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The effects of high- vs. Low-load resistance training on strength and hypertrophy: A systematic review.

Los efectos del entrenamiento de fuerza comparando cargas altas versus cargas bajas sobre la fuerza y la hipertrofia: una revisión sistemática.

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Abstract

INTRODUCTION: Current evidence shows that the improvement of both strength and hypertrophy can be obtained with similar resistance training protocols. The purpose of this systematic review was to examine the existing body of literature pertaining to association between load during resistance training and their effects on strength gains and muscle hypertrophy.

METHODOLOGY: Searches were conducted on Web of Science, PubMed/Medline, and Embase. Selected studies met the following inclusion criteria: (a) studies that included a combination of healthy young and old males and females; (b) including a resistance training with high-loads (≥60% of one-repetition maximum, 1RM) or low-loads (<60% 1RM); (c) equal duration and frequency of the resistance training protocols; (d) measurement of hypertrophy and/or strength gains; (e) in English and published in peer-reviewed journals.

RESULTS: 24 studies were included. Overall, the increase in muscle mass were similar for both high-load and low-load resistance training protocols. However, in 10 out of 24 studies, the gains in strength were significantly higher with the high-load resistance training when compared to the low-load protocol.

CONCLUSIONS: The use of loads above ≥60% of 1RM during a resistance training induces higher gains in muscle strength while muscle hypertrophy is similar to resistance training with lower loads.

Keywords: muscle force; strength training; maximal strength; exercise performance; muscle performance.

Resumen

INTRODUCCIÓN: Tradicionalmente, se ha propuesto que las ganancias de fuerza y la hipertrofia muscular requerían características distintas para lograrse con el entrenamiento de fuerza. Sin embargo, la evidencia actual muestra que la obtención de mejoras de fuerza e hipertrofia se puede obtener con un solo protocolo de entrenamiento de fuerza. El propósito de esta revisión sistemática fue examinar el cuerpo de literatura existente relacionado con la asociación entre la carga durante el entrenamiento de fuerza y sus efectos sobre las ganancias de fuerza y la hipertrofia muscular.

METODOLOGÍA: Las búsquedas se realizaron en Web of Science, PubMed/Medline y Embase sin restricción de año aplicada a la estrategia de búsqueda. Los estudios seleccionados cumplieron con los siguientes criterios de inclusión: (a) estudios que incluyeron una combinación de hombres y mujeres jóvenes y mayores, sin afecciones médicas ni lesiones conocidas; (b) incluir un entrenamiento de fuerza con cargas altas (≥60% de una repetición máxima, 1RM) o cargas bajas (<60% 1RM); (c) la duración y frecuencia de los protocolos de entrenamiento de fuerza fue igual; (d) medición de hipertrofia y/o ganancias de fuerza inducidas por el entrenamiento; (e) en inglés y publicado en revistas revisadas por pares.

RESULTADOS: Se incluyeron un total de 24 estudios en la revisión. En general, el aumento de la masa muscular fue similar para los protocolos de entrenamiento de fuerza de carga alta y baja. Sin embargo, en 10 de 24 estudios, las ganancias en fuerza fueron significativamente

mayores con el entrenamiento de fuerza de alta carga en comparación con el protocolo de baja carga.
CONCLUSIONES: El uso de cargas por encima de ≥60% de 1RM durante un entrenamiento de fuerza induce mayores ganancias en la fuerza muscular mientras que la hipertrofia muscular es similar al entrenamiento de fuerza con cargas más bajas. Esto sugiere que se recomienda el uso de cargas altas durante el entrenamiento de fuerza con el objetivo de maximizar las adaptaciones al entrenamiento.
Palabras clave: fuerza muscular; entrenamiento de fuerza; fuerza máxima; rendimiento deportivo; rendimiento muscular.

Introduction

Until recently, strength gains and muscle hypertrophy were thought to be two different training adaptations that required distinct training characteristics to be achieved (Suchomel, Nimphius, Bellon & Stone, 2018). With this background, bodybuilders -focused on muscle size gains and anthropometry changes- would train with lower loads, high number of repetitions, and shorter rest intervals between set with the aim of maximizing the gains in muscle hypertrophy (Meijer, Jaspers et al. 2015). In the other hand, weightlifters and powerlifters -focused in strength and power improvements- would train with higher loads and lower number of repetitions to maximize the gains in maximal strength induced by the training (Suchomel et al., 2018). For years, it was thought that resistance-based training should be defined by these attributes in order to produce either one of those training adaptations while training for both strength and hypertrophy gains was suboptimal or even impossible. However, as more research started to emerge on the topic, evidence has shown that the improvement of strength and hypertrophy can be obtained with resistance training and the dichotomic view to obtain these training adaptation is less common in the present (Schoenfeld, Ogborn & Krieger, 2016).

There is still no consensus on what is the optimal way to induce muscle hypertrophy and strength gains through training. In fact, there are a few guidelines that have been agreed upon by the scientific community when it comes to resistance-based training (Schoenfeld, Grgic, Van Every & Plotkin, 2021); to maximize muscle hypertrophy gains the athlete should adhere to multiple sets of 8 to 12 repetitions using moderate loads with 60 to 90 seconds rest, with at least some of the sets carried out to the point of concentric muscular failure (Schoenfeld, 2010); to maximize muscle strength gains, the athlete should perform multiple sets close to failure of up to 5 repetitions at a higher load with 2 to 5 minutes of rest in between sets (Schoenfeld et al., 2021). To the date, there is no previous research that has summarized the magnitude of the training adaptations induced by different resistance training protocols to determine what characteristics are required to obtain both muscle strength and muscle hypertrophy gains. For this reason, the purpose of this systematic review was to examine the existing body of literature pertaining to association between load during resistance training and their effects on strength gains and muscle hypertrophy.

