intensity" or "volume" or "recovery interval" or "execution speed" or "muscular failure". Twenty-three articles were included in the review. The PEDro scale was used to analyse the quality of the selected articles. It was concluded that the variables intensity and volume must be carefully analysed in a training program. Despite not having a direct impact on hypertrophy, the other variables affect the intensity and volume and must be manipulated according to what is intended with the others.

KEYWORDS: muscle strength; hypertrophy; resistance training.

INTRODUCTION

Resistance training (RT) is one of the most popular physical exercise forms in sports performance and health-related environments. RT is generally used to refer to strength exercise training using some external load and equipment. Thus, by means of systematically demanding muscle activation in the involved musculature to overcome a certain external resistance, RT leads to increase muscle force-generating capacity, elicits a hypertrophic response or enhances muscular endurance (American College of Sports Medicine, 2009; Schoenfeld, Peterson, Ogborn, Contreras, & Sonmez, 2015; Moreira et al., 2019).

Initially, RT programs promote increased strength, initially dependent on neural adaptations. Subsequently, both neural and hypertrophic factors account for these strength gains, with hypertrophic factors becoming predominant after the first 3-5 weeks of training (Moritani & DeVries, 1979). To trigger muscle hypertrophy, a longer period of training is needed to increase the contractile protein contained in all muscle fibres (Morton et al., 2018). Thus, muscle hypertrophy can be considered a result of the expansion of the contractile elements in series and the extracellular matrix of muscle fibre, caused by the addition of sarcomeres in series and myofibrils in parallel or by an increase of fluid content and non-contractile elements in the extracellular matrix (Schoenfeld, 2010).

The correct manipulation of some variables of the RT program can maximise hypertrophic gains and improve muscle fitness levels (American College of Sports Medicine, 2009). In this sense, to promote muscle hypertrophy, it is recommended to perform the RT at an intensity of 70 to 85% of a maximum repetition (1RM) for debutants and/or intermediate individuals and from 70 to 100% of 1RM for advanced individuals (American College of Sports Medicine, 2009). The training volume can be defined as series × repetitions × load, and it is assumed to be one of the most important variables in RT to promote muscle hypertrophy (Schoenfeld, Ogborn, & Krieger, 2017a). In the same line, one of the most neglected RT variables is the rest interval between sets, exercises and training sessions (Suchomel, Nimphius, Bellon, & Stone, 2018). Still, this variable is associated with muscle hypertrophy, promoting increased metabolic stress (Schoenfeld, 2010). In this sense, it seems that a large number of rest intervals can be used effectively to target hypertrophy, but it depends heavily on its relationship with training intensity. Another variable associated with muscle hypertrophy is the execution speed (American College of Sports Medicine, 2009; Schoenfeld, 2010). It seems that the variation in the use of different speeds guarantees better hypertrophic effects for advanced individuals in the long run (American College of Sports Medicine, 2009). Finally, training performed to failure also increases metabolic stress, thus enhancing the hypertrophic response (Schoenfeld, 2010).

However, manipulation of RT variables can directly impact the success or failure of a determined training program. Therefore, it is necessary to determine to what extent the intensity of RT could maximise the hypertrophic gains induced by training or what is the relationship between training volume and muscle hypertrophy in order to establish which would be the best options for setting up a training program, or also which rest interval would be most associated with muscle hypertrophy, or yet what would be the ideal RT speed for maximising hypertrophic, or finally to establish the magnitude of the RT up to the concentric failure on the hypertrophic gains, to assist coaches in manipulating this variable and achieving training objectives and also to indicate or contraindicate this practice.

Thus, this study aimed to systematically review the current literature about RT variables (intensity, volume, rest interval, execution velocity and muscle failure) for inducing muscle hypertrophy; and determine the optimal RT prescription dosage to promote muscle hypertrophic effects.

METHODS

This systematic review was designed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Protocols (PRISMA-P) (Moher, Liberati, Tetzlaff & Altman, 2009). The PRISMA-P statement includes 27 points, grouped in 17 kinds of items checklist, and it is designed to be used as a basis for reporting a systematic review of randomised trials. A review protocol was registered for this review PROSPERO CRD42021273700.

Eligibility criteria

The inclusion criteria were: studies published in English; sample composed of healthy humans; use of RT as a training method; minimum intervention of six weeks; comparison of at least two protocols associated with at least one of the variables (intensity, volume, rest interval, speed of execution and muscle failure); studies with at least one method of analysing hypertrophy.

Exclusion criteria were used: case studies; review studies; studies with animal model; studies with people with a disease or disability; studies with a sample group composed of the elderly, adolescents or children; studies that used other training methods, in addition to RT; studies that used blood flow restriction in RT; studies that did not assess muscle hypertrophy.

Information sources

A systematic, computerised search of the literature in PubMed, Web of Science, Scopus and Scielo was conducted by two researchers (WMLM and CEPO) with controlled vocabulary and keywords related to resistance training and muscle hypertrophy. Our search time frame was restricted to 20 years (January 2000 to December 2020).

Search strategy

We developed our search strategy based on others reviews and meta-analysis of Maroto-Izquierdo et al. (2017) and Moreira et al. (2019). To do this, the search strategy by previous reviews in the field of RT and muscle hypertrophy was used (Schoenfeld et al., 2016b; Schoenfeld et al., 2017a; Schoenfeld et al., 2017b). The search language was restricted to English, and a filter containing Medical Subject Headings (MeSH) terms was applied. A more specific search included the terms *Intensity*: (“resistance training” OR “resistance exercise” OR “strength training” OR “strength exercise” OR “weight training” OR “weight exercise”) AND (“intensity” OR “load” OR “loading” OR “training load” OR “high-load” OR “high load” OR “low-load” OR “low load” OR “high intensity” OR “low-intensity” OR “higher-repetition” OR “lower-repetition” OR “exercise load” OR “training load”) AND (“hypertrophy” OR “muscle hypertrophy” OR “muscular hypertrophy” OR “muscle fibre” OR “muscle fiber” OR “muscle thickness” OR “CSA” OR “cross-sectional area” OR “muscle size” OR “muscle mass”); *Volume*: (“resistance training” OR “resistance exercise” OR “strength training” OR “strength exercise” OR “weight training” OR “weight exercise”) AND (“volume” OR “frequency” OR “frequencies” OR “single sets” OR “multiple sets” OR “training frequency” OR “split training” OR “total body training” OR “split-routine” OR “split weight training”) AND (“hypertrophy” OR “muscle hypertrophy” OR “muscular hypertrophy” OR “muscle fibre” OR “muscle fiber” OR “muscle thickness” OR “CSA” OR “cross-sectional area” OR “muscle size” OR “muscle mass”); *Rest Interval*:

