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Review

Effects of plyometric *vs.* resistance training on skeletal muscle hypertrophy: A review

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Abstract

Objective: In this review, we critically evaluate studies directly comparing the effects of plyometric *vs.* resistance training on skeletal muscle hypertrophy.
Methods: We conducted electronic searches of PubMed/MEDLINE, Scopus, SPORTDiscus, and Web of Science to find studies that explored the effects of plyometric *vs.* resistance training on muscle hypertrophy.
Results: Eight relevant studies were included in the review. Six studies compared the effects of plyometric *vs.* resistance training on muscle hypertrophy, while 2 studies explored the effects of combining plyometric and resistance training *vs.* isolated resistance training on acute anabolic signaling or muscle hypertrophy. Based on the results of these studies, we conclude that plyometric and resistance training may produce similar effects on whole muscle hypertrophy for the muscle groups of the lower extremities. Therefore, it seems that plyometric training has a greater potential for inducing increases in muscle size than previously thought. Despite the findings observed at the whole muscle level, the evidence for the effects of plyometric training on hypertrophy on the muscle fiber level is currently limited for drawing inferences. Compared to isolated resistance training, combining plyometric and resistance exercise does not seem to produce additive effects on anabolic signaling or muscle growth; however, this area requires future study. The limitations of the current body of evidence are that the findings are specific to (a) musculature of the lower extremities, (b) short-term training interventions that lasted up to 12 weeks, and (c) previously untrained or recreationally active participants.
Conclusion: This review highlights that plyometric and resistance training interventions may produce similar effects on whole muscle hypertrophy, at least for the muscle groups of the lower extremities, in untrained and recreationally trained individuals, and over short-term (i.e., ≤12 weeks) intervention periods.

Keywords: Effects; Muscle; Muscle size; Protein

1. Introduction

Plyometric exercise involves a rapid eccentric action immediately followed by rapid concentric action.[1] This quick transition from the eccentric to the concentric portion of the movement is known as the stretch−shortening cycle.[1] The stretch−shortening cycle results in energy conservation as well as enhanced propulsive forces in the final phase (i.e., the concentric action).[2] Plyometric training has been extensively studied in the literature, with a recent scoping review highlighting more than 200 studies that examined its influence on various outcomes.[3] Thus far, research has established plyometric training as effective for a wide range of health and athletic aspects. For example, plyometric training can increase bone mass and enhance muscular strength, jumping, sprinting, agility, and endurance performance among others.[1] One aspect of plyometric training that has been less studied is its effects on skeletal muscle hypertrophy.

In a 2010 comprehensive review of neuro-musculoskeletal and performance adaptations to plyometric training, Markovic and Mikulic[1] concluded that plyometric exercise has the

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potential to induce muscle hypertrophy and that these effects are generally lower compared with those induced by resistance training. The authors generally based these conclusions on the comparisons of the effects of independent studies that included only a resistance training group or only a plyometric training group.[1,4,5] In other words, there was a lack of studies that investigated the effects of both modes of exercise in the same cohort. This limitation is relevant because the most robust conclusions on the effects of plyometric training (or any other mode of exercise) on muscle hypertrophy can be inferred by conducting a direct comparison with a resistance training intervention, given that the latter mode of exercise is considered to be the most effective for increases in muscle size.[6] The importance of directly comparing hypertrophy effects of other modes of exercise with resistance training is well established. Specifically, a narrative review suggested that aerobic exercise has the potential to induce hypertrophic effects similar to those induced by resistance training;[7] however, this notion was based on the results of independent studies that did not conduct direct comparisons between both modes of exercise. A subsequent meta-analysis included primary studies that compared the effects of aerobic *vs*. resistance training on hypertrophy within the same cohort, and the results showed substantially greater increases in muscle size with resistance training.[8]

In recent years, several studies directly explored the effects of plyometric *vs.* resistance training on muscle hypertrophy.[9−15] However, no reviews have summarized and critically evaluated the results of these studies. This represents a gap in the literature given the popularity of plyometric training in populations of recreational and competitive athletes, and given the importance of muscle mass for general health and for different athletic endeavors.[3,16,17] In adults, it generally is assumed that muscle hypertrophy occurs only in response to resistance exercise.[6] However, recent findings have observed muscle growth across a variety of exercise modalities and intensities.[18,19] Therefore, analyzing the effects of plyometric *vs.* resistance training on muscle hypertrophy may provide additional insights as to how this adaptation occurs in response to different forms of contractile activity. Accordingly, in this review, we critically evaluate the studies comparing the effects of plyometric *vs*. resistance training on skeletal muscle hypertrophy and highlight areas for future research.

