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Review

Resistance training to improve power and sports performance in adolescent athletes: A systematic review and meta-analysis

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Abstract

Objectives: Resistance training in untrained adolescents can positively effect health-related fitness as well as improve muscular power and sports performance. The impact of resistance training on adolescent athletes is less clear. The purpose of this review is to determine the effectiveness of resistance training programs on muscular power and sports performance in adolescent athletes.
Design: Systematic review and meta-analysis of previously published studies investigating resistance training in adolescent athlete populations.
Methods: A systematic search of Medline, Embase, and SPORTDiscus databases was conducted on 21st March 2011 to identify studies evaluating resistance training programs on power and sports performance in adolescent athletes.
Results: Thirty-four studies were identified. All but two of the studies reported at least one statistically significant improvement in an alactic muscular power outcome. The most common indicators of alactic power were vertical jump (25 studies) and sprint running (13 studies) performance. Fourteen studies provided data to allow for pooling of results in a meta-analysis. A positive effect was detected for resistance training programs on vertical jump performance (mean difference 3.08 [95% CI 1.65, 4.51], $Z = 4.23$ [$P < 0.0001$]).
Conclusions: There is sufficient evidence to conclude that resistance-training interventions can improve muscular power in adolescent athletes. A positive effect on sports performance attributable to participation in resistance training was reported by almost half the included studies, however limited objective evidence to support these claims was found. Improvements in motor performance skills, such as jumping, are widely stated as indicators of improvements in sporting performance.

Keywords: Adolescents; Athletic performance; Weight lifting; Muscular power; Vertical jump

1. Introduction

The use of resistance training (RT) by children and adolescents has attracted increased interest as a means to improve health- and performance-related fitness components. The National Strength and Conditioning Association (NSCA) defines RT as a specialised form of conditioning involving the progressive use of a wide range of resistive loads and a variety of training modalities designed to enhance health, fitness, and sports performance.[1] Numerous reviews and position papers published by advisory bodies have dispelled previous concerns regarding the safety and efficacy of RT for children and adolescents.[1–12]

RT in children and adolescents is reported to have beneficial effects on: muscular strength and power[1,5,6,9,10,12]; prevention and rehabilitation of injuries[1,5,9,10]; long-term health[1,5,11]; cardiovascular fitness[1,5,11]; body composition;[1,5,11] bone mineral density[1,5,11]; blood lipid profiles[1,5,11]; and self-esteem, depression and mental health.[1,5] The NSCA reports strength gains of approximately 30% are typically observed after appropriately designed and supervised short-term RT programs undertaken by children and adolescents.[1]

RT may also benefit sports performance.[1,5,10,11] Explosive muscular power and rate of force production are the basis

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for most sporting actions.[13,14] Speed and power are essential characteristics needed for successful performance in a large range of sports.[15] It has been theorised that increases in the muscular strength and power levels of adolescents after participation in RT may improve sporting performance,[1,5,11] but there is little direct evidence to conclude that increases in muscular strength and power alone will improve adolescent sporting performance.[5,10] Increases in strength and power after RT in both pre-adolescents and adolescents are usually attributed to increased neuromuscular activation and coordination rather than muscle hypertrophy.[1,5,10–12,16] Improvements in motor performance skills are also reported to contribute to increases in strength.[1,10,11] Researchers commonly use motor performance skill tests such as horizontal and vertical jumps and sprint times to assess changes in muscular strength and power.[1] These tests are practical, cost-effective tools to assess muscular power.[14,17–20] A recent investigation of the intra-session and inter-session reliability of three devices commonly used to measure vertical jump height revealed an adequate level of reliability (intra-session reliability: ICC 0.92–0.95 and CV% 3.3–5.5%; inter-session reliability: ICC 0.84–0.90 and CV% 5.3–6.3%).[21] The authors highlighted the importance of test familiarisation procedures and protocols including multiple jump attempts, to attain reliable results.[21] Despite a lack of clear evidence supporting the association between measures of motor performance and improved adolescent sports performance, the results of motor performance tests are often used to infer subsequent improvements in sports performance.[17]

A recent review by Behringer et al. [55] concluded that RT is effective for improving motor performance in children and adolescents. Most of these participants had no athletic background (66%) and many studies included both children and adolescents. No previous review has summarised the potential of RT to improve muscular power and sports performance in adolescent athletes. Consequently, the primary aim of this systematic review and meta-analysis is to determine the effectiveness of RT programs on muscular power in adolescent athlete populations. A secondary aim is to determine the effectiveness of RT programs on adolescent sports performance.