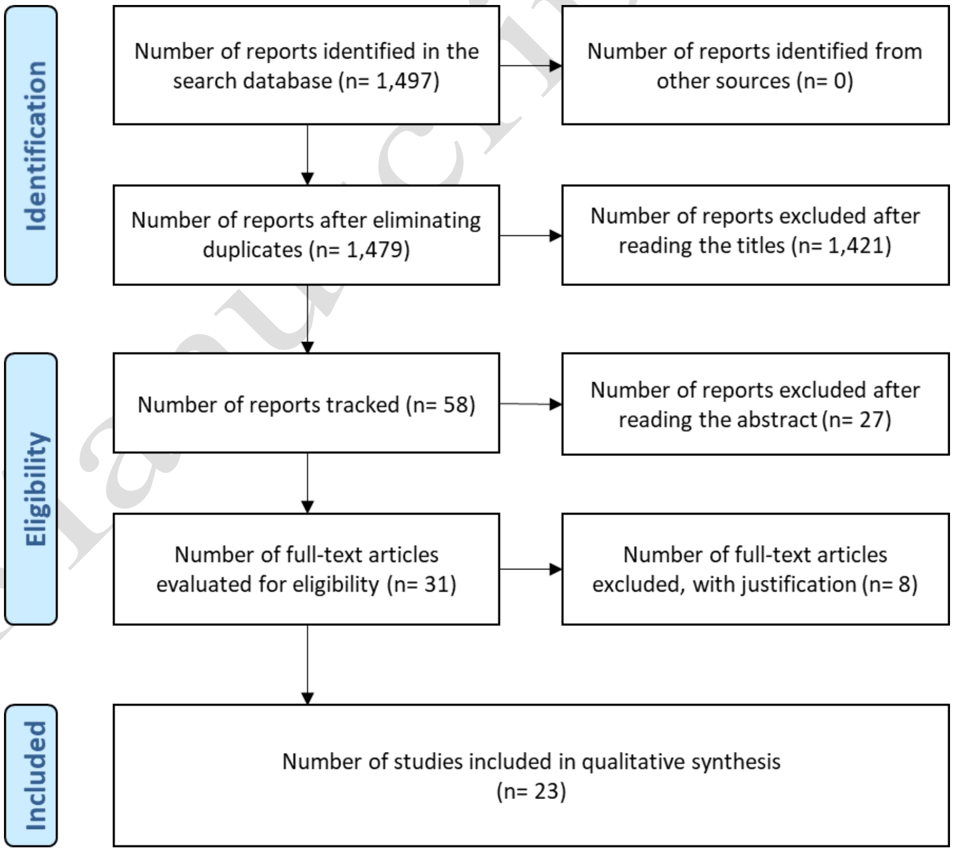
(“resistance training” OR “resistance exercise” OR “strength training” OR “strength exercise” OR “weight training” OR “weight exercise”) AND (“rest interval” OR “rest period” OR “recovery” OR “recovery time” OR “inter-set rest interval”) AND (“hypertrophy” OR “muscle hypertrophy” OR “muscular hypertrophy” OR “muscle fibre” OR “muscle fiber” OR “muscle thickness” OR “CSA” OR “cross-sectional area” OR “muscle size” OR “muscle mass”); *Execution Speed*: (“resistance training” OR “resistance exercise” OR “strength training” OR “strength exercise” OR “weight training” OR “weight exercise”) AND (“execution speed” OR “repetition velocity” OR “repetition speed” OR “repetition duration” OR “repetition tempo” OR “tempo of movement” OR “slow movement” OR “slow-speed” OR “velocity of movement” OR “time under tension” OR “concentric duration” OR “eccentric duration” OR “cadence”) AND (“hypertrophy” OR “muscle hypertrophy” OR “muscular hypertrophy” OR “muscle fibre” OR “muscle fiber” OR “muscle thickness” OR “CSA” OR “cross-sectional area” OR “muscle size” OR “muscle mass”); *Concentric Failure*: (“resistance training” OR “resistance exercise” OR “strength training” OR “strength exercise” OR “weight training” OR “weight exercise”) AND (“concentric failure” OR “repetition failure” OR “failure training” OR “non-failure training” OR “non failure training” OR “muscular failure” OR “muscle failure” OR “muscle fatigue” OR “muscular fatigue” OR “muscular exhaustion” OR “to failure” OR “not to failure” OR “volitional interruption” OR “volitional failure” OR “repetition maximum” OR “maximal repetitions”) AND (“hypertrophy” OR “muscle hypertrophy” OR “muscular hypertrophy” OR “muscle fibre” OR “muscle fiber” OR “muscle thickness” OR “CSA” OR “cross-sectional area” OR “muscle size” OR “muscle mass”).

Selection process

The selection of studies was made independently by two reviewers (WMLM and CEPO), as differences included in the inclusion of any article were made by consensus between the two reviewers. In cases where discrepancies could not be resolved, the final decision was made by another independent researcher (OCM).

Data collection process/Data items

The search and selection of studies included in the review were performed by two authors (WMLM) and (CEPO). The main items extraction form was used to report systematic reviews and meta-analyses (Moher, Liberati, Tetzlaff & Altman, 2009), organised chronologically in Figure 1. The last search performed was in December 2020. Of the studies initially found, 58 were selected after reading the title. Afterwards, the abstract was read, and 31 studies were selected. Then, the selected articles were read in full. From there, 23 articles were selected that were considered suitable for inclusion in the analysis, based on the criteria described in the item eligibility criteria. Tables 2, 3, 4, 5 and 6 summarise the studies included in the analysis according to each variable presented, where they are elucidated: Publication data (authors and year of publication); Sample characteristics (number, sex, age); Variable used (intensity, volume, rest interval, execution speed, muscle failure); Training methods applied and exercises used; Intervention duration (weeks and frequency); Measures Used; Results.



Source: Prisma (Moher, Liberati, Tetzlaff & Altman, 2009).

Figure 1. Flow diagram illustrating the different phases of the search and selection of studies included in the review.

Quality assessment

Methodological quality was assessed using the PEDro scale (1999). The included articles were independently assessed by two reviewers (WMLM and CEPO), taking into account criteria 1, 8, 10 and 11, with 4 points being the maximum score achieved. Divergences between the reviewers' analyses were resolved by consensus. Among the 19 studies included in this systematic review, 18 achieved 4 points on the PEDro scale, and 1 (Schoenfeld et al., 2015) achieved 3 points (items 8, 10 and 11). Table 1 displays the main results of quality assessment from the included studies.

Table 1. PEDro scale score to assess the quality of the included studies.

Studies	1	8	10	11	Total
Barcelos et al. (2018)	1	1	1	1	4
Buresh et al. (2009)	1	1	1	1	4
Carroll et al. (2019)	1	1	1	1	4
Fink et al. (2017)	1	1	1	1	4
Fink et al. (2018)	1	1	1	1	4
Holm et al. (2008)	1	1	1	1	4
Jenkins et al. (2017)	1	1	1	1	4
Lasevicius et al. (2018)	1	1	1	1	4
Mangine et al. (2015)	1	1	1	1	4
Martorelli et al. (2017)	1	1	1	1	4
Mitchell et al. (2012)	1	1	1	1	4
Ochi et al. (2018)	1	1	1	1	4
Radaelli et al. (2015)	1	1	1	1	4
Saric et al. (2019)	1	1	1	1	4
Schoenfeld et al. (2014)	1	1	1	1	4
Schoenfeld et al. (2015)	0	1	1	1	3
Schoenfeld et al. (2019)	1	1	1	1	4
Schoenfeld et al. (2016a)	1	1	1	1	4
Schuenke et al. (2012)	1	1	1	1	4
Sooneste et al. (2013)	1	1	1	1	4
Tanimoto and Ishii (2006)	1	1	1	1	4
Tanimoto et al. (2008)	1	1	1	1	4
Yue et al. (2018)	1	1	1	1	4

Table 2. List of articles included in the present study (intensity).

