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FINAL DEGREE PROJECT

Interference Effect of Concurrent Training on Muscle Hypertrophy: A Systematic Review

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ABBREVIATIONS:

ACSA: anatomical cross-sectional area
AT: aerobic training
CSA: cross-sectional area
CT: concurrent training
DXA: dual energy X-ray absorptiometry
EIMD: exercise induced muscle damage
FCSA: fiber cross-sectional area
HIIT: high-intensity interval training
HR: heart rate
IE: interference effect
LT: lactate threshold
MAP: maximal aerobic power
MICT: moderate intensity continuous training
MIIT: moderate intensity interval training
MRI: magnetic resonance imaging
PEDro scale: Physiotherapy Evidence Database scale
RCT: randomized control trial
RIR: repetitions in reserve
RM repetition maximum
RT: resistance training
SIT: sprint interval training
US: ultrasound
VL: vastus lateralis
W: power

ABSTRACT

The main goal of this systematic review was to determine whether there is any interference between concurrent aerobic and resistance training in muscle hypertrophy adaptations in active or resistance trained people. A systematic literature search on 6 databases (PubMed, SPORTDiscus, Scopus, Dialnet, Scielo and Cochrane Library) was conducted in April, 2022 according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). After analyzing 362 resultant articles only 5 met the inclusion criteria: a) studies were randomized controlled trials or cohort studies evaluating the effect of concurrent training on muscle mass gains b) studies comparing two groups performed identical resistance training protocols and without the use of external implements (i.e., arterial pressure cuffs); c) interventions lasted at least eight weeks; d) participants were recreationally active people or had previous experience in weight training; e) participants' age ranged from 18 to 35 years; f) resistance training frequency was at least 3 times/week; g) studies reported direct measurements of muscle thickness, cross-sectional area and/or lean body mass; h) studies were published in peer-review journals. The findings of this review suggest that as long as the training variables are correctly managed there is no interference effect between concurrent aerobic and resistance training in the development of skeletal muscle hypertrophy. Moreover, aerobic training adaptations can be beneficial to the performance of athletes seeking to maximize muscle mass gains.

Key words: concurrent training, muscle hypertrophy, interference effect

TABLE OF CONTENTS:

INTRODUCTION

Skeletal muscle plays an important role in the performance of exercise and the activities of daily living (Wolfe, 2006), and it has a direct relation with health status (Warburton et al., 2001). For example, this review (Kell et al., 2001) suggests that a development in musculoskeletal fitness is associated with a reduced resting heart rate, a decline in resting systolic and diastolic blood pressures and an improvement in resting lipid levels, glucose and insulin sensitivity.

There are many mechanisms to increase muscle mass and the cross-sectional area (CSA), which is known as “skeletal muscle hypertrophy” (Wackerhage et al., 2019). This complex procedure occurs when the exercise-induced accumulation of muscle proteins exceeds the loss or breakdown of muscle proteins in cumulative periods (Damas et al., 2018). The principal mechanism inducing muscle hypertrophy is mechanical tension, however, there are some other possible mechanisms like metabolic stress or exercise induced muscle damage (EIMD) that could possibly stimulate muscle hypertrophy (Wackerhage et al., 2019).

Regular resistance training (RT) results in muscular hypertrophy, as well as increased strength and power. These physical components are determinant for some sports modalities, however, there are others which, in addition to those mentioned above, require adaptations typical of aerobic training (AT), such as a high aerobic capacity or metabolic changes in skeletal muscle (i.e. high mitochondrial density and capillarisation) (Hughes et al., 2018). In such cases, resistance and aerobic training are performed concomitantly in a training program and the athlete usually performs both modality exercises either in the same training session or period. This is called "concurrent training". Concurrent training (CT) relative to resistance training alone has been shown on several occasions to produce decreases in muscle hypertrophy, strength, and power (Wilson et al., 2012).