2. Methods

The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement[22] guided the conduct and reporting of this review. A systematic search of three electronic databases (Medline, Embase, and SPORTDiscus) was conducted on the 21st March 2011. In consultation with a librarian, search strategies were developed for the different databases. Articles published in English and in peer reviewed journals were considered for the review. No year restriction was placed on the search. In the first stage of screening, titles and abstracts of identified articles were checked for relevance. In the second stage, full-text articles were retrieved and considered for inclusion. In the final stage, the reference lists of retrieved full-text articles were searched for additional articles.

Two authors independently assessed the eligibility of the studies for inclusion using the following criteria: (i) participants were aged 13–18 years and selected from a sports or athletic population (defined as participants who engaged in organised sports training); (ii) study involved the evaluation of a resistance training program (free weights, bodyweight resistance [including plyometrics], elastic tubing, machine weights, isokinetic devices) with an aim to improve sports performance where explosive power is necessary for success; (iii) study was a randomised controlled trial (RCT), quasi-experimental or single group pre-test post-test design; (iv) included a quantitative objective measure of alactic power output (squat jump, vertical jump with double arm swing, standing long jump, sprint times, force plate power recordings); (v) published in English. Conference abstracts, dissertations, theses and articles published in non-peer reviewed journals were not included.

To be included in the meta-analysis, studies had to meet the following additional criteria: (i) the study must have included a comparison group; (ii) must have assessed vertical jump (a vertical jump with double arm swing); and (iii) data were reported in means and standard deviations for the intervention and control groups at post-test. Attempts were made to contact authors in an effort to obtain further details when required.

All meta-analyses were performed in RevMan.[23] The meta-analysis sought to determine intervention effects on vertical jump height. Vertical jump was considered a continuous data variable; therefore the mean difference (MD) with 95% confidence intervals was used to determine effect measures. The inverse-variance random effects model was used for the meta-analysis procedure due to studies being performed with varied populations and methods. Statistical heterogeneity was examined via chi-squared and the *I2*-Index tests. A guide to the interpretation of heterogeneity based on the *I2*-Index is as follows: 0–40% might not be important; 30–60% may represent moderate heterogeneity; 50–90% may represent substantial heterogeneity; and 75–100% considerable heterogeneity.[24] The assessment of methodological heterogeneity was examined by undertaking sub-group meta-analyses. Sub-grouped meta-analyses were performed by grouping studies according to their intervention type (RT; plyometric training; combined RT and plyometric and/or sprint training) and by their risk of bias score (high, medium or low bias). Where studies used multiple intervention groups and a single comparison group, the comparison group participant number was divided equally among intervention groups to allow for inclusion of both intervention groups in the meta-analysis.

Studies were assessed for 'risk of bias' using criteria adapted from the Consolidated Standards of Reporting Trials