Studies	Sample	Protocols	Intervention Duration	Hypertrophy Measurements	Results
Holm et al. (2008)	11 untrained men	Isolated knee extensions, performed 3 weekly sessions, each leg was trained at an intensity: HL= 70% 1RM, performing 8 repetitions, for 25 s LL= 15.5% of 1RM, performing 36 repetitions, one repetition every 5 seconds.	12 weeks	MRI	HL: ↑ Muscular hypertrophy ↑ CSA: HL (7,6± 1,4%) > LL (2,6± 0,8%)
Jenkins et al. (2017)	26 untrained men	2 groups HL= 3 series executed until the concentric failure at 80% of 1RM, with 1s of concentric phase and 1 s of eccentric phase, and two min of rest between the series. LL= 3 series executed until the concentric failure at 30% of 1RM, with 1 s of concentric phase and 1 s of eccentric phase, and two min of rest between the series.	6 weeks	Ultrasound	↑ muscle thickness
Lasevicius et al. (2018)	30 untrained men	The exercises performed were unilateral elbow flexion and unilateral 45° leg press, performed twice a week, with an interval between the series of 120 s and a cadence of 2 s for the concentric phase and 2 s for the eccentric phase, one leg and one arm were from the G20 group and the other member was randomly assigned to one of the other three groups: G20= 20% of 1RM G40= 40% of 1RM G60= 60% of 1RM G80= 80% of 1RM	12 weeks	Ultrasound	↑ of CSA of the elbow flexors ↑ the CSA of the vast lateral
Mangine et al. (2015)	33 trained men	2 groups: INTENSITY (INT)= 4 sets of 3-5 repetitions with 90% of 1RM, with 3 min rest between sets. VOLUME (VOL)= 4 sets of 10-12 repetitions, with 70% of 1RM, with 1 minute rest between sets.	8 weeks	DXA and Ultrasound	↑ lean arm mass: INT> VOL ↑ lean leg mass: INT> VOL ↑ Leg CSA: INT> VOL.
Mitchell et al. (2012)	18 untrained men	Knee extension, each leg randomly assigned to one of the groups: 80% -1= one series up to concentric failure at 80% of 1RM 80% -3= three series until concentric failure at 80% of 1RM 30% -3= three series up to 30% concentric failure of 1RM	10 weeks	MRI and muscle biopsy	↑ quadriceps muscle volume in all groups.
Schoenfeld et al. (2015)	24 trained men	3 weekly sessions of 3 sets per exercise until concentric failure, with a cadence of 1s for concentric and 2s for eccentric, and 90s interval between sets. 2 groups: LL= 30-50% 1RM, performing 25-30 repetitions HL= 70-80% of 1RM, performing 8-12 repetitions	8 weeks	Ultrasound	↑ muscle thickness of the elbow flexors ↑ muscle thickness of the elbow extensors ↑ muscle thickness of the femoral quadriceps

HL: high load; LL: low load; MRI: magnetic resonance imaging; CSA: cross sectional area.

Table 3. List of articles included in the present study (Volume).

Studies	Sample	Protocols	Intervention Duration	Hypertrophy Measurements	Results
Barcelos et al. (2018)	20 untrained men	3 groups RT5= 5 weekly sessions without volume equalisation. RT3= 3 weekly sessions without volume equalisation. RT2= 2 weekly sessions without volume equalisation. The exercise performed was the knee extension on the machine, where three sets of 9-12 repetitions were performed until the concentric failure at 80% of 1RM, with a 2-minute interval between sets.	8 weeks	Ultrasound	↑ CSA of vast lateral.
Ochi et al. (2018)	20 untrained men	2 groups T1= a weekly session of 6 sets of 12 repetitions with 67% of 1RM. T3= three weekly sessions of 2 sets of 12 repetitions with 67% of 1RM. The exercise performed was knee extension, where both groups rested for 2 min between each series, with a cadence of 1s for concentric phase, 1 s for eccentric phase and 1s of rest.	11 weeks	Ultrasound and circumference measurement with tape.	↑ thigh circumference. ↑ thickness of all quadriceps muscles.
Radaelli et al. (2015)	48 untrained men	4 groups 1 SET= 1 set per exercise 3 SETS= 3 sets per exercise 5 SETS= 5 sets per exercise Control group (CG)= did not perform the weight training program but did a traditional military callisthenics program for body weight exercises 3 times a week for approximately 1 hour per session. 3 weekly sessions	6 months	Ultrasound	↑ muscle thickness of the elbow flexors: 5 sets> 3 sets. ↑ muscle thickness of the elbow extensors: 5 sets.
Saric et al. (2019)	27 trained men	2 groups RT3= trained each muscle group 3 times a week with equalised volume. RT6= trained each muscle group 6 times a week with equalised volume. The performed exercises were made of 6-12 repetitions looking for concentric muscle failure, with a 1-2 second cadence, interval between sets of 60-90 seconds and between exercises of 2-3 minutes.	6 weeks	Ultrasound	↑ flexor muscle thickness of the elbow, extensor elbow, rectus femoris and vastus lateralis in RT3. ↑ elbow extensor, rectus femoris and vastus lateralis on RT6.
Schoenfeld et al. (2014)	20 trained men	2 groups ST= 7 sets, 3 repetitions and 3 min interval between sets. HT= 3 sets, 10 repetitions and 90 s of interval between sets.	8 weeks	Ultrasound	↑ muscle thickness of the biceps in all groups.
Schoenfeld et al. (2019)	34 untrained men	3 groups 1 SET = 1 series per exercise per section. 3 SET = 3 sets per exercise per session. 5SET = 5 sets per exercise per session. Seven exercises were performed per session.	8 weeks	Ultrasound and anthropometry	↑ biceps thickness: 5 sets> 3 sets, 1 set. ↑ triceps thickness ↑ rectus femoris: 5 set> 3 set, 1 set. ↑ vast lateral: 5 set> 3 set, 1 set.
Sooneste et al. (2013)	8 untrained men	2 groups 1set= 1 set of dumbbell elbow flexion 3 sets= 3 sets of dumbbell elbow flexion 2 weekly sessions with a rest of 5 min between the protocols, 80% of	12 weeks	MRI	↑ CSA: 3 sets (13,3± 3,6%)> 1 set (8,0± 3,7%)

		1RM, 2 seconds of concentric and 2 of eccentric, looking for concentric muscle failure in both protocols.			
Yue et al. (2018)	18 trained men	2 groups LV-HF= 4 weekly sessions (equalised volume) of 8-12 repetitions, with a 75% load of 1RM and a 2-min rest interval. HV-LF= 2 weekly sessions (equalised volume) of 8-12 repetitions, with a 75% load of 1RM and a 2-min rest interval.	6 weeks	Constant voltage measuring tape, Anthropometric assessment, Ultrasound	HV-LF: ↓ total and relative amount of fat, ↑ fat-free mass, vast medial thickness, circumference of the arm and thickness of the elbow flexors LV-HF: ↑ vast medial thickness.

HT: hypertrophy-type resistance training; ST: strength-type resistance training; LV-HF: low volume per session and high frequency; HV-LF: high volume per session with a low frequency; MRI: magnetic resonance imaging.

Table 4. List of articles included in the present study (rest interval).