The first research paper that demonstrated impaired strength development when performing both resistance and aerobic training (Hickson, 1980) was conducted by Robert C. Hickson in 1980 and he used the term “interference effect” (IE). Since then, there have been many interventions aimed to investigate this phenomenon in muscle hypertrophy. Some of them have results that favour it (Kraemer et al., 1995), however, some others conclude that concurrent performance of both resistance and aerobic training does not impair adaptations in muscle hypertrophy (McCarthy et al., 1995, 2002).

During this time, some potential hypotheses (Berryman et al., 2019) have been proposed as responsible for the interference effect of muscle adaptations during concurrent resistance and aerobic training. According to the acute hypothesis, the residual fatigue induced by aerobic training results in the reduction of the ability to develop tension during the resistance training, so this leads to less muscle adaptations. In the case of the chronic hypothesis it is suggested that the physiological adaptations such as changes in muscle-fiber composition (Schantz and Henriksson, 1983), glycogen stores depletion (Creer et al., 2005) or alterations in protein synthesis (Nader, 2006) for resistance and aerobic training are sometimes incompatible from a molecular standpoint (Hawley, 2009).

Several systematic reviews have been conducted with the aim of evaluating the interference effect of aerobic training on resistance training adaptations, including muscle hypertrophy. The first was conducted by Wilson et al. (2012) and concludes that hypertrophy was not significantly different between resistance and concurrent training groups. In this other review Sabag et al. (2018) investigated the compatibility of concurrent high-intensity interval training (HIIT) and resistance training, it appears that this type of training can be prescribed alongside resistance training without negatively affecting changes in lean muscle mass. In 2021, a group of researchers achieved similar results (Schumann et al., 2021), concurrent aerobic and resistance training does not compromise muscle hypertrophy development. Finally, this group of researchers has recently published a systematic review (Lundberg et al., 2022) suggesting that concurrent training may result in attenuated hypertrophy of muscle fibers compared to resistance training. However, this does not necessarily mean that there are differences in whole muscle hypertrophy.

Much of the research in this area is made with sedentary or older people. In addition, the training regimen used in several of the studies (low frequency and/or low volume of training) does not reflect the reality of the athletes, so it is possible that these results are not replicated in active or trained subjects. In order to try to respond to the idea that the results seen in previous works are not replicated in active or trained populations, we have carried out this systematic review with the investigations that most closely resemble the characteristics aforementioned.

METHODS

- Study Design

A literature search of 6 databases was conducted in April, 2022. The following databases were searched: PubMed, SPORTDiscus, Scopus, Dialnet, Scielo and Cochrane Library. Databases were searched from inception to April 2022, with language limitations: only peer-reviewed articles in English or Spanish were selected. Citations from scientific conferences were excluded.

- Search Strategy

The literature search was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines. In each database article title, abstract and keywords search fields were used. The following MeSH terms and keywords, combined with Boolean operators (AND/OR) were used: (("concurrent training") OR (“combined training”) OR ("interference effect")) AND ((hypertrophy[MeSH]) OR ("muscle mass") OR (“muscle growth”)). No additional search limitations were used. After conducting the initial search, the reference lists of articles retrieved were screened for any additional articles which had relevance to the topic.

- Eligibility Criteria

Studies were eligible for further analysis if the following inclusion criteria were met: a) studies were randomized controlled trials or cohort studies evaluating the effect of concurrent training on muscle mass gains b) studies comparing two groups performed identical resistance training protocols and without the use of external implements (i.e., arterial pressure cuffs); c) interventions lasted at least eight weeks; d) participants were recreationally active people or had previous experience in weight training; e) participants' age ranged from 18 to 35 years; f) resistance training frequency was at least 3 times/week; g) studies reported direct measurements of muscle thickness, cross-sectional area and/or lean body mass; h) studies were published in peer-review journals.

A flow chart of the search strategy and study selection is shown in Figure 1.