2. Assessment of muscle hypertrophy

Before exploring the effects of plyometric *vs.* resistance training on muscle hypertrophy, it is important to briefly discuss the different methods used in research for measuring muscle size. According to Haun et al.,[20] these methods can be classified as macroscopic and microscopic. The most commonly used macroscopic methods in exercise science studies include muscle thickness assessment using B-mode ultrasonography, muscle cross-sectional area estimation using B-mode ultrasonography, computed tomography, or magnetic resonance imaging, as well as lean body mass assessment using dual-energy X-ray absorptiometry. Muscle hypertrophy can also be assessed using a microscopic assessment method that involves muscle biopsy samples. This specific method may provide further insights into the effects of a given intervention specific to different muscle fiber types. The main advantage of macroscopic methods is their high reliability.[20] Some limitations of these methods are that they can be dependent on the skill of the investigator (ultrasound), they expose participants to radiation (computed tomography), or the scans are costly (magnetic resonance imaging).[20] Muscle biopsies are also considered to represent a sensitive assessment of skeletal muscle hypertrophy. However, a limitation of muscle biopsies lies in the difficulties encountered when performing a biopsy twice on the same location in a muscle.[20] Therefore, any changes in muscle size are assumed to extrapolate to the same fibers along their length or surrounding fibers.[20] All these methods, along with a compressive review of their advantages and drawbacks, can be found in the study by Haun et al.[20]

3. Literature search methodology

For this review, we conducted electronic searches of PubMed/MEDLINE, Scopus, SPORTDiscus, and Web of Science. In all of these databases, we used the following search syntax: (“plyometric*” OR “stretch-shortening cycle*” OR “stretch shortening cycle*”) AND (“hypertrophy” OR “muscle size” OR “muscle mass” OR “muscle fiber” OR “muscle fibre” OR “lean body mass” OR “fat-free mass” OR “cross-sectional area” OR “quadriceps size”). No limits regarding language or year of publication were employed. We also examined relevant review articles[1,3,21] to uncover studies that might have been missed in the primary search. The search concluded in October of 2019.

4. Plyometric *vs.* resistance training: Is one training modality superior to another for muscle hypertrophy?

4.1. Macroscopic measurements

Our literature search revealed 6 studies that explored the effects of isolated plyometric *vs.* isolated resistance training on muscle hypertrophy while using macroscopic measurements (either ultrasound or magnetic resonance imaging) to assess pre-to-post changes in muscle size.[10−15] Details regarding study participants as well as the specific training interventions employed in the included studies are summarized in Table 1. All included studies focused on lower extremity plyometrics; thus, the data on muscle hypertrophy are limited to this region of the body. Overall, the data show similar muscle hypertrophy effects between plyometric and resistance training groups. These findings were observed for several muscles and muscle groups, including the quadriceps (4 studies[10,13−15]) and calf muscles (2 studies[11,12]), as well as the hamstrings and hip adductors (1 study[15] for each).

The effects of plyometric training on skeletal muscle hypertrophy are often referred to as relatively minor. For example, Suchomel et al.[22] recently proposed a model with the theoretical potential of training methods to benefit hypertrophy. Here, the potential of a given training method was classified from

Table 1
Summary of the studies comparing the effects of plyometric *vs.* resistance training on measures of muscle hypertrophy.