Studies	Sample	Protocols	Intervention Duration	Hypertrophy Measurements	Results
Buresh et al. (2009)	12 untrained men	2 groups SR= 1 min interval between sets LR= 2.5 min interval between sets	10 weeks	Hydrostatic Weighing	↑ Arm CSA: SR (2,9%), LR (7,2%). ↑ Thigh CSA: SR (3,0%) LR (5,0%).
Fink et al. (2017)	21 untrained men	2 groups SR= 30 sec interval between sets LR= 150 sec interval between sets 2 weekly sessions, 4 sets of bench press and 4 sets of squat (40% 1RM, 1s in the concentric phase and 2 s eccentric phase, performed until the concentric failure).	8 weeks	MRI	↑ CSA do tríceps no SR (9,8± 8,8%), LR (10,6± 9,6%). ↑ CSA da coxa no SR (5,7± 4,7%), LR (8,3± 6,4%).
Fink et al. (2018)	20 untrained men	2 groups SR= 30 sec interval between sets, 20 RM LR= 3 min interval between sets, 8 RM	8 weeks	MRI and ultrasound	↑ of the CSA of the arm: SR, LR. ↑ acute muscle thickness of the long head of the triceps, ↑ GH, ↑ metabolic stress in SR.
Schoenfeld et al. (2016a)	23 trained men	2 groups SR= 1 min interval between sets LR= 3 min interval between sets	8 weeks	Ultrasound	↑ brachial triceps: LR> SR. ↑ brachial biceps ↑ vast lateral.

SR: short rest; LR: long rest; MRI: magnetic resonance imaging; CSA: cross sectional area.

Table 5. List of articles included in the present study (speed of execution).

Studies	Sample	Protocols	Intervention Duration	Hypertrophy Measurements	Results
Schuenke et al. (2012)	34 untrained women	3 groups SS= from 6 to 10 RM for each series with 10 s for concentric phase and 4s for eccentric phase. TS= from 6 to 10 RM, with 1-2 s of concentric phase and 1-2 s of eccentric phase. TE= 20-30 RM, with 1-2 s of concentric phase and 1-2 s of eccentric phase.	6 weeks	Biopsy and Anthropometric Assessment	No differences in anthropometric measurements. ↑ Average fiber CSA in the TS group (38,8± 21,7%), SS (10,6± 8,7%).
Tanimoto and Ishii (2006)	24 untrained men	3 groups LST= 50% of 1RM, with slow movement and tonic force generation (3 s for eccentric and concentric phase, 1 s pause and no relaxation phase) HN= 80% of 1RM, with normal speed (1 s for eccentric and concentric actions and 1s for relaxing) LN= 50% of 1RM and normal speed 3 weekly sessions of 3 sets of knee extension in a sitting position, with a rest interval of 60 s.	12 weeks	MRI	↑ CSA of knee extensor muscles: LST (5,4± 3,7%), HN (4,3± 2,1%).
Tanimoto et al. (2008)	36 untrained men	3 groups LST= ~ 55-60% of 1 RM, and 8 repetitions, with slow movement and tonic force generation (3 s for eccentric and concentric phase, and no relaxation phase) HN= ~ 80-90% of 1 RM, and 8 repetitions, with normal speed (1 s for eccentric and concentric actions and 1 s for relaxing) CON = without training	13 weeks	Ultrasound and DXA	↑ muscle thickness: LST (6,8± 3,4%), HN (9,1± 4,2%), CON (1,3± 2,2%).

LTS: low-intensity and slow movement; HN: high-intensity and normal speed; LN: low-intensity and normal speed; SS: slow-speed; TS: normal-speed/traditional-strength; TE: normal-speed/traditional muscular endurance; MRI: magnetic resonance imaging; CSA: cross sectional area.

Table 6. List of articles included in the present study (muscular failure).

Studies	Sample	Protocols	Intervention Duration	Hypertrophy Measurements	Results
Carroll et al. (2019)	15 trained men	2 groups/3 weekly sessions RI= 65-92.5% of 1 RM, 3-5 sets of 2-10 repetitions, block periodization. RM= maximum repetitions of 8-12, 4-6, 2-4, 1-3; 3-5 repetitions, block periodization	10 weeks	Biopsy and ultrasound	↑ in CSA type I ($p= 0.018$), CSA type II ($p= 0.012$), ACSA ($p= 0.002$) and muscle thickness ($p< 0.001$) in RI. ↑Muscle thickness ($p= 0.003$) in the RM group.
Martorelli et al. (2017)	89 untrained women	3 groups/2 weekly sessions FR= 3 series of repetitions until failure at 70% of 1 RM RNFV= 4 sets of 7 repetitions at 70% of 1RM RNF= 3 sets of 7 repetitions at 70% of 1RM	10 weeks	Ultrasound	↑ muscle thickness in the RF, RNFV groups after 5 weeks.

RF: repetitions to failure; RNFV: repetitions not to failure with equalised volume; RNF: repetitions not to failure; RI: relative intensity; RM: repetition maximum; CSA: cross sectional area.

RESULTS

Intensity

At the end of the analysis and selection of articles for the intensity variable, the articles included were (Holm et al., 2008; Mitchell et al., 2012; Mangine et al., 2015; Schoenfeld et al., 2015; Jenkins et al., 2017; Lasevicius et al., 2018).

Volume

At the end of the analysis and selection of articles for the volume variable, the articles included were (Sooneste, Tanimoto, Kakigi, Saga, & Katamoto, 2013; Schoenfeld et al., 2014; Radaelli et al., 2015; Barcelos et al., 2018; Ochi et al., 2018; Yue et al., 2018; Saric et al., 2019; Schoenfeld et al., 2019).

Rest interval

At the end of the analysis and selection of articles for the rest interval variable, the articles included were (Buresh, Berg, & French, 2009; Schoenfeld et al., 2016a; Fink, Schoenfeld, Kikuchi, & Nakazato, 2017; Fink, Kikuchi, & Nakazato, 2018).

Execution speed

At the end of the analysis and selection of articles for the execution speed variable, the articles included were (Tanimoto & Ishii, 2006; Tanimoto et al., 2008; Schuenke et al., 2012).

Concentric muscle failure

At the end of the analysis and selection of articles for the concentric muscle failure variable, the articles included were (Martorelli et al., 2017; Carroll et al., 2019).

Intensity

In the studies by Mitchell et al. (2012) and Jenkins et al. (2017), groups of 80% of 1RM and 30% of 1RM were analysed, in which significant improvements were found in both groups, however, no inter-group differences were found. In the study by Lasevicius et al. (2018), a greater intensity range and a larger number of groups were used, in which there was a significant improvement in all groups 20% of 1RM, 40% of 1RM, 60% of 1RM, 80% of 1RM, however, group 20 % showed an improvement below the other groups, which had similar improvement. In the study by Holm et al. (2008), the difference in inter-group intensities was also high, with one group of 70% of 1RM and the other group 15.5% of 1RM. Both groups showed improvement, however, only the 70% group showed a significant difference in the middle of the leg, and the cross-sectional area of the quadriceps had a significantly greater improvement in the 70% group. The findings obtained in the analysed studies bring us a new hypothesis for the range of working intensities in hypertrophy, in which a range of 70 to 85% of 1RM was recommended for beginners (American College of Sports Medicine, 2009), being suggested that this range can start at 30% of 1RM, without a lesser magnitude in hypertrophic gains. One of the justifications for not using intensities below the recommended range was that, despite causing metabolic stress, the lower intensities were not able to recruit motor units of higher threshold (Schoenfeld, 2010). Corroborating the findings of the present study are the meta-analyses by Schoenfeld, Wilson, Lowery, and Krieger (2016b) and Schoenfeld, Grgic, Ogborn, and Krieger (2017b), in which the authors state that even at low intensities, hypertrophic gains are similar to gains obtained at higher intensities. The only study analysing the intensity variable that used a sample composed of trained individuals was that of Schoenfeld et al. (2015), in which a group of 30-50% of 1RM and one of 70-80% of 1RM were analysed, and the inter-group results were similar for elbow flexors, elbow extensors and femoral quadriceps. These results corroborate the findings of the present study for untrained individuals, however, it is not possible to state that for trained individuals, the gains will be similar since only one study in the sample was composed of trained individuals. The study by Schoenfeld et al. (2016b) found a small tendency for greater growth when using higher intensities. The authors mention that, for more experienced individuals' training, it is necessary to use more demanding protocols, including the use of higher intensities.