- Quality Assessment

Oxford's level of evidence (OCEBM Levels of Evidence Working Group et al., 2011) and the Physiotherapy Evidence Database (PEDro) scale (de Morton, 2009) were used to assess the methodological quality of the studies included in the systematic review. Oxford's level of evidence ranges from 1a to 5, with 1a being systematic reviews of high-quality randomized controlled trials (RCT) and 5 being expert opinions. The PEDro scale consists of 11 different items related to scientific rigor. The items include random allocation, concealment of allocation, comparability of groups at baseline, blinding of subjects, researchers and assessors, analysis by intention to treat, and adequacy of the follow-up. Given that the assessors are rarely blinded, and that it is hard to blind participants and investigators in supervised exercise interventions, items 5–7, which are specific to blinding, were removed from the scale (Baz-Valle et al., 2018). With the removal of these items, the maximum result on the modified PEDro 8-point scale was 7 (the first item was not included in the total score) and the lowest, 0. Zero points were awarded to a study that failed to satisfy any of the included items, and 7 pointed to a study that satisfied all the included items.

RESULTS

- Study Selection

The search strategy yielded 362 total citations and other 2 additional articles which had relevance to the topic were included as presented in Figure 1. After removing 188 duplicates and 170 studies in the screening, 16 studies were determined to be potentially relevant to the topic based on the information contained in the abstract, from which only 5 studies met the inclusion criteria. Excluded studies had at least one of the following characteristics:

a) participants were not physically-active or did not have previous experience with weight training; b) resistance training protocol was not identical in both groups; c) studies reported indirect measurements of muscle thickness (i.e. limb girth); b) resistance training frequency was ≤2 times/week (Figure1). Finally, a total of five studies with an overall sample of 104 subjects were included for the present systematic review (Table 2).

- Level of evidence and quality of the studies

According to Oxford's level of evidence, two of the included studies had an evidence level 1b (high quality randomized controlled trial). Two other studies had a level of evidence 2b due to the following reason: less than 85% of participants completed the protocol. The remaining study had a 2c evidence level. Scores from the PEDro scale were on average 3.8 ± 0.8, and ranged from 3 to 5 (Table 1).

- Characteristics of the studies

The following are the general characteristics of the studies selected for the systematic review:

Fyfe et al. (2016) made a research with 23 recreationally-active males (29.6 ± 5.5 years), participants were divided into "resistance training" (RT), "high-intensity interval training and resistance training" (HIIT+RT) and "moderate intensity continuous training and resistance training" (MICT+RT) groups for a 8-week period.

The RT group trained 3 times per week whereas CT performed 6 sessions/week, three AT + three RT with a separation of 10 minutes between the two modalities. Both groups implemented the same RT programme with a total volume of 21 ± 3 and 31 ± 5 sets per week with 2-3' recovery for the upper and lower body, respectively. Additionally, CT group did an AT cycling programme which consisted of 5-10 intervals of 2' duration at 120-150% LT intensity with 1' passive recovery for the HIIT+RT group and 15-33' at 80-100% LT for the MICT+RT group. Progressive overload was applied by modulating the number of intervals and relative exercise intensity (HIIT) and the duration of cycling and relative exercise intensity (MICT).

Regarding the measurements, total lean mass, as well as leg and upper-body lean mass and fat mass were assessed pre-, mid- and post-intervention by dual energy X-ray absorptiometry (DXA).

Hendrickse et al. (2021) made a research with 8 highly resistance-trained males (28.5 ± 4.8 years). Participants underwent a 10-week CT programme composed by their habitual RT routine and a superimposed AT performed on the same or different day. When both modalities were performed on the same day or within the same session, resistance training was always completed first.

The RT group did not follow a prescribed resistance-training regimen, but all performed resistance exercise at least 4 times per week (2 sessions for upper body, 2 sessions for lower body). During 1-6 weeks of the programme, AT consisted of cycling 45' at 75% HRmax intensity. During 7-10 weeks participants did 5 intervals with 4’ of duration at 90% HRmax intensity with 6’ active recovery at 75% HRmax. Intensity increased progressively during weeks.

The anatomical cross-sectional area (ACSA) of the thigh muscles, fiber cross-sectional area (FCSA) for type I and type II fibers, fiber type composition in the m. *vastus lateralis (VL)*, and capillaries around fibers were determined pre- and post-superimposed AT with magnetic resonance imaging (MRI) and biopsies.