Methods

Search Strategy

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline was followed to conduct and identify the studies to be included as part of the systematic review (Moher et al., 2009). The databases used for the search were Web of Science, PubMed (Medline, and Embase. Searches were conducted from all time points up until the 24th of January 2022. The following search syntax was used: “muscle hypertrophy AND muscle strength AND (high load AND low load)”. All articles from the search were screened and the duplicates were removed. Secondary searches consisted of screening the reference lists of the included studies as well as the examination of the papers that have cited the included studies through the Scopus database.

A two-step screening process was applied for the selection of the studies. In the initial step, all the titles and abstracts were evaluated to identify any relevant articles according to the search and eligibility criteria. At this stage, articles that were determined to be suitable were included. In the second stage of the selection process, the full texts of the studies identified in the first stage were read to determine whether they met the inclusion criteria. The reference sections of all the relevant articles were also examined through the snowball strategy.

Eligibility Criteria

The selection of the studies was based on the PICOS model of eligibility criteria which refers to P as population, I as the intervention, C as the comparators, O as the outcomes, and S as the study design (Huang, Lin & Demner-Fushman, 2006). Therefore, the studies selected had to meet the following criteria: (a) studies that included a combination of young and old males and females, with no known medical conditions or injuries; (b) including a resistance training with high-loads (≥ 60% of one-repetition maximum, 1RM) or low-loads (<60% 1RM); (c) the duration and frequency of the resistance training protocols was equal; (d) measurement of hypertrophy and/or strength gains induced by the training; (e) in English and published in peer-reviewed journals. Studies were excluded under the following criteria: (a) conducted on animal subjects; (b) studies conducted on participants with a previous injury or condition; (c) studies that did not specify the characteristics of the load, in relationship with the 1RM, used in training protocol; (d) with no full-text available. Opinion pieces, review articles, commentaries, and editorials were also excluded.

Data Extraction

The following information was extracted from the selected articles: study source (authors and year of publication), subject characteristics (level of activity, number of subjects, age, and gender), intervention protocol (training load, number of sets and reps, rest period, tempo, duration and frequency of the training protocol, and exercises used), main outcomes (pre-post- training gains in muscle strength and hypertrophy), as well as other variables (methods of assessing the outcome and whether or not volume was equated).

Quality Assessment and Risk of Bias

The articles that met the inclusion/exclusion criteria were assessed for methodologic quality using the Downs and Black checklist (Downs & Black, 1998). The Downs and Black checklist is a 27 -item instrument that evaluates study quality in the following categories: 1) reporting, 2) external validity, 3) internal validity, and 4) power.

Results

Study Selection

Through the database searches, 417 Studies were identified. 4 additional studies were identified from other sources. Of these 421 studies, 162 duplicates were removed and 223 were excluded after reading the title and abstract. This left 36 studies to be evaluated for eligibility. Of the 36 studies left, another 12 were removed due to them not meeting the inclusion/exclusion criteria or not being available in full text. Ultimately, 24 studies were included in this systematic review. The flow diagram of the search is presented in Figure 1.