Study	Sample; training duration (weekly frequency)	Plyometric training	Resistance training	Muscle group measured and measurement tool	Study results
Earp et al. (2015)[10]	27 young untrained men; 8 weeks (3 days/week)	Parallel-depth or volitional-depth jump squats performed for 5−7 sets and 5−6 repetitions with loads between 0%−30% 1RM[a]	Parallel-depth squat performed for 3 sets and 3−8 repetitions with loads between 75%−90% 1RM	QF, VL, VI, VM, RF; B-mode ultrasound	Significant pre-to-post increase in muscle size in all groups and at all sites (except for RF), with no between-group differences
Kubo et al. (2007)[11b]	10 young untrained men; 12 weeks (4 days/week)	Hopping and drop jump performed for 5 sets and 10 repetitions with loads of 40% 1RM	Calf raises performed for 5 sets and 10 repetitions with 80% 1RM	MG, LG, SOL; MRI	Significant pre-to-post increase in muscle size in both groups with no between-group differences
Kubo et al. (2017)[12b]	11 young untrained men; 12 weeks (3 days/week)	Hopping and drop jump performed for 5 sets and 10 repetitions with loads of 40% 1RM	Isometric plantar flexion exercise performed for 10 contractions at 80% MVC for 15 s	MG, LG, SOL, PF; B-mode ultrasound	Significant pre-to-post increase in muscle size in both groups with no between-group differences
McKinlay et al. (2018)[13]	27 young (age: 11−13 years) male soccer players; 8 weeks (3 days/week)	Countermovement jumps, knees-to-chest jumps, drop jumps, consecutive long jumps, jump lunges, straight-legged jumps with toe-touch, side-to-side lateral hops, high-knee skips, hop and skip jumps, 1-legged countermovement jumps, 1-legged knees-to-chest jumps, and 1-legged consecutive long jumps performed for 3 sets and 12 repetitions	Squats, lunge, step-ups, calf-raises, wide-stance-squats, raised-rear-foot lunge, 1-legged sit-to-stand rises, and 1-legged squats performed for 3 sets of 8−12 repetitions with 80% 1RM	VL; B-mode ultrasound	Significant pre-to-post increase in muscle size in both groups with no between-group differences
Váczi et al. (2014)[14]	16 recreationally active older men; 10 weeks (2−3 days/week)	Knee extensions performed for 4 sets and 8−14 repetitions in an SSC type of contraction	Knee extensions performed for 4 sets and 8−14 repetitions in an eccentric muscle action	QF; MRI	Significant pre-to-post increase in muscle size in both groups with no between-group differences
Vissing et al. (2008)[15]	15 young untrained men; 12 weeks (3 days/week)	Countermovement jumps, hurdle jumps, and drop jumps performed for 2−15 sets and 3−15 repetitions	Leg press, knee extensions, and hamstring curl performed for 3−5 sets and 4−12 repetitions	QF, HM, and AD; Type I and Type II muscle fiber CSA; MRI and muscle biopsy	Significant pre-to-post increase in quadriceps, hamstrings, and adductor CSA in both groups with no-between group differences; significant pre-to-post increase in Type I and Type IIa fiber CSA only in the group performing resistance training; no significant pre-to-post changes at the muscle fiber CSA in the group performing plyometric training

[a] Squat jumps were performed with a countermovement.
[b] Within-subject study design
Abbreviations: 1RM = 1 repetition maximum; AD = adductor; CSA = cross-sectional area; HM = hamstrings; LG = lateral gastrocnemius; MG = medial gastrocnemius; MRI = magnetic resonance imaging; MVC = maximum voluntary contraction; PF = plantar flexor; QF = quadriceps femoris; RF = rectus femoris; SOL = soleus; SSC = stretch-shortening cycle; VI = vastus intermedius; VL= vastus lateralis; VM = vastus medialis.

"+" (denoting low potential) to "+++++" (denoting very high potential). Plyometric training was categorized only as "+", suggesting that this mode of exercise has a limited ability to induce muscle hypertrophy. However, the proposed model did not take into account studies that directly compared plyometric and resistance training. Based on the results of these studies, it seems that plyometric training has a greater potential for inducing increases in muscle size than previously thought. In fact, these effects are similar to those observed with the most potent exercise intervention (i.e., resistance training). In order to be effective for muscle hypertrophy, the exercise session generally needs to have a positive effect on muscle protein balance. To the best of our knowledge, muscle protein synthesis responses were not directly examined in response to plyometric exercise in humans. However, there are some relevant data from research using an animal model.[23] In this study, rats subjected to plyometric training experienced significantly greater increases in the rate of protein synthesis (both fractional and total) than their non-exercising counterparts.[23] These results, in part, may explain why plyometric training has the potential to induce increases in muscle size in humans. Additionally, the findings that plyometric exercise may produce hypertrophy similar to that produced by resistance training may challenge the concepts of generally accepted mechanisms of hypertrophy.[24] Specifically, given that there is less time under tension with plyometric exercise and that there is minimal metabolic stress, it could be hypothesized that a brief high-force mechanical stimulus provides sufficient stimulus for inducing a hypertrophic response. Future research is needed to explore the mechanisms by which plyometric exercise induces hypertrophy.