Kikuchi et al. (2016) made a research in which 14 males (20.6 ± 1.8 years) with previous experience with weight-training participated. They were divided into RT and CT groups for a 8-week period.

The RT group trained 3 times per week on nonconsecutive days whereas CT performed 6 sessions/week, three AT + three RT. AT and RT sessions were carried out on the same day. Both groups implemented the same RT programme with a total volume of 9 sets with 1’ 30’’ recovery per week in the arm-curl machine. Also, CT group did an AT cycling programme which consisted of 4 maximal effort intervals of 30’’ using a resistance equal to 7.5% of the subject’s body weight with 4’ 30’’ recovery between intervals.

Concerning the measurements, muscle cross-sectional area (CSA) of the biceps and the brachialis was measured using a magnetic resonance (MR) pre- and post-intervention.

Lee et al. (2020) made a research with 29 moderately-active males (24.5 ± 4.7 years), participants were divided into RT, HIIT+RT and R+HIIT groups for a 9-week period.

The RT group trained 3 times per week whereas CT performed 6 sessions/week, three AT + three RT with a separation of 3 hours between the two modalities. Both groups implemented the same RT programme with a total volume of 21 ± 3 and 32 ± 5 sets per week with 2’ recovery for the upper and lower body, respectively. Also, CT group did an AT cycling programme which consisted of 8-13 intervals of 2’ at ~85-97% W_{PEAK} intensity with 1’ recovery periods. Progressive overload was achieved by modifying the volume and intensity.

Total lean mass, as well as leg and upper-body lean mass and fat mass was assessed before, and after both 5 and 9 weeks of training. It was estimated via whole-body DXA.

Shamim et al. (2018) made a research with 32 recreationally-active males (25 ± 5 years), participants were divided into RT, AT and CT groups for a period of 12 weeks.

The RT and AT groups trained 3 times per week whereas CT performed 6 sessions/week, three AT + three RT. CT performed identical resistance and aerobic programs on alternating days as those in the RT and AT groups. The resistance programme contains a total of 19 ± 4 and 22 ± 4 sets per week with 3’ recovery for the upper and lower body, respectively. The aerobic programme was composed of a hill-simulation ride of varying intensity (25-110% MAP), MICT at 50% MAP, moderate intensity interval training (MIIT) at 70% MAP and HIIT at 100% MAP. Intervals were separated by a 20 to 60 second recovery period at ~40% MAP, 2.5:1 or 5:1 work-to-rest ratio.

Total lean mass, as well as leg and upper-body lean mass, and fat mass were estimated by DXA pre-intervention, after 4 and 8 weeks and post-intervention**.** *Vastus lateralis* segmental muscle thickness and volume were also evaluated utilizing B-mode ultrasound at baseline, after weeks 2, 4, 8 and post-intervention.

- Evidence against the interference effect

Three out of the five studies included in this review support that aerobic training does not impair muscle hypertrophy during concurrent training. Hendrickse et al. (2021) did not find a significant decrease in thigh ACSA or FCSA area in highly-resistance trained males after a 10–week concurrent training period. In the study carried out by Lee et al. (2020) all training groups increased total lean mass (~3-4%) with no clear differences between groups regardless of the exercise order, the duration of the training program was 9 weeks. Last, Shamim et al. (2018) realized a 12-week intervention in which total lean mass increased ~4% in both groups. Moreover, ultrasound estimated *vastus lateralis* volume increased ~15% in concurrent training and ~11% in aerobic training with no difference between groups.

These results provide evidence that the inverse relationship between fiber size and oxidative capacity can be overcome. So, adding aerobic training to resistance training, regardless of the exercise order, can lead to positive endurance-related adaptations without negative consequences for muscle size when performed ≥3 days/week either on the same or alternate days. It should be noted that these articles did not compare alternate modes of endurance training (i.e. cycling vs. running).