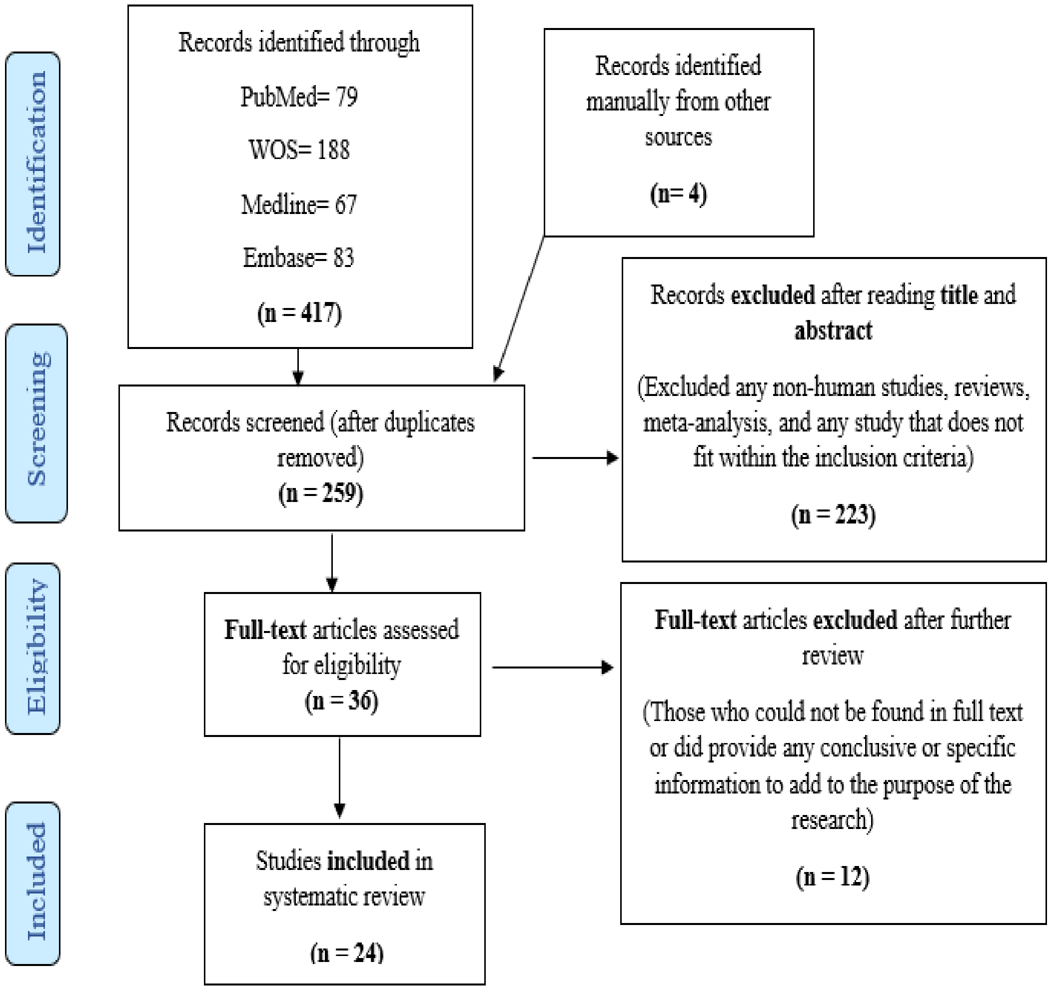

Figure 1. PRISMA Flow Diagram

Study Characteristics

In total, there were 789 total participants in the 24 studies selected for this review (556 men and 233 women). All studies were conducted on young individuals (18-35 years of age) except for one that tested older (60+) participants. Out of the 24 studies, 22 used untrained individuals or individuals with no previous experience in resistance training, and only 2 used resistance-trained individuals. Every study selected used a protocol that involved at least two groups: one group that trained with a high load (i.e., ≥60% 1RM) and another group that training with a low load (i.e., <60% 1RM). From the total, 21 studies measured both muscle strength and hypertrophy gains induced by the training, two measured strength changes exclusively, and only one focused on hypertrophy improvements alone. Even though some of the studies measured many outcomes that resulted from the training protocol, this review will only focus on those related to muscle strength and hypertrophy gains induced by the resistance training protocol.

Quality Assessment and Risk of Bias

Each item in the Downs and Black checklist Downs and Black (1998) was given a score of 1, 0, or was unable to be determined. Those items that could not be determined based upon the information included in the manuscript were labeled using the symbol ∅ and no score was assigned for that item. Each one of the studies was given a final quality score that ranged from 0 to 27. Scores ranging from 0-13 were considered poor, 14-18 were considered fair, 19-24 were considered good, and 25-27 were considered excellent. Out of the 24 studies selected, 21 were determined to be fair and 3 were determined to be good (Table 1). None of the studies was classified as excellent.

Table 1. Downs and Black checklist

Study	**Year**	**Reporting**										**External Validity**			**Internal Validity**														**Power**	**Score**
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	
Au et al. 2017	2017	1	1	1	1	0	1	1	0	1	1	∅	∅	∅	0	0	1	1	1	1	1	1	∅	1	0	∅	1	1	**17**
Dankel et al. 2020	2020	1	1	1	1	0	1	1	1	1	1	∅	∅	1	0	0	1	1	1	1	1	1	∅	1	0	∅	1	1	**19**
Dinyer et al. 2019	2019	1	1	1	1	0	1	1	0	1	1	∅	∅	∅	0	0	1	1	1	1	1	1	∅	1	0	∅	1	1	**17**
Fink et al. 2016	2016	1	1	1	1	1	1	1	0	1	1	1	1	∅	0	0	1	1	1	1	1	1	∅	0	0	∅	1	1	**19**
Fisher and Steele, 2017	2017	1	1	1	1	1	1	1	0	1	1	∅	∅	∅	0	0	1	1	1	1	1	1	∅	∅	0	∅	1	1	**17**
Holm et al. 2008	2008	1	1	1	1	1	1	1	0	1	1	∅	∅	∅	0	0	1	1	1	1	1	∅	∅	1	0	∅	1	1	**17**
Jenkins et al. 2016	2016	1	1	1	1	1	1	1	0	1	1	∅	∅	∅	0	0	1	1	1	1	1	∅	∅	1	0	∅	1	1	**17**
Jenkins et al. 2017	2017	1	1	1	1	1	1	1	0	1	1	∅	∅	∅	0	0	1	1	1	1	1	∅	∅	1		∅		1	**17**
Jessee et al. 2018	2018	1	1	1	1	1	1	1	0	1	1	∅	∅	∅	0	0	1	1	1	1	1	0	∅	1	0	∅	1	1	**17**
Lasevicius et al. 2018	2018	1	1	1	1	1	1	1	0	1	1	∅	∅	∅	0	0	1	1	1	1	1	0	∅	1	0	∅	1	1	**17**
Lasevicius et al. 2022	2022	1	1	1	1	1	1	1	0	1	1	∅	∅	∅	0	0	1	1	1	1	1	0	∅	1	0	∅	1	1	**17**
Lim et al. 2019	2019	1	1	1	1	1	1	1	0	1	1	∅	∅	∅	0	0	1	1	1	1	1	0	∅	1	0	∅	1	1	**17**
Mitchell et al. 2012	2012	1	1	1	1	1	1	1	0	1	1	∅	∅	∅	0	0	1	1	1	1	1	0	∅	1	0	∅	1	1	**17**
Morton et al. 2016	2016	1	1	1	1	1	1	1	0	1	1	∅	∅	∅	0	0	1	1	1	1	1	0	∅	1	0	∅	1	1	**17**
Nóbrega et al. 2018	2018	1	1	1	1	1	1	1	0	1	1	∅	∅	∅	0	0	1	1	1	1	1	0	∅	1	0	∅	1	1	**17**
Ogasawara et al. 2013	2013	1	1	1	1	1	1	1	0	1	1	∅	∅	∅	0	0	1	1	1	1	1	0	∅	0	0	∅	1	1	**16**
Popov et al. 2006	2006	1	1	1	1	1	1	1	0	1	1	∅	∅	∅	0	0	1	1	0	1	1	0	∅	0	0	∅	1	1	**15**
Schoenfeld et al. 2020	2020	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1	1	1	1	1	∅	1	0	1	1	1	**23**
Schuenke et al. 2012	2012	1	1	1	1	1	1	1	0	1	1	∅	∅	∅	0	0	1	1	1	1	1	0	∅	1	0	∅	1	1	**17**
Stefanaki et al. 2019	2019	1	1	1	1	1	1	1	0	1	1	∅	∅	∅	0	0	1	1	1	1	1	0	∅	1	0	∅	1	1	**17**
Tanimoto and Ishii 2016	2016	1	1	1	1	1	1	1	0	1	1	∅	∅	∅	0	0	1	1	1	1	1	0	∅	1	0	∅	1	1	**17**
Tanimoto et al. 2008	2008	1	1	1	1	1	1	1	0	1	1	∅	∅	∅	0	0	1	1	1	1	1	0	∅	1	0	∅	1	1	**17**
Van Roie et al. 2013a	2013	1	1	1	1	1	1	1	0	1	1	∅	∅	∅	0	0	1	1	1	1	1	0	∅	1	0	1	1	1	**18**
Van Roie et al. 2013b	2013	1	1	1	1	1	1	1	0	1	1	∅	∅	∅	0	0	1	1	1	1	1	0	∅	1	0	∅	1	1	**17**