The work of Mangine et al. (2015) compared a group of 90% of 1RM with a group of 70% of 1RM, where the volume and the rest interval were different. More marked improvements were found in the lean mass of the arm and the leg for the group that trained at 90% of 1RM. However, the groups that were analysed had very different protocols, with one group performing 4 sets of 3 to 5 repetitions with 90% of 1 RM and interval between sets of 3 minutes, while the other group performed 4 sets of 10 to 12 repetitions with 70% of 1RM and interval between sets of 1 minute, therefore it is impossible to attribute hypertrophic gains only to the intensity variable.

However, we can note that the improvements found in the articles had similar results, as long as the intensities exceed 30% of 1RM, which differs in parts of the ACSM guidelines (American College of Sports Medicine, 2009), which suggest that intensities above 70% are necessary for the hypertrophy. Thus, the hypothesis arises that even at lower intensities, hypertrophy can occur, thus obtaining a greater working range within the intensity variable.

Volume

In the studies by Yue et al. (2018) and Saric et al. (2019), groups composed of trained individuals were outlined, in which the effect of different numbers of weekly sessions on hypertrophy was analysed, with the volume equalised. In the study by Yue et al. (2018), one group held 4 weekly sessions while the other held 2 weekly sessions. Only the group of 2 weekly sessions showed improvement in body composition. As for the muscular thickness of the vast medial, both groups showed significant improvement. Only the group of 2 weekly sessions showed a change in the thickness of the elbow flexors. In the study by Saric et al. (2019), one group trained each muscle group 3 times a week, and one group trained each muscle group 6 times a week. Significant improvement was identified for the 3-fold group compared to the 6-fold group only in the elbow flexor muscle, with no significant difference for the other muscle groups. Both studies can identify a small advantage for less frequent weekly training protocols, as long as the volume is equalised. Hence the hypothesis that for trained individuals, a division of training in which each muscle group is trained at lower frequencies but with a high volume of series and repetitions would be more advantageous, that is, for trained individuals, an ABCD training protocol would be more advantageous than a full-body protocol for example, even with volume equalised. Schoenfeld (2010) mentions that a divided training routine combines the training volume with longer recovery time, greater intensities and greater muscle tension, thus being more advantageous for advanced individuals who need greater training volumes. Corroborating the aforementioned study, American College of Sports Medicine (2009) indicates that higher frequencies of RT are suggested for hypertrophy, however, only a few muscle groups are trained per session, which agrees with the idea of a more divided training, but with less frequency for each muscle group. In the study by Ochi et al. (2018), a group of untrained individuals who performed a weekly 6-series session was analysed, and a group of three weekly 2-series sessions, the results showed a significant increase in thigh circumference and thickness, but there was no significant difference between groups. What shows is that, for beginners, the most important thing is equalising the volume, with no direct interference from the number of weekly sessions. Figueiredo, Salles, and Trajano (2018) cite that, when considered, volume is one of the most important factors in muscle hypertrophy, as long as the training has sufficient intensity. However, the authors also cite that a minimum of ten weekly series per muscle group is necessary to maximise muscle hypertrophy in untrained individuals, which is at variance with the study by Ochi et al. (2018), where only with six weekly series there was a significant increase in thigh circumference and thickness. The study by Barcelos et al. (2018) presented a group that performed 5 weekly sessions, one that performed 3 weekly sessions and one that performed 2 weekly sessions without equalising the volume, and both groups showed similar improvement in the thigh cross-section area, however the group of higher volume had a larger effect size. This result is in agreement with Figueiredo et al. (2018), who mentions that volume is the variable with the most evident response in muscle hypertrophy, with a clear dose-response relationship.

Regarding the number of series performed, Schoenfeld et al. (2014) found significant increases in both groups, which were composed of trained individuals, however, there was no significant difference between group 7 series and 3 repetitions, and group 3 series and 10 repetitions. One hypothesis for this is that the training volume was very close, and therefore there was no difference in the results obtained. In the studies by Radaelli et al. (2015), Schoenfeld et al. (2019) and Sooneste et al. (2013) and it was possible to identify a dose-response relationship for the groups that performed more sets with a greater degree of muscle hypertrophy. Similarly, Krieger (2010) mentions in his review that a greater number of series presented hypertrophy 40% greater than a single series. Schoenfeld (2010) also mentions that protocols composed of more series are superior to protocols composed of a single series.

It is possible to note that muscle volume and hypertrophy have a dose-response relationship, that is, higher volumes are associated with higher degrees of hypertrophy

(American College of Sports Medicine, 2009; Krieger, 2010; Schoenfeld, 2010; Figueiredo et al., 2018). Additionally, when the volume is equalised, a greater division of muscle groups in trained individuals proved to be more effective compared to a smaller division, that is, training performed in fewer weekly sessions was more effective than training performed in more weekly sessions, as long as the volume is equalised. This agrees with the principles of the training progression, mainly the principle of overload, which says that an overload is necessary to generate the hypertrophic stimulus (Schoenfeld, 2010), and is also in accordance with the guidelines of the American College of Sports Medicine (2009), which indicate that for more advanced users the training should be more voluminous and more divided between sessions. All of these results are in line with the findings of this review since the articles that showed greater benefits in a greater division with equalised volume were performed with trained individuals.

Rest interval

The study by Buresh et al. (2009) showed significant inter-group differences only for the cross-sectional area of the arm, in which the 2.5-minute interval group was superior to the 1-minute interval group, however, both groups showed improvement, both in the cross-sectional area of the arm, as well as the thigh. Similarly, Robinson et al. (1995) found no significant differences in muscle circumference between 30, 90 and 180 seconds intervals. In contrast, Schoenfeld et al. (2016a) found greater increases in the triceps brachii for the group with a 3-minute interval compared to the 1-minute interval group, whereas for the brachial biceps, there was no inter-group difference, however, the effect size favoured the group again. of 3 minutes, in relation to the thigh thickness, both groups showed a similar increase. However, the study by Schoenfeld et al. (2016a), composed of a sample of trained individuals, corroborates the hypothesis raised by Grgic, Lazinica, Mikulic, Krieger, & Schoenfeld (2017) that higher training volumes are needed for trained individuals to achieve greater magnitudes of hypertrophy, and longer rest intervals can enable performers to reach these volumes. De Salles et al. (2009) cite that when training with intensities of 50% to 90% of 1RM, rest intervals of 3 to 5 minutes allowed the execution of a greater number of repetitions per series, that is, a short rest period can be below ideal for a trained individual to maximise hypertrophy (2017). Along these lines, Fink et al. (2017) found greater growth of the thigh and the triceps for the 150s interval group compared to the 30s interval group, with effect size favouring the 150s rest group. These findings can be justified by the fact that with high levels of strength, the recruitment of motor units of higher threshold is necessary, and a longer rest seems to benefit the maintenance of training intensities (Fink et al., 2017). In the study by Fink et al. (2018), no significant inter-group difference was found for the cross-sectional area of the arm, however, only the 30s interval group showed significant improvement in the acute muscle thickness of the long head of the triceps, acute increase in growth hormone (GH), and greater metabolic stress. Schoenfeld (2010) mentions that short rest intervals (30 seconds or less) generate greater metabolic stress, thus increasing the anabolic processes associated with the accumulation of metabolites. De Salles et al. (2009) also mention that when muscle hypertrophy is aimed, the combination of sets with 30 to 60 seconds intervals may become more effective due to the increase in growth hormone levels during these exercises.