- Evidence favouring the interference effect

The two remaining interventions show attenuation of muscle hypertrophy when resistance and aerobic training are performed concomitantly. Fyfe et al. (2016) found that lower-body lean mass similarly increased for RT and MICT+RT. However, this change was attenuated for HIT+RT, even though a moderate effect for higher average total energy intake was noted for HIT+RT compared with RT during during the 8 weeks of training. In the 8-week intervention conducted by Kikuchi et al. (2016) significant increase in CSA was observed in the RT group but not in the CT group.

According to this, increases in lower-body lean mass can be attenuated with concurrent training incorporating HIT, but not MICT. Moreover, concurrent lower limb HIIT interferes with arm muscle hypertrophy. Some of the limitations in these studies are the small sample size, not controlling nutrition factors such as energy intake and in the case of Kikuchi et al. (2016) that the resistance exercise protocol was minimalistic.

Flow-diagram of the literature search: Figure 1

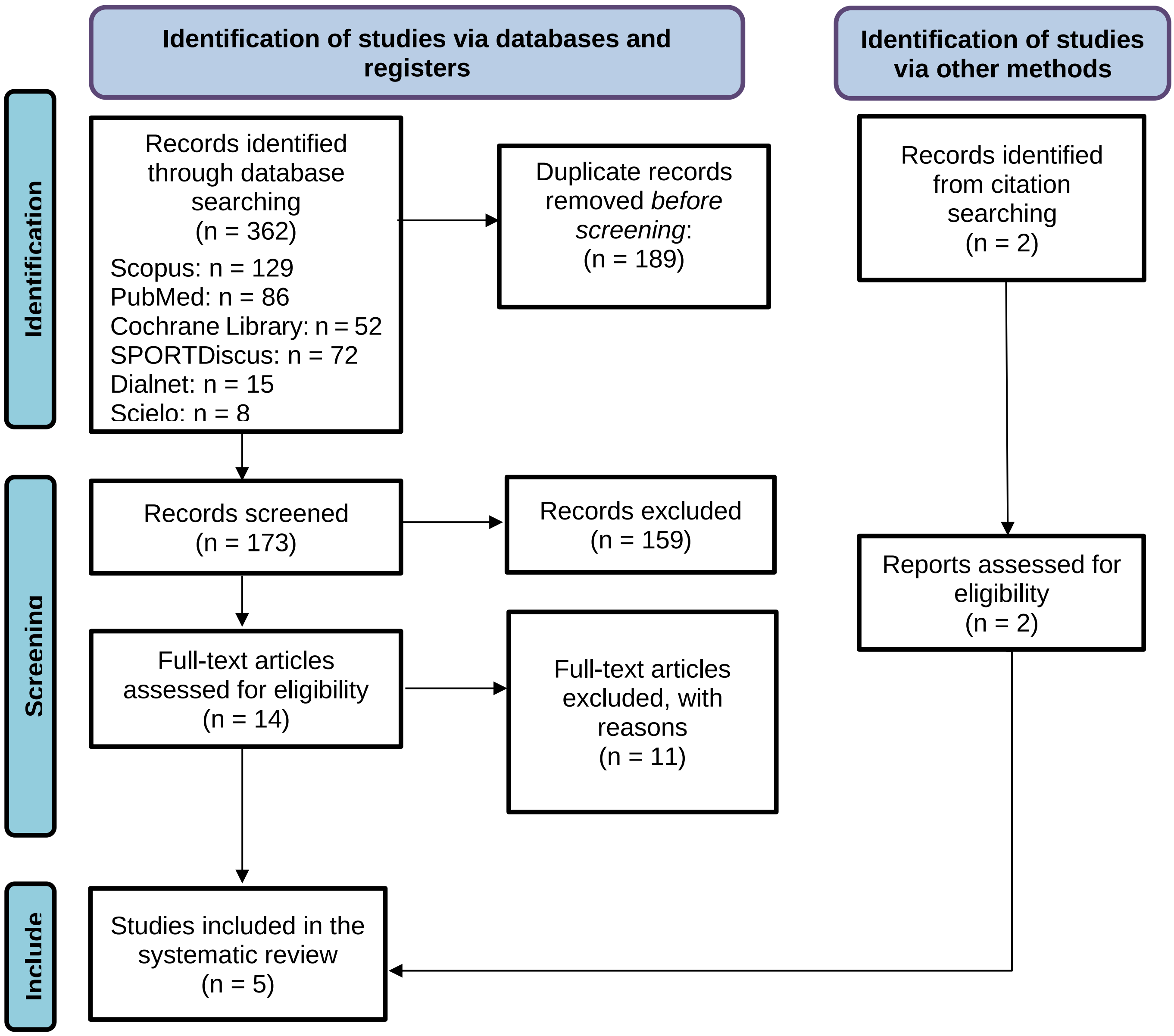

Table 1
Physiotherapy Evidence Database (PEDro) ratings and Oxford evidence levels of the included studies

	1	2	3	4	5	6	7	8	TOTAL	Evidence Level
Fyfe et al. (2016)	No	1	0	1	0	0	1	1	4	1b
Hendrickse et al. (2021)	No	0	0	1	1	0	0	1	3	2c
Kikuchi et al. (2016)	No	1	0	1	1	1	1	0	5	1b
Lee et al. (2020)	No	0	0	1	1	0	1	1	4	2b
Shamim et al. (2018)	No	0	0	1	0	0	1	1	3	2b
Total									3,8	

Items in the PEDro scale: 1 = eligibility criteria were specified; 2 = subjects were randomly allocated to groups; 3 = allocation was concealed; 4 = the groups were similar at baseline regarding the most important prognostic indicators; 5 = measures of 1 key outcome were obtained from 85% of subjects initially allocated to groups; 6 = all subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least 1 key outcome were analyzed by "intention to treat"; 7 = the results of between-group statistical comparisons are reported for at least 1 key outcome; 8 = the study provides both point measures and measures of variability for at least 1 key outcome.

Table 2
Characteristics of the studies, participants and training programs

Study	Participants	Age (years)	Training intervention		Resistance training	Aerobic training (cycling)	Outcomes