Results of Individual Studies

Out of the 24 screened studies (Table 2), all of them showed similar increases in muscle hypertrophy in the groups with high and low loads of training, but 10 studies showed a higher increase in muscle strength in the group with high loads of training (Au et al., 2017; Fink et al., 2016; Jenkins et al., 2016; Jenkins et al., 2017; Jessee et al., 2018; Lasevicius et al., 2018; Lasevicius et al., 2022; Mitchell et al., 2012; Ogasawara et al., 2013; Van Roie et al., 2013b). Au et al. (2017) studied 46 young, healthy, trained male participants undergoing a 12-week training program and found that the leg press 1RM increased similarly in both high- and low-load groups. Bench press 1RM increased in both groups but with a larger increase in the high-load group. They also found that fat-free mass increased similarly in both groups. Similarly, when evaluating 21 young, healthy, and untrained men undergoing an 8-week resistance training, Fink et al. (2016) found larger improvements in elbow flexor isometric strength for the high-load group compared with training with low loads or switching from high to low loads (mixed loads group). They also found significant increases in the left elbow flexor cross-sectional area (CSA) in all groups, without significant differences between groups. Jenkins et al. (2016) included 15 young, healthy, and untrained men, and found that 1RM strength increased after 2 and 4 weeks of forearm flexion resistance training in the high-load group only. In this same experiment, muscle thickness increased from baseline to week 4 of resistance training similarly for both high- and low-load groups. Likewise, Jenkins et al. (2017) found that in 27 young, healthy, untrained men, both 1RM and the strength during a maximal voluntary contraction (MVC) in the leg extensors increased from after 3 and 6 weeks of resistance training to a greater extent in the high-load compared to the low-load group. Also, there were similar increases in muscle thickness from baseline till the end of the training protocol in both groups. Jessee et al. (2018) studied 40 young, healthy, and untrained men and women for 8 weeks of unilateral knee extension training and found that there was a condition by time interaction for knee extension 1RM, indicating that muscle strength increased to a greater degree for the high-load vs. the low-load group. On the other hand, Jessee's investigation reported that the increase in muscle thickness was similar in both groups, with no significant difference between groups. In similar fashion, a 2018 study by Lasevicius et al. found that in 30 young, healthy, untrained men, training arm curl and leg press for 12 weeks, there was a time effect for elbow flexion and unilateral leg press strength in the groups irrespective of the training load used for the training. However, the magnitude of increase was higher in groups with the higher loads (60 and 80% 1RM) when compared to lower loads (40% and 20% 1RM). Again, the adaptation induced by the training in the CSA for the vastus lateralis and elbow flexors was similar in all training groups. While studying 25 young, healthy, untrained men, Lasevicius et al. (2022) found that 1RM changes were significantly higher for the HL-RF (33.8%, effect size [ES]: 1.24) and HL-RNF training protocol (33.4%, ES: 1.25) compared with the LL-RF and LL-RNF protocols (17.7%, ES: 0.82 and 15.8%, ES: 0.89, respectively). In this sense, high-load groups reached larger strength gains compared to low-load groups, regardless of the proximity to failure. Also, the CSA in the quadriceps increased significantly for HL-RF (8.1%, ES: 0.57), HL-RNF (7.7%, ES: 0.60), and LL-RF (7.8%, ES: 0.45), whereas no significant changes were observed in the LL-RNF (2.8%, ES: 0.15). Ogasawara et al. (2013) studied 9 young, healthy, untrained men for 6 weeks of bench press training and found that both groups increased 1RM and maximal elbow extension strength following training; however, the percent increases in 1RM and elbow extension strength were significantly lower for the low-load training protocol. Also, increases in magnetic resonance imaging (MRI) measured triceps brachii and pectoralis major muscles CSA were similar for both training protocols. Lastly, Van Roie et al. (2013b) studied 56 old, healthy, and untrained men and women for 9 weeks of leg extension training and found that the high-load resulted in greater improvements in 1RM strength than the low-load group. In addition, muscle volume of the upper leg increased significantly over time, with no difference between the high vs low-load groups.

From the remaining studies, 8 showed that both showed that both high- and low-load training groups obtained similar increases in strength and hypertrophy. Lim et al. (2019) found that in 21 young, healthy, and untrained men, both training groups showed an increase in peak torque and type I fiber CSA irrespective of the training load used (30 vs 80% 1RM). Similarly, while studying 18 young, healthy, untrained men, Mitchell et al. (2012) found that the training-induced isometric strength gains were significant irrespective of the load employed (80% vs 30-50%RM) but with a bigger increase in strength for high load group. In addition, increases in muscle volume after the training protocol was equally present in all training groups. Morton et al. (2016) found that, in 49 young, healthy, untrained men undergoing a 12-week training program with several exercises, 1RM strength increased for all exercises in the groups with high and low-load with only the change in bench press being significantly higher in the low-load group. Also, lean body mass and type I and II muscle fiber cross-sectional area increased following training in all groups with no significant differences between groups. Likewise, Nóbrega et al. (2018) found that in 32 young, healthy, untrained men undergoing a 12-week leg extension training program, 1RM increased similarly after 6 and 12 weeks of training in both high- and low-load groups. Both groups were similarly effective in increasing muscle CSA during the training protocol. A study by Popov et al. (2006) found that in 18 young, healthy, untrained men undergoing 8 weeks of leg press training, there was an increase in strength and volume of the quadriceps and gluteus maximus muscles of similar magnitude irrespective of the load employed during the training protocol (50 vs 80% 1RM). In similar fashion, Schoenfeld et al. (2020) studied 30 young, healthy, untrained men, and found negligible differences in the changes induced by the training in strength values when comparing light and heavy load groups. Similarly, changes in muscle thickness were the same for the soleus and the gastrocnemius regardless of the magnitude of load used in the study by Schoenfeld. Stefanaki et al. (2019) studied 13 young, healthy, untrained women for 6 weeks of knee extensions and biceps curls training, and found that the increases in muscle thickness and strength were not different between groups with high and low-loads. Tanimoto et al. (2008) studied 36 young, healthy, untrained men undergoing a 13-week program of resistance-based training and found that the increases in muscle thickness, lean body mass, and strength values was similar in groups with high and low-loads.