4.2. Microscopic measurements

Skeletal muscle fibers are broadly classified as "slow-twitch" (Type I) and "fast-twitch" (Type II).[25] These muscle fibers have profound physiological differences. For example, Type I and Type IIa fibers primarily rely on oxidative metabolism, whereas Type IIx fibers primarily rely upon glycolytic metabolism.[25] It is commonly acknowledged that Type I and Type II muscle fibers also differ in the context of their hypertrophic response.[26] As compared to Type I fibers, Type II fibers have been suggested to have a greater potential for hypertrophy, possibly because of the findings that the muscle fibers experience greater phosphorylation of ribosomal protein S6 kinase (p70S6K) post resistance exercise.[26–28] Nonetheless, the idea that there are possible hypertrophy responses specific to fiber type also remains controversial.[27,29,30]

Given that plyometric exercise is characterized by high-velocity, short-duration, and maximum-effort movement, activation of motor units associated with fast-twitch, Type II muscle fibers is required.[31] Indeed, a study that used a plyometric exercise protocol consisting of 10 sets of 10 countermovement jumps reported that this type of exercise caused preferential damage of Type II muscle fibers.[31] Based on these results, it might be that plyometric training also produces greater hypertrophy of Type II muscle fibers than of Type I muscle fibers. However, this hypothesis is not necessarily corroborated in the literature. For example, a study that included only a group performing plyometric training reported that 8 weeks of this mode of exercise increased single-fiber cross-sectional area by +23% in Type I, +22% in Type IIa, and +30% in Type IIa/IIx fibers.[4] These results suggest similar hypertrophy from plyometric training intervention in both major muscle fiber types. These effects are similar to those observed following traditional resistance training.[29] Still, it is important to emphasize that the study did not include a direct comparison of adaptations to a group performing resistance training.[4] This is relevant because muscle fiber cross-sectional area values obtained with muscle biopsy may vary among studies, based on muscle tissue processing, biopsy location, and measurement methods.[20]

To date, only 1 study compared the effects of plyometric *vs.* resistance training intervention on muscle fiber hypertrophy[15] (Table 1). In the study, participants in the resistance training group experienced significant increases in the cross-sectional area of Type I and Type IIa muscle fibers, whereas no pre-to-post differences were found in Type IIx fibers. In the group performing plyometric training, no significant pre-to-post increases in the cross-sectional area were observed in any of the analyzed fiber types. However, the analysis from the study included a total of 9 biopsy samples (5 in the plyometric group and 4 in the resistance training group), limiting the ability to draw inferences from the data. Future studies with larger sample sizes are needed to elucidate the isolated effects of plyometric *vs.* resistance training interventions on muscle fiber hypertrophy.

5. Can a training intervention combining plyometric and resistance exercises provide additive benefits?

Given that plyometric and resistance training may provide similar effects on whole muscle hypertrophy, it is logical to hypothesize that a combination of both exercise modalities may provide additive benefits for increases in muscle size. We found 2 studies that compared the effects of combining plyometric and resistance training *vs.* isolated resistance training on acute anabolic signaling or muscle hypertrophy (Table 2). Correa et al.[9] included a sample of 58 older women (age = 67 ± 5 years, mean ± SD) who were initially randomized to a control group (n = 17) and a group performing resistance training (n = 41). After the initial 6 weeks of training, the 41 participants initially allocated to the resistance training group were further randomized to 3 groups that performed: (a) traditional resistance training that included 3 resistance exercises (leg press, knee extension, and knee flexion), (b) resistance training that included maximal concentric actions, and (c) 2 resistance exercises (knee extension and knee flexion) and 1 plyometric-type exercise (lateral box jump exercise). Following 6 weeks of training, increases in muscle thickness of vastus lateralis, vastus medialis, and rectus femoris were similar across all groups. These initial results suggest that plyometric and resistance training may not provide additive effects on muscle growth. One study that examined the effects of isolated resistance training and combined resistance and plyometric training on anabolic signaling reported that both exercise protocols

Table 2
Summary of the studies comparing the effects of combining plyometric and resistance training *vs.* isolated resistance training on measures of muscle hypertrophy or anabolic signaling.