Fyfe et al. (2016)	23 recreationally active males RT=9 HIIT+RT=9 MICT+RT=10	29.6 ± 5.5	8 weeks RT: 3 s/wk CT: 6 s/wk (3 RT + 3 AT)	Same session CT. AT performed 10 min before RT	• Exercise: whole body exercises • Set configuration: 4-12 reps (RIR 0-2) /2–3' recovery at ~65-90% 1RM • Volume: - Upper-body: 21 ± 3.2 sets/week - Lower-body: 31 ± 4.8 sets/week	• HIIT: (set nº x high intensity duration/recovery) 5-10x2' (120-150% LT)/ 1' passive recovery • MICT: 15-33' (80-100% LT)	Lower body lean mass change was attenuated for HIIT+RT (DXA)
Hendrickse et al. (2021)	8 highly resistance trained males CT=8	28.5 ± 4.8	10 weeks CT: ≥ 7 s/wk (≥4 RT + 3 AT)	Same session, different session or different day CT. RT was performed before AT	Performed resistance exercise at least 4 times per week (2 sessions for upper-body, 2 sessions for lower-body)	• 1-6 weeks: 45' (75% HRmax • 7-10 weeks: 5x4'/6' (90/75% HRmax)	The AT did not induce significant decrease in thigh ACSA or FCSA (MR)
Kikuchi et al. (2016)	14 males with previous weight training experience RT=6 CT=6	20.6 ± 1.8	8 weeks RT: 3 s/wk CT: 6 s/wk (3 RT + 3 SIT)	Same day CT. RT performed before AT	• Exercise: bilateral-arm curl in machine • Set configuration: 3x10 reps 80% 1RM/90'' •Volume: Biceps: 9 sets/week	• SIT: 4x30'' (resistance equal to 7.5% of the subject's body weight)/4' 30'' recovery	Significant increase in CSA was observed in the RT group but not in the CT group (MRI)
Lee et al. (2020)	29 recreationally active males RT=9 HIIT+RT=10 RT+HIIT=11	24.5 ± 4.7	9 weeks RT: 3 s/wk CT: 6 s/wk (3 RT + 3 AT)	Same day CT. AT before RT (HIIT+RT), RT before AT (RT+HIIT), separated by 3 hours	• Exercise: whole body exercises • Volume: - Upper-body: 21 ± 3.2 sets/week - Lower-body: 32 ± 4.8 sets/week	8-13x2' (~85-97% Wpeak)/1' recovery	Training groups increased total lean mass (~3-4%) with no clear differences between groups (DXA)
Shamim et al. (2018)	32 recreationally active males RT=10 AT=10 CT=12	26 ± 4	12 weeks RT: 3 s/wk AT: 3 s/wk CT: 6 s/wk (3 RT + 3 AT)	Different day CT	• Exercise: whole body exercises • Set configuration: 2-15 reps (RIR failure-3)/3' recovery at ~60–98% 1RM • Volume: - Upper-body: 19 ± 4 sets/week - Lower-body: 22 ± 4.1 sets/week	Hill simulation ride of varying intensity. • MICT: 45'/50% MAP • MIIT: 70% MAP/1' recovery 40% MAP • HIIT: 100% MAP/20-60'' recovery 40% MAP	Total lean mass increased ~4% in both CT and RT (DXA). *Vastus lateralis* volume increased ~15% in CT and ~11% in RT, with no difference between groups (US)