Two of the studies in this review measured changes in strength but did not assess hypertrophy changes. The first one by Van Roie et al. (2013a) found that in 36 young, healthy, untrained men and women, there was a significant increase in 1RM present in all groups irrespective of the load used during the training session, but the improvements were of higher magnitude in the group with high loads. However, the second study by Fisher and Steele (2017) found that in 7 young, healthy, untrained males, there were significant increases in strength for both high- and low-load groups, with no significant between-group differences. Additionally, the only study that did not measure strength changes was on by Schuenke et al. (2012) who found that in 34 young, healthy, untrained women, the changes in CSA were similar in high and low-loads groups after 6 weeks of resistance training.

The remaining studies had unclear results when comparing the training outcomes of high vs low-load groups. Tanimoto and Ishii (2006) found that in 24 young, healthy, untrained men, there were significant increases in cross-sectional area and isometric strength (MVC) of the knee extensors in the high-load and low-load groups, whereas no significant changes were seen in the LN group (low-intensity with normal speed). A study by Dankel et al. (2020) found that in 158 young, healthy, and untrained men and women, the strength increases in the high- and low-load groups were equivalent after 6 weeks of resistance-based training. However, the increase in muscle size of the low-load group exceeded that of the high-load group. Holm et al. (2008) found that in 11 young, healthy and untrained men undergoing a 12-week training program of isolated knee extensions, 1RM strength increased in both groups irrespective of the load used for the training the enhancement was larger in the high-load group when compared to the low-load group. Likewise, quadriceps muscle cross-sectional area increased in both groups, with a greater gain in the high- vs. low-load group. Dinyer et al. (2019) found that in 23 young, healthy, and untrained females, 1RM strength increased the same in both high- and low-load groups after 12 weeks of resistance-based training. They also found that there were no significant changes in body composition for none of the groups under investigation.

Table 2. Summary of findings from the studies examining the effects of high- vs low-loads on muscle strength and hypertrophy.

Source	Sample	Training protocol [sets × repetition × (rest interval)]	Tempo	Was the volume equated?	Study duration; weekly training frequency	Exercises used in the study	Method of assessing strength and hypertrophy	Results
Au et al. 2017	Young trained men (n = 46)	High-load: 3 × 8–12RM × (1min) Low-load: 3 × 20–25RM × (1min) Non-exercising control group	Not reported	No	12 weeks; 4 times a week	Inclined leg press, seated row, bench press, cable hamstring curl, front planks, machine-guided shoulder press, bicep curls, triceps extension, wide grip pull-downs, and machine-guided knee extension	BOD-POD 1RM bench press 1RM leg press	Lean body mass increased the same in both groups Leg press 1RM increased to a similar degree in both training groups. Bench press 1RM increased in both groups with a greater increase in the high-load group
Dankel et al. 2020	Young untrained men (n = 60) and women (n = 98)	High-load: 5 × 1 w/ 80-85% 1RM × (90 sec) Low-load: 4 × 8-12RM × (60 sec) Non-exercising control group	Not reported	No	6 weeks; 3 times a week	Dumbbell elbow flexion exercise on the dominant arm	Ultrasound imaging 1RM elbow flexion	Increases in muscle CSA in both groups, with significantly larger increases in the low- vs high-load group Increase in 1RM strength in both groups, with no significant differences between groups
Dinyer et al. 2019	Young untrained women (n = 23)	High-load: 2 × 80% 1RM × (90 sec) Low-load: 2 × 30%1RM × (90 sec)	2 second concentric and 2 second eccentric	No	12 weeks; 2 times a week	Leg extension, seated military press, leg curl, and lat-pull down	DEXA scan 1RM leg extension 1RM seated military press 1RM leg curl 1RM Lat pull down	No change in body composition Similar increases in upper- and lower-body 1RM strength in both groups
Fink et al. 2016	Young untrained men (n = 21)	High-load: 3 × 80 % 1RM × (90 sec) Low-load: 3 × 30 % 1RM × (90 sec) Mixed RT: 4 weeks of 3 × 80 % 1RM × (90 sec) and 4 weeks of 3 × 30 % 1RM × (90 sec)	1 second concentric and 2 second eccentric	No	8 weeks; 3 times a week	Unilateral biceps preacher curls	MRI MVC	significant increases in muscle CSA in all groups, With no significant differences between groups Significant changes in elbow flexor isometric MVC in the high-load group versus the other groups
Fisher and Steele, 2017	Young untrained men (n = 7)	High-load: 3 × 80 % MVIT × (2 min) Low-load: 3 × 50 % MVIT × (2 min)	2 second concentric, 1 second isometric and 3 second eccentric	No	6 weeks; once a week	Unilateral dynamic leg extension	MVIT leg extension RPE scale	Significant increases in strength for both groups, with no significant differences between groups
Holm et al. 2008	young untrained men (n = 12)	High-load: 10 × 70 % 1RM × (2 min) Low-load: 10 × 15.5 % 1RM × (2 min)	Not reported	Yes	12 weeks; 3 times a week	Isolated knee extensions	MRI Muscle biopsy 1RM knee extensions	Significant increase in muscle CSA in both groups, with significantly larger improvement in the high-load vs low-load group Higher 1RM strength improvement in the high-load vs. low-load group
Jenkins et al. 2016	Young untrained men (n = 15)	High-load: 3 × 80 % 1RM × (2 min) Low-load: 3 × 30 % 1RM × (2 min)	1 second concentric and 1 second eccentric	No	4 weeks; 3 times a week	Forearm flexion resistance training	Ultrasound MVC	Muscle thickness increased in both groups, with no significant differences between groups Significantly larger Increase in 1RM strength in the high-