Study	Study design	Sample	Training duration and frequency	Resistance training	Combined resistance and plyometric training	Outcomes	Study results
Correa et al. (2012)[9]	Between group	41 untrained older women	6 weeks; 2 times per week	Leg press, knee extension, and knee flexion performed for 3–4 sets and 7–12 repetitions; in 1 group the training was performed with 2-s concentric and 2-s eccentric actions; in the other group, concentric and eccentric actions were performed as fast as possible	Knee extension and knee flexion performed for 3–4 sets and 7–12 repetitions as well as lateral box jump exercise performed for 3–4 sets and 7–12 repetitions with box heights between 10 cm and 30 cm	Vastus lateralis, vastus medialis, and rectus femoris thickness using B-mode ultrasound	Significant pre-to-post increase in muscle size in all groups with no between-group differences
Lim et al. (2017)[32]	Between group	18 young male weightlifters	n/a[a]	Squats, lunge, and deadlift performed for 3 sets of 6 repetitions at 60% 1RM (this rotation was repeated twice)	Squats, depth jump, lunge, split squat jump, deadlift, and double leg bounds performed for 3 sets of 6 repetitions at 60% 1RM	Muscle cross-sectional area, satellite cell content, myonuclei, and central nuclei content; Ki67/CD56 satellite cell activity; PI3K/Akt, mTOR, p70S6K, and 4E-BP1 protein expression	Muscle cross-sectional area, satellite cell content, myonuclei, and central nuclei content were not affected by the exercise bouts; Ki67/CD56, PI3K/Akt, and 4E-BP1 increased in both groups, with a greater increase in the resistance training group; mTOR and p70S6K increased in both groups with no between-group differences

[a] Acute study design. Ki67/CD56 means a marker of satellite cell activity.
Abbreviations: 1RM = 1 repetition maximum; 4E-BP1 = eukaryotic translation initiation factor 4E binding protein 1; mTOR = mammalian target of rapamycin; n/a = not applicable; p70S6K = ribosomal protein S6 kinase; PI3K/Akt = phosphatidylinositide 3-kinases/protein kinase B.

produced similar mammalian target of rapamycin and p70S6K responses.[32] Given that mammalian target of rapamycin and p70S6K are some of the key intracellular enzymes associated with resistance exercise-induced muscle hypertrophy,[33] these acute results lend support to the similar increases in muscle size observed over 6 weeks of training across the groups in the Correa et al.[9] study.

It is also important to emphasize that the study by Correa et al.[9] included a group of older women as study participants. Older adults, compared to their younger counterparts, appear to have a blunted hypertrophic response, possibly because of the age-associated reduction in muscle protein synthesis.[34,35] One study[34] that included young and older adults in a 16-week training intervention reported a significant Age $\times$ Training interaction, where young individuals increased their muscle cross-sectional area, whereas no significant pre-to-post intervention changes in muscle size were found in older adults. These results suggest that young individuals may have a greater potential for muscle hypertrophy; therefore, a combination of resistance and plyometric exercise may be more beneficial in this population. Future studies in young individuals are needed to explore this hypothesis.

6. Additional factors to consider

6.1. *Injury risk*

Although evidence appears to indicate that plyometric and resistance training may promote similar lower body muscle hypertrophy, it is important to discuss potential safety issues between modalities. Bodybuilders, athletes whose training routines revolve around resistance training to increase muscle size, have a very low incidence of injury (from 0.24 to 1.00 injuries per 1000 h of training).[36] Plyometric training can produce significant stress on the body because, for example, this type of training is associated with ground reaction forces up to 7 times body weight,[1,37] which hypothetically can increase the potential for injury.[38] However, similar to resistance training, plyometric training is generally considered safe and is even used for injury prevention, particularly among female athletes.[1] In addition to studies conducted with athletes, studies conducted with older adults also report minimal adverse effects associated with plyometric training.[21] No adverse effects were noted in the studies discussed in our review. Overall, both exercise modalities seem generally safe, with low injury risks. However, the safety of plyometric exercise would also conceivably depend on the intensity of the exercise, with higher intensity plyometrics (e.g., depth jumps) carrying a greater injury risk than lower intensity alternatives (e.g., bounding).