DISCUSSION

The aim of this systematic review was to analyze the interference effect of concurrent aerobic and resistance training in relation to skeletal muscle hypertrophy adaptations. After analyzing five relevant studies, we found that three of them show that aerobic and resistance concurrent training are compatible in relation to muscle fiber hypertrophy adaptations (Hendrickse et al., 2021; Lee et al., 2020; Shamim et al., 2018), whilst the other two suggest that it is not (Fyfe et al., 2016; Kikuchi et al., 2016).

Coincidence or not, interference effect was only found in cases where HIIT was included in the aerobic training, but not in all groups containing HIIT were observed decreases in muscle adaptations. However, no signs of the interference effect in skeletal muscle hypertrophy have been observed in any of the training groups where aerobic training was based on moderate intensity continuous training.

Previous research has already investigated the effect of concurrent high-intensity interval training and resistance training on hypertrophy (Sabag et al., 2018). According to this research, high-intensity interval cycling does not inhibit resistance exercise-induced muscle hypertrophy.

Several strategies can be used in order to minimize the possible interference effect and optimize the desired adaptations. Intelligently periodizing is probably the most important (Evans, 2019). Periodization can be defined as the planned manipulation of training variables to optimize performance and manage fatigue (Plisk and Stone, 2003). For example, a rest period of 6 to 24 hours is presented as suitable between training modalities (Berryman et al., 2019). Work-volume is also a variable to consider, adding aerobic training to the resistance training considerably increases the total volume of work, so properly managing the weekly total sets per muscle is a good way to maximize muscle hypertrophy. Moreover, the type of aerobic training must be chosen appropriately.

Lundberg et al. (2022) observed a significant interference effect for type I fibers when aerobic training was performed by running but not cycling. Running has a higher eccentric component than cycling, which mainly consists of concentric activity. For this reason running is associated with greater inflammatory stress compared with cycling (Nieman et al., 2014; Doma et al., 2019). However, in accordance with a phenomena known as “the repeated bout effect”, running induced muscle damage and its symptoms are known to decrease after the first exercise session (McHugh, 2003). So, even though it is debatable, athletes may consider cycling rather than running as an aerobic training modality to increase muscle hypertrophy.

Nutrition factors, mainly total energy intake, distribution of macronutrients and the use of supplementation, must also be taken into account. We have already mentioned that mechanical tension is indispensable for the gain of muscle mass (Wackerhage et al., 2019), but additionally it is necessary that the energy intake is greater than the expenditure, that is to say that there is a caloric surplus (Slater et al., 2019). In this way, part of this energy can be used for muscle hypertrophy, which requires high energy expenditure (Bier, 1999).