Source	Sample	Training protocol [sets × repetition × (rest interval)]	Tempo	Was the volume equated?	Study duration; weekly training frequency	Exercises used in the study	Method of assessing strength and hypertrophy	Results
								load group vs. the low-load group
Jenkins et al. 2017	Young untrained men (n = 27)	High-load: 3 × 80 % 1RM × (2 min) Low-load: 3 × 30 % 1RM × (2 min)	1 second concentric and 1 second eccentric	No	6 weeks; 3 times a week	Leg extension resistance training	Ultrasound MVC	Muscle thickness increased in both groups, with no significant differences between groups Muscle strength increased to a greater degree in the high-load vs. the low-load group.
Jessee et al. 2018	Young untrained men (n = 20) and women (n = 20)	High-load: 4 × 70 % 1RM × (90 sec) Low-load: 4 × 30 % 1RM × (30 sec)	1 second concentric and 1 second eccentric	No	8 weeks; 2 times a week	Unilateral knee extensions	Ultrasound 1RM unilateral knee extension machine	Increase in muscle thickness in both groups, with no significant difference between groups Muscle strength increased to a greater degree for the high-load vs. the low-load group.
Lasevicius et al. 2018	Young untrained men (n = 30)	High-load (G80): 4 × 80 % 1RM × (2min) Low-load (G60): 4 × 60 %1RM × (2 min) Low-load (G40): 3 × 40 %1RM × (2 min) Low-load (G20): 3 × 20 %1RM × (2 min)	2 second concentric and 2 second eccentric	Yes	12 weeks; 2 times a week	Unilateral elbow flexion (arm curl) and unilateral leg press 45°	Ultrasound 1 RM Unilateral elbow flexor 1RM unilateral leg press 45°	Increases in muscle CSA in all groups Increase in 1RM strength was significantly higher in the G80 and G60 groups vs. the G40 and G20 groups
Lasevicius et al. 2022	Young untrained men (n = 25)	High-load: 3 × 80 % 1RM × (2 min) Low-load: 3 × 30 % 1RM × (2 min)	Not reported	Yes	8 weeks; 2 times a week	Unilateral knee extension exercise	1RM unilateral leg extension machine MRI	Significant increase in muscle CSA in both groups. 1RM changes were significantly higher for high-load vs. the low-load group.
Lim et al. 2019	Young untrained men (n = 21)	High-load (80FAIL): 3 × 80 % 1RM Low-load (30FAIL): 3 × 30 % 1RM Low-load (30WM): 3 × 30 % 1RM	Not reported	Yes (2 groups (80 FAIL and 30 WM) were matched for volume))	10 weeks; 3 times a week	Leg press, leg extension, and leg curl	Isokinetic muscle function test Muscle biopsies 1RM leg press 1RM leg extension 1RM leg curl	Increase in muscle CSA only in the 30FAIL and 80FAIL groups Increases in strength in all groups, with no significant differences between groups.
Mitchell et al. 2012	Young untrained men (n = 18)	High-load: 3 × 80 % 1RM High-load: 1 × 80 % 1RM Low-load: 3 × 30-50 % 1RM	Not reported	No	10 weeks; 3 times a week	Unilateral knee extension	MRI Muscle biopsy 1RM knee extension MVC	Increases in muscle CSA for all groups, with no significant differences between groups. Significant increase in strength for all groups, with a bigger increase In the high-load vs the low-load group.
Morton et al. 2016	Young trained men (n = 49)	High-load: 3 × 75-90 % 1RM × (2 min) Low-load: 3 × 30 % 1RM × (2 min)	Not reported	No	12 weeks; 4 times a week	Seated row, bench press, front plank, machine guided shoulder press, bicep curls, triceps	DEXA scan Biopsy 1RM bench press 1RM leg press	Increases in muscle CSA and lean body mass for all groups, with no significant differences between groups