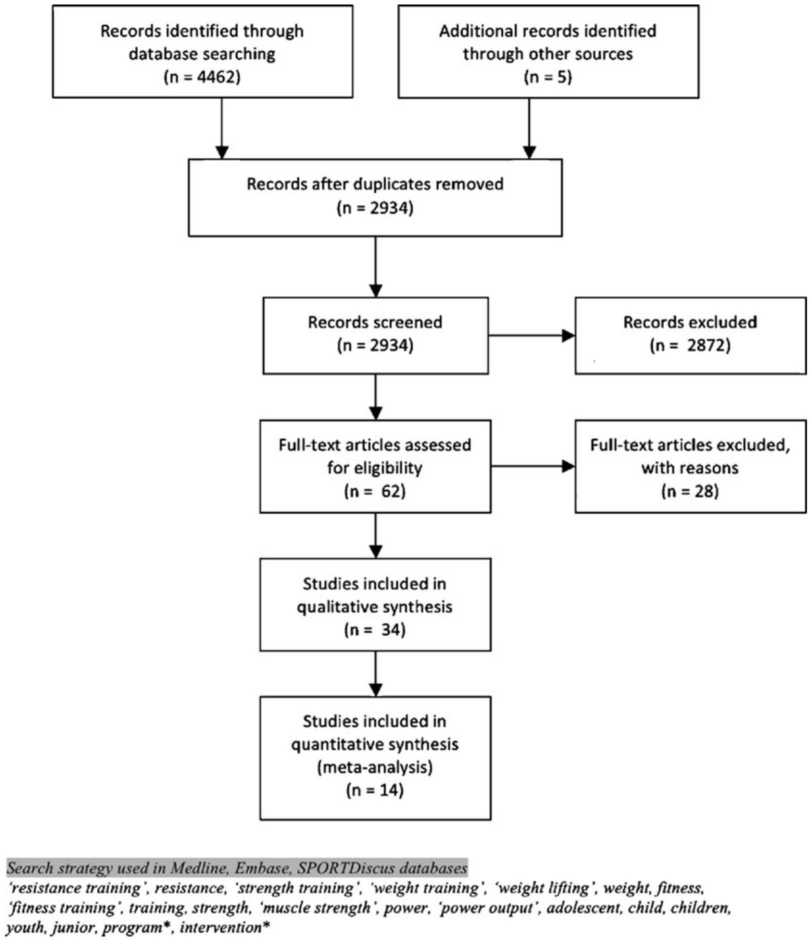

Fig. 1. Flow of studies through the review process.

(CONSORT) statement by two authors independently and in the case of disagreement, further discussion was undertaken to achieve consensus. A 'risk of bias' score for each study was completed on an 8-point scale by assigning a value of 0 (absent or inadequately described) or 1 (explicitly described and present) to each methodological item listed in Supplementary Table 1. Studies that scored 0–2 were regarded as having a high risk of bias, studies that scored 3–5 were classified as having a medium risk of bias and those that scored 6–8 were classified as having a low risk of bias.

3. Results

The flow of studies through the review process is reported in Fig. 1. Sixty-two full-text articles were assessed; 34 met the inclusion criteria (Supplementary Table 2); and 14 studies were included in the meta-analysis.

The total number of participants in the included studies was 1070. Intervention participant numbers were 862 and control participant numbers were 208. Of the included studies: 21 assessed only males[17–19,25–42]; seven assessed only females[43–49]; two studies assessed both sexes[50,51] and the sex of participants in four of the studies was not clearly described.[20,52–54] The age range of participants was 12–18 years, with the estimated mean age being 15.7 years (SD: 1.6). Participants were recruited from high school athletic (67.5%) or semi-elite and elite (32.4%) adolescent sporting populations. Sports training history was reported in 17 studies, ranging from 0 to 7 years, with an average of 3.8 ± 1.6 years. RT history was reported in 14 studies, ranging from 0 to 3 years, with an average of 0.6 ± 1.1 years. Over half the studies (52.9%) were conducted with participants from invasion based team sport backgrounds.