Some discrepancies between the results were found within the analysed articles on rest intervals. The American College of Sports Medicine (2009) indicates that novice and intermediate individuals use rest intervals of 1 to 2 minutes. For advanced individuals, the interval duration must correspond to the objective of each phase of the training, being 2 to 3 minutes with heavier loads and 1 to 2 minutes at moderate intensities. Schoenfeld (2010) mentions that limiting rest to 30 seconds or less does not allow the performer to regain his muscular strength, thus impairing the performance of the next set. In contrast, De Salles et al. (2009) cite that when aiming for hypertrophy, the combination of moderate intensities with intervals of 30 to 60 seconds may be the best alternative due to the sharp increases in GH. Grgic et al. (2017) indicate that rest intervals above 60 seconds are the most suitable for hypertrophy, as it allows the training volume to be greater. However, when analysing the rest interval variable, it is not possible to reach a consensus on which is the most appropriate duration aiming at hypertrophy. Thus, it is possible to think that there is no optimal rest interval for hypertrophy. Still, the interval should be planned according to the objective of the microcycle, taking into account its direct influence on the volume, intensity, and tension and/or metabolic characteristics of the training.

Execution speed

The studies by Tanimoto et al. (2008) and Schuenke et al. (2012) found no significant differences between the movement speeds employed. In his study, Schoenfeld (2010) mentions that, concerning concentric repetitions, there is some evidence that has greater benefits in faster execution speeds. However, the American College of Sports Medicine (2009) suggests that novice and intermediate individuals perform slow and moderate repetitions, whereas, for advanced individuals, the use of slow, moderate and/or fast repetitions is suggested.

The study by Tanimoto and Ishii (2006) showed no significant difference between the group that performed the slow movement and the group that performed the normal movement but with higher intensity, however, the group that performed the normal movement with a low intensity presented a lower performance than the others, which suggests that the low training intensity directly impacted the performance of this group. Schoenfeld (2010) mentions that the potential effect of slower repetitions, even with lower intensities, is related to factors that increase the metabolic effect and the maintenance of muscle tension, which generates an increase in muscle ischemia and hypoxia, which are effects presented by the group of 50% of 1RM with slow execution speed, where there was a greater lack of O2 and a longer contraction time. In the review by Hackett, Davies, Orr, Kuang, and Halaki (2018), the findings indicate that slow and moderate execution speeds are more effective for quadriceps hypertrophy, and fast execution speeds are more effective for brachial biceps hypertrophy.

However, the American College of Sports Medicine (2009) suggests that the variation in execution speeds has better effects on long-term hypertrophy in advanced individuals. Despite the findings, it is not possible to conclude whether there is an ideal range of execution speed, being more effective to vary the speed according to the planning, as well as in the other training variables.

Concentric muscle failure

Both analysed studies (Martorelli et al., 2017; Carroll et al., 2019) did not find a positive benefit in relation to concentric muscle failure, however, if we take into account the principle of variability, it is suggested that the process of changing one or more variables over the periodisation becomes an effective method to make training challenging and effective

(2009). Therefore, the use of concentric muscle failure should not be neglected within a training program, but it must be carefully planned because although training to failure can generate benefits in hypertrophy, it also increases psychological exhaustion and can generate a state of overtraining (Schoenfeld, 2010).

In the study by Carroll et al. (2019), both groups used a block periodisation model without statistical differences in volume. The results supported the group that did not reach concentric muscle failure. The authors assumed that the superior result was due to a greater variety of loads used during the training weeks and better control of fatigue in the group without failure. While in the other group, the constant training until the failure may have caused a decline in their recovery levels. This is in accordance with the literature, where a program that uses a variation or periodisation, mainly of load and volume, presents superior results to a program that does not (Rhea & Alderman, 2004; American College of Sports Medicine, 2009). Also, concentric failure can generate greater exhaustion and potentiate overtraining (Schoenfeld, 2010).

In the study by Martorelli et al. (2017), the group that did not use the failure but had the volume equalised obtained similar results to the group that performed the concentric muscle failure. In a recent review, Schoenfeld and Grgic (2019) suggested that training to concentric muscle failure is less relevant when using heavier loads, and in the study by Martorelli et al. (2017), the load used in the protocols was 70% of 1RM. in their review, Schoenfeld and Grgic (2019) concluded that the volume variable is of fundamental importance when considering the relevance of training to failure, corroborating the findings of the present study, in which when the volume is equalised, the use or not of muscle failure present similar results.

However, Schoenfeld (2010) justifies that one of the hypotheses for muscle failure in RT is that this type of training promotes greater recruitment of motor units and induces greater metabolic stress, potentiating the hypertrophic response. These hypotheses are based on the belief that heavier loads are necessary to recruit the higher threshold motor units, which are mainly responsible for promoting muscle adaptations (Schoenfeld et al., 2017b). With muscle failure, it would be possible to recruit these same fibres using smaller loads. However, the articles analysed in the present study used loads between 65% of 1RM and 92,5% of 1RM in the study by Carroll et al. (2019) and 70% of 1RM in the study by Martorelli et al. (2017), which is the indicated range for hypertrophy to occur (American College of Sports Medicine, 2009), therefore, it is not possible to estimate the impact of muscle failure on recruitment of motor units, making it necessary to carry out studies that analyse the impact of muscle failure when training at lower intensities.

DISCUSSION

Intensity

In the studies by Mitchell et al. (2012) and Jenkins et al. (2017), groups of 80% of 1RM and 30% of 1RM were analysed, in which significant improvements were found in both groups, however, no inter-group differences were found. In the study by Lasevicius et al. (2018), a greater intensity range and a larger number of groups were used, in which there was a significant improvement in all groups 20% of 1RM, 40% of 1RM, 60% of 1RM, 80% of 1RM, however, group 20 % showed an improvement below the other groups, which had similar improvement. In the study by Holm et al. (2008), the difference in inter-group intensities was also high, with one group of 70% of 1RM and the other group of 15.5% of 1RM, both groups showed improvement however, only the 70% group showed a significant difference in the middle of the leg, and the cross-sectional area of the quadriceps had a significantly greater improvement in the 70% group. The findings obtained in the studies analysed bring us a new hypothesis for the range of working intensities in hypertrophy, in which a range of 70 to 85% of 1RM was recommended for beginning individuals (ACSM, 2009); with the findings, it is suggested that this range can start at 30% of 1RM, without a lesser magnitude in hypertrophic gains. One of the justifications for not using intensities below the recommended range was that, despite causing metabolic stress, the lower intensities were not able to recruit motor units of higher threshold (Schoenfeld, 2010). Corroborating the findings of the present study are the meta-analyses by Schoenfeld et al. (Schoenfeld et al. 2016b, Schoenfeld et al. 2017b), in which the authors cite that even at low intensities, hypertrophic gains are similar to gains obtained at higher intensities. The only study analysing the intensity variable that used a sample composed of trained individuals was that of Schoenfeld et al. (2015), in which a group of 30-50% of 1RM and one of 70-80% of 1RM were analysed, and the inter-group results were similar for elbow flexors, elbow extensors and femoral quadriceps. These results corroborate the findings of the present study for untrained individuals, however, it is not possible to state that for trained individuals, the gains will be similar since only one study in the sample was composed of trained individuals. The study by Schoenfeld et al. (Schoenfeld et al. 2016b) found a small tendency for greater growth when using higher intensities, and the authors mention that, for training more experienced individuals, it is necessary to use more demanding protocols, including the use of higher intensities.