As long as these factors are controlled it seems that there is no interference between aerobic and resistance exercise on muscle mass gains. There are many studies and reviews that support it (Schumann et al., 2021). Despite this, there are some other studies that show an attenuation in the muscle adaptations (Wilson et al., 2012). A possible explanation for this inconsistency is the different inclusion criteria between these two reviews, Wilson et al. (2012) included fiber hypertrophy as an outcome parameter whilst Schumann et al, (2021) did not. A decade later, the recent systematic review by Lundberg et al. (2022), which also included fiber hypertrophy as an outcome parameter, shows similar results. This supports the above explanation.

The results of the present review are in line with this. In the study by Kikuchi et al. (2016) there is a major limitation, the resistance training program is tremendously minimalistic. It is based on 9 single sets per week carried out in a monoarticular exercise. Therefore, it is difficult to draw clear conclusions with this study, as it goes against the literature in that area (Sabag et al., 2018). However, according to the authors, it is to be expected that if a higher training volume and multi-joint exercises were used, the interference effect would be greater. Furthermore, the attenuation of the increase of the lower-body lean mass in the HIT+RT training group (Fyfe et al., 2016) can be explained by the poor management of the training variables. In this exercise group the aerobic training is performed in the same session and 10 minutes before the resistance training. The residual fatigue induced by aerobic training results in the reduction of the ability to develop tension during the resistance training and in the consequent interference in muscle adaptations.

Therefore, it is possible to benefit from the adaptations of aerobic training in strength modalities as long as the training variables are well managed in active or trained people, something that was to be clarified. Beyond the health benefits, these adaptations of aerobic training can even be beneficial for the sports performance of people oriented to strength modalities. These adaptations include increases in the mitochondrial content and respiratory capacity of the muscle fibers (Holloszy and Coyle, 1984). The fact of having a greater aerobic capacity improves the work capacity in resistance training and delays fatigue in series with high repetition ranges.

- Limitations

We have to acknowledge several limitations: 1) the number of included studies is small: 5; 2) the quality of the studies analyzed is moderate; 3) the order of the different types of exercise was not the same in all the studies, RT was performed both before or after AT; 4) the training protocol for CT was not the same: RT+MICT, RT+HIIT or RT+SIT; 5) two out of the five studies analyzed did not report the energy intake, macronutrient distribution and supplementation during the training intervention, being determinant for the muscle hypertrophy.

When interpreting the conclusions of this review all these limitations should be taken into account.

CONCLUSION

This systematic review shows that there is no interference effect between concurrent aerobic and resistance training in the development of skeletal muscle hypertrophy in active or resistance-trained people, as long as the training variables are correctly managed. Therefore, athletes who want to maximize their muscle mass gains should not be afraid of aerobic exercise, as it can be beneficial to both health and performance.

FUTURE RESEARCH LINES

It would be interesting for future research to recruit highly resistance-trained individuals to better determine if these results are replicated. In addition, the duration of the interventions could be extended to determine whether the results vary from short to long term. Last, the next interventions should clearly show nutritional aspects such as energy intake or macronutrient partitioning, as this can greatly influence the results.

Therefore, further research would be useful to solve these and some other remaining unknowns.

PRACTICAL APPLICATIONS

According to the scientific literature surrounding concurrent performance training, practitioners should pay attention to the following recommendations in order to limit the interference effect and maximize muscle mass gains. First, separate resistance and aerobic training sessions on alternate days, if this is not possible, separate them at least 6 hours apart to optimize the outcomes (Berryman et al., 2019). Second, individuals that train concurrently with no time between modes of training should perform resistance before endurance exercise to avoid residual fatigue induced by aerobic training results in the reduction of the ability to develop tension during the posterior resistance training (Eddens et al., 2018). Third, keep the frequency of endurance training low to ensure good recovery between resistance sessions.

Last, if you start doing aerobic exercise be aware that you may not be able to tolerate so much resistance training volume at first and you may have to lower your total sets per week. Subsequently, you can increase it until you reach the volume prior to including aerobic exercise.

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