The training programs varied in duration from six to 16 weeks (mean 9.5 ± 6 weeks) with a mean training frequency of 2.6 ± 1.0 sessions per week. Session duration was reported in only 12 studies, where it ranged from 15 to 90 min. Fourteen of the studies were performed in-season, seven during the pre-season, four during the off-season, and eight studies did not report the sporting season in which the study was conducted. Twenty-seven (50%) of 54 training groups participated in a RT only program and 10 (18.5%) performed a plyometric only training program. Combined resistance and plyometric training programs were used in six (11.1%) training groups and five (9.3%) training groups experienced combined resistance, plyometric and sprint training programs. Three (5.6%) training group interventions consisted of resistance and sprint training programs, one (1.8%) combined resistance and aerobic training, and two (3.7%) performed sports specific training only. Of note, 30 of the 54 (55.6%) training groups in addition to their designated intervention also undertook regular sport training activities. Comparison groups were either prescribed no intervention (33.3%) or continued with habitual sport practice activities as designated by their regular sport coach (66.7%). Of the total intervention and comparison groups, 14 groups performed sports specific training only with five of these groups showing a significant improvement in at least one strength or power measure. Vertical jump was measured in 25 (73.5%), sprint running performance in 13 (38.2%), and medicine ball throwing performance in four (11.8%) studies. Sixteen studies assessed maximal muscular strength and all reported significant improvements in maximal muscular strength.

After the initial risk of bias assessment there was 97% agreement between authors and full consensus was achieved after discussion (Table 1). The risk of bias was high in 18 (52.9%) and medium in 16 (47.1%) studies. No studies had a low risk of bias. Only six studies included a true control group and only one of these adequately described the process of randomisation.[27] Only one study reported a power calculation[30] to determine whether their study was adequately powered to detect their hypothesised effects whereas nine studies reported effect sizes.[17,26,30,32,33,36,37,50,51] Analyses in 20 of the studies accounted for potential baseline differences. Of note, participants were reportedly randomly assigned to groups in 15 studies and in 15 studies no attempt to randomly assign participants to groups was made.

Sprint running performance. Thirteen (38.2%) studies assessed sprint running performance over distances ranging from 5 to 40 m.[25–33,43,48,53,54] Eleven of these studies reported statistically significant improvements in sprint performance ranging from 1.1 to 6.2% whereas two studies found no change in sprint performance.[27,32] Eight of these studies involved participants with no previous RT experience[25–27,30,32,33,43,54] and the remaining five studies did not report participant RT experience.[28,29,31,48,53]

Vertical jump. Twenty-five studies (73.5%) assessed vertical jump height via a vertical jump with double arm swing test.[17–20,25–34,38,39,42–45,47,48,51,53,54] Nineteen of these studies reported statistically significant increases ranging from 5.1 to 24.6%; six found no change.[28,29,32,38,43,47] The two studies with the smallest significant increases in vertical jump[27,33] implemented training programs where the exercise load used was not individualised to participants' repetition maximum levels and therefore evidence of appropriate progressive overload was not shown. The study[26] with the largest reported change (24.6%) in vertical jump adjusted exercise loads to individual participant repetition maximum levels and implemented a clear progression of exercise loading throughout the study.

Meta-analyses. Fourteen studies corresponding to 19 intervention groups and 14 comparison groups were evaluated in a meta-analysis comparing vertical jump height at post-intervention (Fig. 2a). Overall, the studies were found to be significantly heterogeneous ($\chi^2 = 56.97$, d.f. = 18 [$P = 0.00001$], $I^2 = 68\%$). The meta-analysis showed an effect favouring the intervention groups (MD 3.08 [1.65, 4.51], $Z = 4.23$ [$P < 0.0001$]).

Five studies, consisting of eight intervention and five comparison groups, where the intervention groups undertook a RT only program were combined in a subgroup meta-analysis. These studies had low-moderate heterogeneity ($\chi^2 = 11.21$, d.f. = 7 [$P = 0.13$], $I^2 = 38\%$). A difference in effects between intervention and comparison groups was found (MD 2.09 [−0.01, 4.20], $Z = 1.95$ [$P = 0.05$]).

Three studies where the intervention groups participated in a plyometric only training program, consisting of four intervention and three comparison groups, were combined in a subgroup meta-analysis. These studies were found to be moderately heterogeneous ($\chi^2 = 5.72$, d.f. = 3 [$P = 0.13$], $I^2 = 48\%$). This meta-analysis showed an effect favouring the intervention groups (MD 5.47 [1.95, 9.00], $Z = 3.04$ [$P = 0.002$]).