Source	Sample	Training protocol [sets × repetition × (rest interval)]	Tempo	Was the volume equated?	Study duration; weekly training frequency	Exercises used in the study	Method of assessing strength and hypertrophy	Results
						extension, wide grip pull-downs, inclined leg press, cable hamstring curl, machine guided knee extension	1RM shoulder press 1RM knee extension	Significant increase in strength for both groups, with no significant difference between groups
Nóbrega et al. 2018	Young untrained men (n = 32)	High-load (HIRT-F): 3 × 75-90 % 1RM × (2 min) High-load (HIRT-V): 3 × 75-90 % 1RM × (2 min) Low-load (LIRT-F): 3 × 30 % 1RM × (2 min) Low load (LIRT-V): 3 × 30 % 1RM × (2 min)	Not reported	No	12 weeks; 2 times a week	Leg-extension	1RM knee extension Ultrasound EMG	Increases in muscle CSA for all groups, with no significant differences between groups significant increases in 1RM in all groups, with no significant differences between groups
Ogasawara et al. 2013	Young untrained men (n = 9)	High-load: 3 × 75% 1RM (3 min) Low-load: 4 × 30% 1RM (3 min)	1 second concentric and 1 second eccentric	No	6 weeks; 3 times a week	Bench press	1RM bench press MRI MVC	Increases in muscle CSA for both groups, with no significant differences between groups Increases in strength for both groups, with significantly greater increases in the high-load vs. low-load group.
Popov et al. 2006	Young untrained men (n = 18)	High-load: 3 and 7 × 80% MVC (10 min) Low-load: 1 and 4 × 50% MVC (10 min)	Not reported	No	8 weeks; 3 times a week	Leg press	MRI MVC	Increases in muscle CSA and strength for all groups, with no significant differences between groups.
Schoenfeld et al. 2020	Young untrained men (n = 30)	High-load: 4 × 6-10 RM Low-load: 4 × 20-30 RM	Controlled concentric and 2 second eccentric	No	8 weeks; 2 times a week	Seated and standing calf raise exercises	Anthropometry Ultrasound MVC	Increases in muscle CSA and strength for all groups, with no significant differences between groups.
Schuenke et al. 2012	Young untrained women (n = 34)	High-load (TS group): 3 × 80-85% Low-load (SS group): 3 × 40-60% 1RM Low-load (TE group): 3 × 40-60% 1RM Non-exercising control Group.	10 second concentric and 4 second eccentric for SS group. 1-2 second concentric and 1-2 second eccentric for TE and TS GROUPS	No	6 weeks; 2 times a week for the first week and 3 times a week for the last 5 weeks	Leg press, back squat (Smith machine), and knee extension	Skinfolds	No significant differences in lean body mass between groups
Stefanaki et al. 2019	Young untrained women (n = 13)	High-load: 1 × 80 % 1RM Low-load: 1 × 30 % 1RM	1 second concentric and 1 second eccentric	No	6 weeks; 2 times a week	Knee extensions and biceps curls	Ultrasound 1RM knee extension 1RM bicep curl	Increases in muscle CSA and strength for all groups, with no significant differences between groups.
Tanimoto and Ishii 2016	Young untrained men (n = 24)	High-load (HN group): 3 × 80% 1RM (1 min) Low-load (LST group-Slow Motion): 3 ×	1 second concentric, 1 second isometric and 1 second eccentric for	No	12 weeks; 3 times a week	Knee extension	1RM knee extension MRI MVC	Increases in muscle CSA and MVC strength in the high-load group only Increases in 1RM strength in all groups,

Source	Sample	Training protocol [sets × repetition × (rest interval)]	Tempo	Was the volume equated?	Study duration; weekly training frequency	Exercises used in the study	Method of assessing strength and hypertrophy	Results
		50% 1RM (1 min) Low-load (LN group-Normal Speed): 3 × 50% 1RM (1 min)	the HN and LN groups 3 second concentric and 3 second eccentric for the LST group					with no significant differences between groups
Tanimoto et al. 2008	Young untrained men (n = 36)	High-load: 3 × 80% 1RM (1 min) Low-load: 3 × 55–60% 1RM (1 min Non-exercising control group	1 second concentric, 1 second isometric and 1 second eccentric for the high load group 3 second concentric and 3 second eccentric for the low load group	No	13 weeks; 2 times a week	Chest press, lat pull-down, abdominal bend, back extension, and squat	1RM squat 1RM chest press 1RM lat pull-down 1RM abdominal bend 1RM back extension DEXA scan Ultrasound	Increases in muscle thickness, lean body mass, and strength in both groups, with no significant difference between group
Van Roie et al. 2013a	Young untrained men (n = 21) and women (n = 15)	High-load (HI max): 1 × 10-12 with 80% 1RM Low-load (LO max): 1 × 60 with 20-25% 1RM Then 1 × 10-12 with 40% 1RM Low-load (LO): 1 × 10–12 with 40% 1RMz	1 second concentric and 2 second eccentric	No	9 weeks; 3 times a week	Leg extension	1RM knee extensions MVC	Significant increases in 1RM strength in all groups, with a greater improvement in the Hi max group
Van Roie et al. 2013b	Old untrained men (n = 26) and women (n = 30)	High-load: 2 × 80% 1RM (1 min) Low-load: 1 × 20% 1RM Low-load (LOW +): 1 × 20-40% 1RM	2 second concentric and 3 second eccentric	No	12 weeks; 3 times a week	Leg press and knee extension	1RM leg press 1RM knee extension MVC CT scan	Increases in muscle CSA for all groups, with no significant differences between groups Significant increases in 1RM strength in the high- and low-load+ groups more than the low load group.

BOD-POD: air displacement plethysmography; **CSA**: Cross-sectional area; **CT**: computed thermography; **DEXA**: Dual-energy X-ray absorptiometry; **EMG**: Electromyography; **FAIL**: %1RM to volitional fatigue; **MRI**: Magnetic resonance imaging; **MVC**: maximal voluntary contraction; **MVIT**: Maximum voluntary isometric torque; **RM**: Repetition maximum; **RPE**: Rating of perceived exertion; **WM:** volume matched to 80FAIL; **HIRT-F:** High Intensity Resistance training to Failure; **HIRT-V**: High Intensity Resistance training to volitional interruption; **LIRT-F:** Low Intensity Resistance training to Failure; **LIRT-V:** Low Intensity Resistance training to volitional interruption.

Discussion

Strength Adaptations

Strength gains induced by resistance training happen as a result of several structural and physiological adaptations at different levels such as muscle and tendon tissue or nervous system (Alix-Fages et al., 2022). In this sense, not only skeletal muscle hypertrophy contributes to strength gains. Then, resistance training protocols could be different for targeting strength compared to hypertrophy adaptations. Out of the 23 studies that measured changes in strength, 13 of them found that training with high loads was superior to a similar training protocol with low loads, when it comes to eliciting strength gains after a resistance training protocol, and 10 found no significant differences between a high- and low-load training protocols. Therefore, training at with high loads (with a load beyond 60% of participants' 1RM) might be equally or more beneficial for individuals with no previous resistance training background trying to increase their muscle strength. This agrees with a previous meta-analysis on the topic which states that heavy loading demonstrated a clear advantage for increases in 1RM strength (Schoenfeld et al., 2017).