The work of Mangine et al. (2015) compared a group of 90% of 1RM with a group of 70% of 1RM, where the volume and the rest interval were different, and more marked improvements were found in both the lean mass of the arm and the leg, for the group that trained at 90% of 1RM. However, the groups that were analysed had very different protocols, with one group performing 4 sets of 3 to 5 repetitions with 90% of 1 RM and interval between sets of 3 minutes, while the other group performed 4 sets of 10 to 12 repetitions with 70% of 1RM and interval between sets of 1 minute, therefore it is impossible to attribute hypertrophic gains only to the intensity variable.

However, we can note that the improvements found in the articles had similar results, as long as the intensities exceed 30% of 1RM, which differs in parts of the ACSM guidelines (ACSM, 2009), which suggest that intensities above 70% are necessary for the hypertrophy. Thus, the hypothesis arises that even at lower intensities, hypertrophy can occur, thus obtaining a greater working range within the intensity variable.

Volume

In the studies by Yue et al. (2018) and Saric et al. (2019), groups composed of trained individuals were outlined, in which the effect of different numbers of weekly sessions on hypertrophy was analysed, with the volume equalised. In the study by Yue et al. (2018), one group held 4 weekly sessions and the other group held 2 weekly sessions. Only the group of 2 weekly sessions showed improvement in body composition. As for the muscular thickness of the vast medial, both groups showed significant improvement. Only the group of 2 weekly sessions showed a change in the thickness of the elbow flexors. In the study by Saric et al. (2019), one group trained each muscle group 3 times a week, and one group trained each muscle group 6 times a week. Significant improvement was identified for the 3-fold group compared to the 6-fold group only in the elbow flexor muscle, with no significant difference for the other muscle groups. In both studies, we can identify a small advantage for less frequent weekly training protocols, as long as the volume is equalised. Hence the hypothesis that for trained individuals, a division of training in which each muscle group is trained at lower frequencies but with a high volume of series and repetitions would be more advantageous, that is, for trained individuals, an ABCD training protocol would be more advantageous than a full-body protocol for example, even with volume equalised. Schoenfeld (2010) mentions that a divided training routine combines the training volume with longer recovery time, greater intensities and greater muscle tension, thus being more advantageous for advanced individuals who need greater training volumes. Corroborating the aforementioned study, ACSM (2009) indicates that higher frequencies of ST are suggested for hypertrophy, however, only a few muscle groups are trained per session, which agrees with the idea of a more divided training, but with less frequency for each muscle group. In the study by Ochi et al. (2018), a group of untrained individuals who performed a weekly 6-series session was analysed, and a group of three weekly 2-series sessions, the results showed a significant increase in thigh circumference and thickness, but there was no significant difference between groups. What shows is that, for beginners, the most important thing is the equalisation of the volume, with no direct interference from the number of weekly sessions. Figueiredo et al. (2018) cite that, when considered, volume is one of the most important factors in muscle hypertrophy, as long as the training has sufficient intensity. However, the authors also cite that a minimum of ten weekly series per muscle group is necessary to maximise muscle hypertrophy in untrained individuals, which is at variance with the study by Ochi et al. (2018), in only six weekly series, there was a significant increase in thigh circumference and thickness. The study by Barcelos et al. (2018) presented a group that performed 5 weekly sessions, one that performed 3 weekly sessions and one that performed 2 weekly sessions without equalising the volume, and both groups showed similar improvement in the thigh cross section area, however, the group of higher volume had a larger effect size. This result is in agreement with Figueiredo et al. (2018), who mentions that volume is the variable with the most evident response in muscle hypertrophy, with a clear dose-response relationship.

Regarding the number of series performed, Schoenfeld et al. (2014) found significant increases in both groups, which were composed of trained individuals, however there was no significant difference between group 7 series and 3 repetitions and group 3 series and 10 repetitions. One hypothesis for this is that the training volume was very close, and therefore there was no difference in the results obtained. In the studies by Schoenfeld et al. (2019), Sooneste et al. (2013) and Radaelli et al. (2015), it was possible to identify a dose-response relationship for the groups that performed more sets with a greater degree of muscle hypertrophy. Similarly, Krieger (2010) mentions in his review that a greater number of series presented hypertrophy 40% greater than a single series. Schoenfeld (2010) also mentions that protocols composed of more series are superior to protocols composed of a single series.

It is possible to note that muscle volume and hypertrophy have a dose-response relationship, that is, higher volumes are associated with higher degrees of hypertrophy (ACSM, 2009; Figueiredo et al., 2018; Krieger, 2010; Schoenfeld, 2010). Additionally, when the volume is equalised, a greater division of muscle groups in trained individuals proved to be more effective in relation to a smaller division, that is, training performed in fewer weekly sessions was more effective than training performed in more weekly sessions, as long as the volume is equalised. This agrees with the principles of the training progression, mainly the principle of overload, which says that an overload is necessary to generate the hypertrophic stimulus (Schoenfeld, 2010), and is also in accordance with the guidelines of ACSM (2009), which indicate that for more advanced users the training should be more voluminous and more divided between sessions. All of these results are in line with the findings of this review since the articles that showed greater benefits in a greater division with equalised volume were performed with trained individuals.

Rest Interval

The study by Buresh et al. (2009) showed significant inter-group differences only for the cross-sectional area of the arm, in which the 2.5-minute interval group was superior to the 1-minute interval group however, both groups showed improvement, both in the cross-sectional area of the arm, as well as the thigh. Similarly, Robinson et al. (1995) found no significant differences between intervals of 30, 90 and 180 seconds on muscle circumference. In contrast, Schoenfeld et al. (2016a) found greater increases in the triceps brachii for the group with a 3-minute interval compared to the 1-minute interval group, whereas for the brachial biceps, there was no inter-group difference however, the effect size favoured the group again. of 3 minutes, concerning the thigh thickness, both groups showed a similar increase. However, the study by Schoenfeld et al. (2016a) was composed of a sample of trained individuals, which corroborates the hypothesis raised by Grgic et al. (2017) that higher training volumes are needed for trained individuals to achieve greater magnitudes of hypertrophy, and longer rest intervals can enable performers to reach these volumes. De Salles et al. (2009) cite that when training with intensities of 50% to 90% of 1RM, rest intervals of 3 to 5 minutes allowed the execution of a greater number of repetitions per series, that is, a short rest period can be below ideal for a trained individual to maximise hypertrophy (2017). Along these lines, Fink et al. (2017) found greater growth, both of the thigh and of the triceps, for the 150s interval group compared to the 30s interval group, with effect size favouring the 150s rest group. These findings can be justified by the fact that with high levels of strength, the recruitment of motor units of higher threshold are necessary, and the longer rest seems to benefit the maintenance of training intensities (2017). In the study by Fink et al. (2018), no significant inter-group difference was found for the cross-sectional area of the arm however, only the 30s interval group showed significant improvement in the acute muscle thickness of the long head of the triceps, acute increase in growth hormone (GH), and greater metabolic stress. Schoenfeld (2010) mentions that short rest intervals (30 seconds or less) generate greater metabolic stress, thus being able to increase the anabolic processes associated with the accumulation of metabolites. De Salles et al. (2009) also mention that when muscle hypertrophy is aimed at, the combination of sets with intervals of 30 to 60 seconds may become more effective due to the increase in growth hormone levels during these exercises.