Six studies where the interventions consisted of a RT program combined with either a plyometric and/or a speed training component, consisting of seven intervention and six comparison groups, were pooled in a subgroup meta-analysis. Considerable heterogeneity was found ($\chi^2 = 29.41$, d.f. = 6 [$P < 0.0001$], $I^2 = 80\%$). A positive effect for the intervention groups was shown (MD 3.03 [0.83, 5.24], $Z = 2.69$ [$P = 0.007$]).

Of the 14 studies included in the meta-analysis, after the risk of bias assessment six studies were classified as having a medium risk of bias and eight studies as having a high risk of bias. A subgroup meta-analysis for each level of risk of bias was undertaken (Fig. 2b). Both the medium and high risk of bias studies were found to have substantial heterogeneity (Medium risk: $\chi^2 = 16.48$, d.f. = 10 [$P = 0.09$], $I^2 = 39\%$; high risk: $\chi^2 = 11.38$, d.f. = 7 [$P = 0.12$], $I^2 = 38\%$). The medium risk of bias studies were found to have a large positive effect for the intervention groups compared to a very low effect for the high risk of bias studies (Medium risk: MD 4.29 [2.91, 5.66], $Z = 6.12$ [$P < 0.00001$]; high risk: MD 1.58 [−0.29, 3.45], $Z = 1.65$ [$P = 0.10$]).

4. Discussion

The primary aim of this systematic review was to determine the effectiveness of RT interventions on muscular power in adolescent athletic populations. Despite considerable heterogeneity in terms of study design and types of training, there is sufficient evidence to conclude that RT interventions have the potential to improve muscular power in adolescent athletes. All but two of the studies reported at least one statistically significant improvement in an alactic muscular power

Table 1
Bias assessment of included studies.

Studies	Were the groups comparable at baseline on key characteristics?	Did the study include a true control group (randomised participants – not a comparison group)	Was the randomisation procedure adequately described and carried out?	Did the study report a power calculation and was the study adequately powered to detect intervention effects?	Were the assessors blinded to treatment allocation at baseline and posttest?	Did at least 80% of participants complete follow up assessments?	Did the study analyses account for potential differences at baseline?	Did the study report effect sizes?	Total
Siegler et al. [43]	0	0	0	0	0	1	1	0	2
Gorostiaga et al. [27]	1	1	1	0	0	1	1	0	5
Christou et al. [26]	1	0	0	0	0	1	1	1	4
Chelly et al. [25]	1	0	0	0	0	1	0	0	2
Mujika et al. [28]	1	0	0	0	0	0	0	0	1
Meylan and Malatesta [53]	0	0	0	0	0	1	1	0	2
Wong et al. [11]	0	0	0	0	0	1	1	1	3
Buchheit et al. [30]	1	0	0	1	0	0	1	1	4
Alves et al. [29]	1	0	0	0	0	1	1	0	3
Rubley et al. [45]	1	0	0	0	0	0	1	0	2
Wroble and Moxley [34]	0	0	0	0	0	1	0	0	1
Coutts et al. [31]	1	0	0	0	0	1	1	0	3
Gabbett et al. [32]	0	0	0	0	0	1	1	1	3
Channell and Barfield [4]	0	0	0	0	0	1	0	1	2
Brown et al. [18]	1	1	0	0	0	1	1	0	4
Matavulj et al. [19]	0	1	0	0	0	1	1	0	3
Soh et al. [47]	0	0	0	0	0	1	0	0	1
Santos and Janeira [39]	1	1	0	0	0	1	0	0	3
King and Cipriani [20]	1	0	0	0	0	0	1	0	2
Tsimahidis et al. [54]	1	1	0	0	0	1	1	0	4
Milić et al. [46]	0	0	0	0	0	1	1	0	2
Lehnert et al. [44]	0	0	0	0	0	1	0	0	1
Vladu [49]	0	0	0	0	0	1	0	0	1
Szymanski et al. [40]	1	0	0	0	0	1	1	0	3
Szymanski et al. [41]	1	0	0	0	0	1	1	0	3
Szymanski et al. [42]	1	0	0	0	0	0	1	0	2
Gonzalez-Badillo et al. [36]	1	0	0	0	0	1	1	1	4
Gonzalez-Badillo et al. [37]	1	0	0	0	0	1	0	1	3
Gorostiaga et al. [38]	0	0	0	0	0	1	0	0	1
Drinkwater et al. [35]	1	0	0	0	0	1	1	0	3
Myer et al. [48]	0	0	0	0	0	1	0	0	1
Rhea et al. [51]	0	0	0	0	0	1	0	1	2
Bishop et al. [52]	0	1	0	0	0	1	0	0	2
Barber-Westin et al. [50]	0	0	0	0	0	1	0	1	2