The reasons explaining why the majority of the studies favored the high-load training protocols are yet to be fully understood. However, one of those reasons may be due to the principle of specificity, which states that the closer the training protocol is to the requirements of the desired outcome (i.e. a specific exercise task or performance criteria), the better the outcome will be (Hawley et al., 2008). Therefore, since the high-load training protocol uses loads closer to an individual's 1RM, it is likely that this type of training will cause greater improvements to that individual's 1RM. Another possibility for the greater increases in muscle strength following high-load training could be neural adaptations. Jenkins et al. (2016) found that similar to the increases in strength, the high-load group also made greater neural adaptations when compared to the low-load group. This was concluded after seeing the greater voluntary muscle activation in the high-load group when compared with the low-load group.

From the 22 studies that measured muscle hypertrophy, 17 found that both high- and low-load training produced similar gains in muscle mass, 3 favored the high-load group, 1 favored the low-load group, and 1 did not find any significant changes in muscle mass. Similar to the strength results, these findings are in the line with a previous meta-analysis on this topic, which stated that both heavy and light loads can be equally effective in increasing muscle mass (Schoenfeld et al., 2017).

Hypertrophy Adaptations

Hypertrophy of a muscle happens when muscle fibers are stimulated after they are under a certain level of mechanical load. It was previously thought that hypertrophy is muscle fiber specific and that depending on what kind of mechanical load the muscle is under, there will be more activation of a certain type of muscle fiber. For example, under higher load conditions, type II muscle fibers are recruited more than type I, therefore, the hypertrophic response would be greater in type II vs. type I muscle fibers. However, recent studies by Morton et al. (2016, 2019) and Lim et al. (2019) provided evidence indicating that there is a similar hypertrophic response in both muscle fiber types that is independent of load, as long as these heavier and lighter loads are lifted to task failure. This seems to somewhat agree with our findings. All of the studies selected for this review had their participants go to failure except for one, which showed higher muscle CSA gains in the higher load vs. the lower load group. A result that differs from the majority of our studies, which found similar increases in both modalities of training. With all of that being said, further research is needed in this area to arrive at a decisive conclusion.

Training Volume

It should be considered that one of the main drivers of hypertrophy, training volume, was only equated between high- and low-load groups in 4 out of the 24 studies included in this review. Two of those studies found that when it comes to increasing muscle strength and size, both high- and low-loads were similarly effective when the resistance training protocol for both groups was equal in total volume. Lasevicius et al. (2022) even suggested that muscle failure does not provide any added strength or hypertrophy benefits compared with stopping before failure as long as total training volume is equated between groups. However, due to the insufficient number of studies that took volume into consideration, more research needs to be done to come to a decisive conclusion on this matter.

Considerations

Limitations should be considered when interpreting the findings of this review. First, most of the studies included were conducted on untrained individuals. With only 2 of the studies using previously trained subjects. When it comes to increasing strength, training specificity (i.e. training closer to one's 1RM) may become more important as one progressively gains training experience. Second, only 9 of the studies used a within-subject crossover study design where each participant acted as their own control. With the other 15 studies not using this type of design, their results could be affected by confounding variables such as sleep, nutrition, genetics, hormone levels, and other factors that could influence one's ability to gain strength and muscle mass. However, the crossover study design can also have its own limitations such as the crossover phenomenon (Cirer-Sastre, Beltrán-Garrido & Corbi, 2017). Lastly, some of the studies used different rest intervals and lifting tempos for each group. For example, Jessee et al. (2018) gave the high-load group 90 seconds of rest between sets whereas the low-load group only got 30 seconds. Similarly, Tanimoto and Ishii (2006) used a concentric-isometric-eccentric tempo of 1-1-1 for the high-load group and 3-3-3 for the low-load group.

Conclusions

In conclusion, although the load that maximized training adaptations in resistance-based exercise depends on multiple factors, the load should be selected depending on the adaptations desired. When the training program is aimed at increasing muscle strength, it seems that using high loads is the optimal approach. However, if the individual is trying to increase muscle size, then it appears that both high and low loads are equally effective and it will come down to personal preference the selection of the load. From a practical perspective, it may be recommended to train across a wide range of loading zones to maximize the benefits and the obtaining of wider training adaptations, at least with muscle strength gains is not the priority. This can be done by following a concurrent training approach where both high- and low-loads are used in the same microcycle, or a sequential approach where training is periodized in such a way that the trainee goes through a period of high-load training, followed by a period of low-load training. The individual should train to volitional failure or very close to it and perform enough volume to achieve the desired adaptations.

Practical applications

One argument that could be made for the high-load training approach is that it can be more time-efficient. As it would take fewer repetitions to reach failure, and fewer sets to reach the desired volume. However, this kind of training also comes with a higher potential risk for injury. Similarly, a low-load approach may have a lower potential for injury but could be more painful, fatiguing, and cause more muscle soreness as it would require more repetitions and more sets (Fisher & Steele, 2017) making it harder to adhere to. Therefore, all these factors must be considered when designing a training program for an individual. Finally, instead of thinking about strength and hypertrophy as separate entities, a better way to look at them is through the Strength-Endurance Continuum, a concept proposed by Fleck and Kraemer (1988). It refers to a structure in which both strength and muscle endurance occur on a continuum that dictates the association between load, repetitions, and training results. Strength is represented by the 1 repetition maximum (1RM), which is defined as the maximum amount of weight that a person can possibly lift for one repetition. In contrast, muscle endurance is the capacity to exert a lower amount of force continually over a specific time period. According to this concept, using a higher load and lower repetitions causes an improvement in strength, using a lower load and higher repetitions causes an increase in endurance, and hypertrophy would fall somewhere in that range. Therefore, there is a continuous transition from strength to endurance as Load decreases and repetitions increase, with hypertrophy occurring at both ends of the spectrum when sets are taken to failure.

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