Some discrepancies between the results were found within the analysed articles on rest intervals. The ACSM (2009) indicates that rest intervals of 1 to 2 minutes are used by novice and intermediate individuals, and for advanced individuals, the duration of the interval must correspond to the objective of each phase of the training, being 2 to 3 minutes with heavier loads, and 1 to 2 minutes at moderate intensities. Schoenfeld (2010) mentions that limiting rest to 30 seconds or less does not allow the performer to regain his muscular strength, thus impairing the performance of the next set. In contrast, De Salles et al. (2009) cite that when aiming for hypertrophy, the combination of moderate intensities with intervals of 30 to 60 seconds may be the best alternative due to the sharp increases in GH. Grgic et al. (2017) indicate that rest intervals above 60 seconds are the most suitable for hypertrophy, as it allows the training volume to be greater. However, when analysing the rest interval variable, it is not possible to reach a consensus on which is the most appropriate duration aiming at hypertrophy. Thus, it is possible to think that there is no optimal rest interval for hypertrophy, but the interval should be planned according to the objective of the microcycle, taking into account its direct influence on the volume, intensity, and tension and/or metabolic characteristics of the training.

Execution Speed

The studies by Schuenke et al. (2012) and Tanimoto et al. (2008) found no significant differences between the movement speeds employed. Schoenfeld (2010) mentions in his study that, with respect to concentric repetitions, there is some evidence of greater benefits in faster execution speeds. However, ACSM (2009) suggests that novice and intermediate individuals perform slow and moderate repetitions, whereas for advanced individuals, the use of slow, moderate and/or fast repetitions is suggested.

The study by Tanimoto and Ishii (2006) showed no significant difference between the group that performed the slow movement and the group that performed the normal movement, but with higher intensity however, the group that performed the normal movement with a low intensity presented a lower performance than the others, which suggests that the low training intensity directly impacted the performance of this group. Schoenfeld (2010) mentions that the potential effect of slower repetitions, even with lower intensities, is related to factors that increase the metabolic effect and the maintenance of muscle tension, which generates an increase in muscle ischemia and hypoxia, which are effects presented by the group of 50% of 1RM with slow execution speed, where there was a greater lack of O2 and a longer contraction time. In the review by Hackett et al. (2018), the findings indicate that slow and moderate execution speeds are more effective for quadriceps hypertrophy, and fast execution speeds are more effective for brachial biceps hypertrophy.

However, ACSM (2009) suggests that the variation in execution speeds has better effects on long-term hypertrophy in advanced individuals. That is, despite the findings, it is not possible to conclude whether there is an ideal range of execution speed, being more effective to vary the speed according to the planning, as well as in the other training variables.

Concentric Muscle Failure

Both analysed studies (Carrol et al. 2019; Martorelli et al. 2017) did not find a positive benefit in relation to concentric muscle failure, however, if we take into account the principle of variability, it is suggested that the process of changing one or more variables over the periodisation becomes an effective method to make training challenging and effective (2009). Therefore, the use of concentric muscle failure should not be neglected within a training program, but it must be carefully planned because although training to failure can generate benefits in hypertrophy, it also increases psychological exhaustion and can generate a state of overtraining (Schoenfeld, 2010).

In the study by Carroll et al. (2019), both groups used a block periodisation model without statistical differences in volume, in which the results supported the group that did not reach concentric muscle failure, where the authors assumed that the superior result was due to a greater variety of loads used during the training weeks and better control of fatigue in the group without failure, while in the other group the constant training until the failure may have caused a decline in their recovery levels. This is in accordance with the literature, in which a program that uses a variation or periodisation, mainly of load and volume, presents superior results to a program that does not (ACSM, 2009; Rhea and Alderman, 2004). Also, the use of concentric failure can generate greater exhaustion and potentiate overtraining (Schoenfeld, 2010).

In the study by Martorelli et al. (2017), the group that did not use the failure but had the volume equalised obtained similar results to the group that performed the concentric muscle failure. In a recent review, Schoenfeld and Grgic (2019) suggested that training to concentric muscle failure is less relevant when using heavier loads, and in the study by Martorelli et al. (2017), the load used in the protocols was 70% of 1RM. Schoenfeld and Grgic (2019) concluded that the volume variable is of fundamental importance when considering the relevance of training to failure, corroborating the findings of the present study, in which when the volume is equalised, the use or not of muscle failure presents similar results.

However, Schoenfeld (2010) justifies that one of the hypotheses for using muscle failure in ST is that this type of training promotes greater recruitment of motor units and induces greater metabolic stress, potentiating the hypertrophic response. These hypotheses are based on the belief that heavier loads are necessary to recruit the higher threshold motor units, which are mainly responsible for promoting muscle adaptations (Schoenfeld et al. 2017b), and with muscle failure, it would be possible to recruit these same fibers, using smaller loads. However, the articles analysed in the present study used loads between 65% of 1RM and 92,5% of 1RM in the study by Carroll et al. (2019) and 70% of 1RM in the study by Martorelli et al. (2017), which is the indicated range for hypertrophy to occur (ACSM, 2009), therefore, it is not possible to estimate the impact of muscle failure on recruitment of motor units, making it necessary to carry out studies that analyse the impact of muscle failure in the training of lower intensities.

CONCLUSIONS

It is concluded that for the intensity variable, loads above 30% of 1RM are effective in generating hypertrophy and that there was no marked hypertrophic difference in intensities ranging from 30 to 80% of 1RM. Regarding the volume, we noticed a dose-response relationship for hypertrophy, in which higher volumes generated more relevant results. Another interesting aspect is that a greater division of training showed a greater hypertrophic response for trained individuals, and for untrained individuals, the results were similar, provided the volume was equalised. Regarding the rest interval, the results diverged between studies, in which some showed better responses in long intervals and others in short intervals, that is, it was not possible to identify whether there is an optimal rest interval however, we know that the variable has a direct impact on the intensity and volume of the training, and therefore your planning must be done in conjunction with the others. In the variable execution speed, no significant differences were found for hypertrophy, however, when the speed was associated with a lower intensity, the results were lower, which suggests that the speed of execution may affect other variables that have a greater impact on hypertrophy. Therefore, it must also be planned in conjunction with the other variables. Finally, in the muscle failure variable, no advantages were found when the training volume was equalised, which suggests that the failure may be a strategy used to increase the volume of the sets, however, the failure alone did not demonstrate a relevant impact.

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