1 = yes; 0 = no.
Score of 0–2 = high risk of bias; score of 3–5 = medium risk of bias; score of 6–8 = low risk of bias.

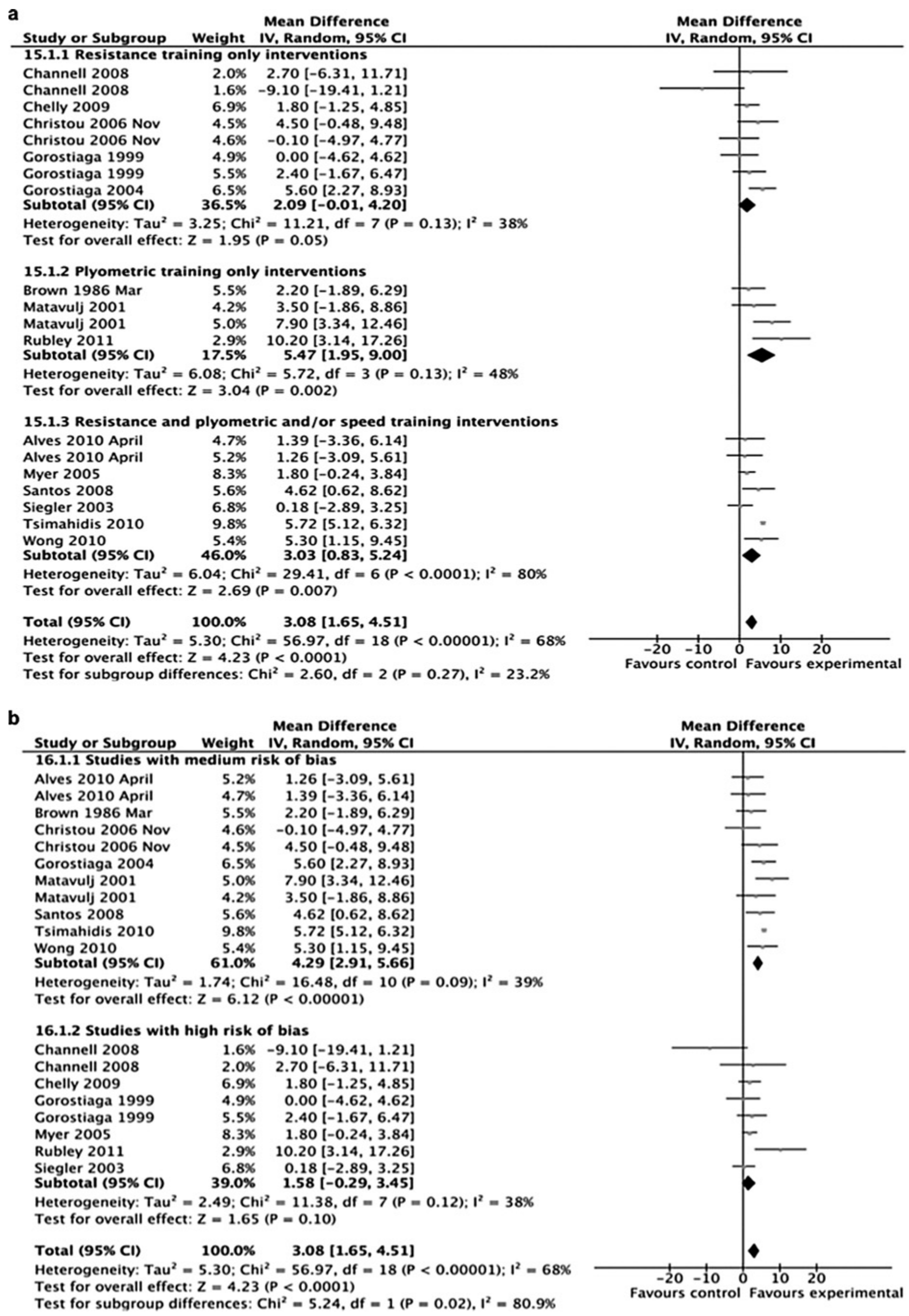

Fig. 2. (a) Forest plot comparison of resistance training intervention groups vs comparison groups; outcome vertical jump height in cm. (b) Forest plot comparison of resistance training intervention groups vs comparison groups subgrouped by risk of bias assessment; outcome vertical jump height in cm. Chi^2 = chi square test; df = degrees of freedom; I^2 = I-squared statistic; IV = inverse variance; Z = Z-test.

outcome. The most common indicators of alactic power were vertical jump and sprint running performance. A secondary aim of the review was to investigate the effects of RT on sporting performance. Almost half of the studies explicitly stated that their intervention had a positive effect on sports performance. However, few of these studies were able to support their claims with an objective measure of sports performance.

RT interventions were found to improve muscular power in adolescent athletes. Of the 34 studies included in this review, 32 reported at least one statistically significant improvement in alactic muscular power outcomes. It is not entirely clear which aspects of RT interventions are responsible for inducing improvements in muscular power as studies often included combined training modalities in addition to habitual sporting practice. It does appear that improvements are specific to the type of training employed and are influenced by movement pattern, movement velocity, contraction type, and contraction force.[1] Plyometric only training had a larger overall effect (Z = 3.04) on vertical jump height than studies with RT combined with plyometric and/or speed training ($Z = 2.69$) or studies that consisted of RT only ($Z = 1.95$). Studies that compared RT to combined RT and plyometric training all found larger improvements in measures of muscular power for the group who performed plyometric training in addition to RT.[17,40–42,51] However, these larger improvements may be in part attributable to an increased volume of work performed, as none of these studies equated the amount of work performed between groups.