6.2. *Training duration*

One of the most commonly reported barriers to regular participation in physical activity is the perceived lack of time available for such activity.[39] Therefore, many studies focus on developing time-efficient exercise programs.[40] For resistance training, it is well-established that very short-duration training (5–10 min per session) can produce substantial increases in muscle size.[29] The majority of studies analyzed in our review did not report per-session training time for the groups performing plyometric or resistance training, but, based on the studies' descriptions of the employed training interventions, it seems that the groups were relatively well matched in terms of training time. For example, in the Kubo et al.[12] study, both plyometric and resistance training groups exercised approximately 8 min per session and achieved similar increases in muscle size. Therefore, it seems that both training modes are comparably time-effective. However, future studies should report training time to allow for better extrapolation of the practical implications.

7. Limitations

Even though the studies included in this review reported similar increases in muscle size with plyometric and resistance training interventions, these results are specific to short-term training interventions, with the longest intervention lasting 12 weeks. Regular participation in resistance training has the potential to induce muscle hypertrophy over the long term. For example, in a study,[41] initial increases in muscle size were found after 10 months of resistance training, with additional gains observed after 22 months of training. It remains unclear (and perhaps even questionable) if plyometric exercise has the same potential to produce continuous increases in muscle size or if this type of exercise only may induce hypertrophy over the short term.

Furthermore, in our review, all studies that compared plyometric training with resistance training involved study participants who did not have prior resistance training experience. Increases in muscle size attenuate with training experience, and it therefore remains unclear whether plyometric training produces hypertrophic effects that are similar or disparate to those produced by resistance training in individuals who already have high muscle mass.[42] Also, the current body of literature on the topic has focused exclusively on the muscles of the lower extremities; this is because plyometric training routines generally involve lower body muscles.[1] Future studies are needed to explore whether these results can be replicated using an upper body/upper extremities plyometric training intervention.

Finally, when comparing the effects of any 2 modes of exercise on a given outcome, the difficulties in equating the training intensity, effort, or total volume of work need to be noted. The authors of the studies we included in this review attempted to equate training volume by matching the number of repetitions in the group performing resistance training with the number of performed jumps in the plyometric training groups (Table 1). However, from a training intensity standpoint, 1 repetition of calf raises would not likely produce the same stress on the body as 1 repetition of drop jumps, which suggests that a 1:1 ratio cannot be assumed. This limitation needs to be taken into account when extrapolating the presented results to practical settings.

8. Suggestions for future research

Based on our review of the current evidence, there are several considerations and subsequent suggestions that we provide for future studies on this topic.

1. In the studies that directly compared the effects of resistance training *vs.* plyometric training on muscle hypertrophy, the sample sizes ranged from 10 to 27 participants. We acknowledge that there are inherent difficulties in recruiting a large sample for training interventions, but future studies on this topic would benefit from larger samples because they allow for a more precise estimate of the treatment effect.
2. Even though none of the studies included in this review found significant between-group differences, with small sample sizes, non-significant test results should not be considered indicative of the absence of a true effect in the population.[43] Therefore, an additional suggestion is to use equivalence tests, where an upper and lower equivalence bound is determined based on the smallest effect size that is of interest.[43] This procedure is used in cases when researchers want to argue that there is an absence of an effect that is considered to be large enough and worthwhile enough to examine.[43] For a detailed review of this topic, we recommend the work by Lakens.[43]
3. Only 2 studies included in our review involved a time-matched control group that did not exercise.[10,13] These 2 studies reported a significant Group × Time interaction effect, where both training groups (i.e., resistance and plyometric training) experienced a significant increase in muscle size post-intervention, whereas no pre-to-post changes were found in the control groups. This is important to consider given that a control group allows the researchers to gauge the overall effects of the intervention and to compare the differences in effects between interventions.[44] Therefore, researchers examining this topic should also consider involving a non-exercising control group when designing their experiments.

9. Conclusion

This review highlights that plyometric and resistance training interventions may produce similar effects on whole muscle hypertrophy, at least for the muscle groups of the lower extremities. The evidence for the effects of plyometric training on hypertrophy on the muscle fiber level is currently limited for drawing inferences. Combining plyometric and resistance exercise does not seem to produce additive effects on anabolic signaling or muscle growth as compared to isolated resistance training; however, this conclusion is based on limited evidence and thus warrants future research. The limitations of the current body of evidence are that the findings are specific to (a) musculature of the lower extremities, (b) training interventions that last only up to 12 weeks, and (c) previously untrained participants. Future studies are needed to fill in the existing gaps in the literature.

Authors' contributions

JG conceived the idea for the review and drafted the manuscript; BJS and PM critically revised its content. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

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