The addition or continuation of habitual sport practice in intervention and/or comparison groups makes it difficult to determine the independent contribution of the RT interventions. Christou et al.[26] identified the confounding nature of habitual sport practice in their investigation into the effects of a 16-week RT program in adolescent soccer players. Lower body strength increased significantly in a strength plus soccer training group (58.8%), a soccer training only group (33.8%), and a comparison group (17.3%).[26] Soccer requires the development and application of high forces from the lower limb musculature, thus causing a larger increase in leg strength in the soccer only training group than growth alone, however only the strength plus soccer training group significantly improved squat jump and vertical jump height.[26] Meylan et al.[53] reported significant increases in vertical jump height in a plyometric plus soccer training group compared to no improvement in a soccer only training group after eight weeks of plyometric training. Wong et al.[33] reported similar findings in their 12-week intervention with adolescent soccer players. These results suggest improvements in the muscular power of adolescent athletes are not significantly improved with habitual sport practice alone but can be improved by resistance or plyometric training.

The results of this review confirm that RT interventions improve the maximum strength of adolescent athletes. All sixteen studies that assessed maximal strength reported significant improvements, with improvements in squat performance increasing by as much as 92% in one study with adolescent female basketball, soccer and volleyball players.[48] Whether RT interventions in adolescent athletes are employed in the in-season, pre-season or off-season does not appear to influence the physiological response to RT. In two comparable studies in adolescent soccer players, one performed in the pre-season[33] and the other during the in-season,[53] similar percentage change in vertical jump and sprint performance were reported. This may be attributable in part to the low RT age of adolescent athletes and their capacity for initial improvement with RT.

A positive effect on sports performance attributable to participation in RT was reported by almost half the studies. However, only a few of these studies had an objective measure of sports performance to support their claims. A 6-week plyometric training program with adolescent swimmers showed participants achieved a significant improvement in swim performance time to 5.5 m.[52] Two studies with elite adolescent weightlifters reported significant increases in squat, clean and jerk, and snatch performances after participation in a 10-week RT program.[36,37] In individual sports such as swimming, sprinting or weightlifting where improvements in performance can be easily quantified, researchers can justifiably conclude that their intervention improved sporting performance. In team sports requiring running, jumping, changes of direction, execution of team tactics and many other components, it is much more difficult to assess changes in sports performance, and the evidence is vague in its description of how improvements in sports performance are actually manifested. From this review and meta-analysis it appears that change in jumping performance is widely regarded as an indicator of change in sports performance. The meta-analysis revealed RT interventions have an overall positive effect ($Z = 4.23$) on vertical jump performance in adolescent athletes. A recent meta-analysis reporting the effects of strength training interventions on motor performance skills found that RT programs significantly improve running, jumping, and throwing performance in children and adolescents.[55] Despite significant effects seen in athletes, greater adaptations in motor performance were observed in children, untrained participants and non-athletes, however the authors suggested that the applied training programs may not have been of sufficient intensity to induce adaptation in athletes and more experienced participants. The authors went on to conclude that a positive transfer to sports performance can be assumed with improvements in the motor performance skills of young athletes.[55] When assessing motor performance skills such as vertical jump height, extensive familiarisation with the testing procedures is essential to reduce the systematic error and improve test–retest reliability, particularly where participant knowledge of testing procedures is limited.[21]

The randomisation of participants and adequate description of the randomisation procedures would improve study quality. The lack of randomisation in the identified studies may in part be attributable to the practicalities of working with athletic populations, limiting researchers ability to control the research environment.

Strengths and limitations. To the authors' knowledge this is the first study to systematically review the impact of RT interventions to improve muscular power and sports performance in adolescent athletes. The review was guided by the PRISMA statement and studies were assessed for risk of bias using criteria adapted from the CONSORT statement. A number of meta-analyses were performed, providing objective data to assess the effectiveness of interventions. Despite these strengths, there are some limitations that should be noted. First, there is possible bias in the selection of studies as abstracts, theses, or studies published in non peer-reviewed journals were not included. Second, few studies used a randomised controlled trial study design and the overall risk of bias was high to moderate in all of the studies. Finally, there was considerable heterogeneity between the studies included in the meta-analysis. As such, caution should be taken in the interpretation of the meta-analysis results.

5. Conclusions

RT interventions can improve the muscular power and motor skill performance of adolescents and subsequently may improve sporting performance.[1,5,11,55] This review investigated 34 RT intervention studies in adolescent athletic populations. While it has not been established which types of programs are most suitable for increasing muscular power and improving sporting performance in various adolescent athlete subgroups, RT, plyometric training, speed training or combinations of these training modalities all have the potential to improve muscular power in adolescent athletes. Further research is required, in the absence of habitual sporting practice, to determine the specific effects of RT, plyometric training, speed training and combinations of these training modalities on the muscular power and sporting performance of adolescent athletes.

This review has provided evidence that RT programs have the capacity to improve muscular power in adolescent athletes. This review has also found that improvements in motor performance skills, such as jumping, are widely considered as indicators of improvements in sporting performance. Further research investigating the association between improvements in muscular power and motor performance skills and sports performance is needed.

Practical implications

- Future studies should focus on improving study design and reporting features. Researchers should attempt to conduct randomised controlled trials and clearly describe their process of randomisation.
- Authors are also encouraged to report statistical power calculations and effect sizes of observed changes.
- Familiarisation with the assessments to be used is also recommended, particularly for vertical jump assessment.
- Improvement in the description of the training interventions employed and clear methods for ensuring progressive overload is achieved will improve the quality of research in this area.
- Additionally there is a clear opportunity for the investigation of RT interventions in individual sport athletes where sports performance can be objectively measured.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jsams.2012.02.005.

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