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Increasing Ball Velocity in the Overhead Athlete: A Meta-Analysis of Randomized Controlled Trials

Training Interventions Effecting Ball Velocity

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ABSTRACT

Overhead athletes routinely search for ways to improve sport performance, and one component of performance is ball velocity. The purpose of this meta-analysis was to investigate the effect of different strengthening interventions on ball and serve velocity. A comprehensive literature search with pre-set inclusion and exclusion criteria from 1970 to 2014 was conducted. Eligible studies were randomized control trials including the means and standard deviations of both pretest and posttest ball velocities in both the experimental and control groups. The outcome of interest was ball/serve velocity in baseball, tennis, or softball athletes. Level 2 evidence or higher was investigated in order to determine the effect different training interventions had on velocity. Pre and posttest data were extracted in order to calculate Hedges's g effect sizes with 95% confidence intervals (CI). Methodological qualities of the final 13 articles within the analysis were assessed using the Physiotherapy Evidence Database (PEDro) scale. The majority of the articles included in this analysis had an effect on velocity with the strongest effect sizes found in periodized training (Hedges's g = 3.445; 95% CI = 1.976, 4.914). Six studies had CI that crossed zero indicating that those specific interventions should be interpreted with caution. Consistent and high quality evidence exists that specific resistance training interventions have an effect on velocity. These findings suggest that interventions consisting of, isokinetic training, multi-modal training, and periodization training are clinically beneficial at increasing velocity in the overhead athlete over different windows of time.

Key Words: overhead athlete, velocity, training interventions

INTRODUCTION

Individuals involved in overhead athletics are constantly looking for ways to improve sport performance. One measure of sport performance in the overhead athlete is throwing or serve velocity. Baseball and softball players strive to improve throwing velocity while tennis players strive to improve serve velocity in order to remain competitive. As athletics becomes more competitive additional emphasis is put on increasing athletic performance. Therefore, it is imperative that coaches, clinicians, and strength and conditioning professionals understand the demands involved in baseball, softball, and tennis in order to prescribe an appropriate resistance-training program aimed at increasing velocity.

Resistance training has grown in popularity over the past 30 years.(29) A successful resistance program should incorporate proper exercise prescription and appropriate methods of progression.(29) Resistance training has been shown to increase muscle strength, power, and hypertrophy in many types of athletes (24, 45, 48); thus, becoming an integrated part of athletic performance. The overhead athlete is no exception to this phenomenon as the overhead throw and tennis serve are activities that use both synergistic and dynamic muscle actions, which are maximized through optimization of physiology.(46, 57) Given that the majority of overhead athletes produce maximal throwing/serve velocities through explosive rotational movements,(2, 34, 43) there have been many training techniques investigating resistance training on velocity performance. However, the most effective training regimen for increasing ball/serve velocity has yet to be established within the literature.

In 2004, a systematic review was published reviewing the effect of different training programs on the velocity of overarm throwing. (54) This review focused on 3 different principles of training: training with underweight, overweight balls, and general weight training. The articles references ranged from 1938 to 2003 with the majority of articles published in the 1990s.(54) Since the release of this review, several resistance-based randomized control trials have been conducted on measuring ball velocity in overhead athletes. Therefore, the purpose of this meta-analysis was twofold: to update the current body of literature on interventions that improve ball and serve velocity in the overhead athlete, and secondly, to determine the most effective intervention for increasing ball/serve velocity by conducting a meta-analysis.

METHODS

Published Study Selection

The primary author performed a comprehensive search using both an electronic search and a hand search based on the key word combinations presented in Table 1. The Internet search incorporated published articles identified through PubMed and EBSCO. MEDLINE, SportDiscus, and CINAHL were searched separately within the EBSCO database. The primary author and an independent reviewer systematically reviewed all articles generated via the search strategy. The search strategy was conducted in 5 stages (Figure 1). Stage 1 consisted of an Internet search through four different search engines based on the pre-set inclusion criteria. All duplicates were removed during this stage of the search, and a total of 289 articles were identified for title review. Stage 2 consisted of abstract reviews for each of the articles that were included in the study by title alone. In stage 3 articles were read in full to identify the final studies to be included in the analysis. Upon reading, several articles were dismissed due to the level of evidence and the lack of both pretest and posttest data. Stage 4 consisted of additional resources via a hand search. The references of the final articles included in the study were reviewed in order to perform an exhaustive search and identify any other potential articles. The two independent reviewers were in total agreement on the final 13 articles included in this analysis.

Article Inclusion and Exclusion Criteria. Before conducting the literature search, pre-set inclusion criteria were established in order to identify potential articles. Articles met the following inclusion criteria if:

1. Articles were in the English language and published between January 1970 and February 2014
2. Abstracts were available upon literature search
3. The authors examined the effectiveness of an intervention on ball or serve velocity

4. The authors compared interventions with a control group using a randomized control trial design
5. Prospective cohort designs assessed ball/serve velocity as the final outcome
6. The authors presented both pretest and posttest ball/serve velocity means and standard deviations (SD) or standard error (SE). This information was necessary in order to calculate effect sizes for the meta-analysis.
7. The authors included participants partaking in baseball, softball, or tennis athletics

Exclusion criteria included articles not including an abstract and studies that did not provide means and standard deviations for both pretest and posttest velocity testing. After fully reviewing each article the independent reviewers decided to only include randomized control trials (level 2 evidence based off the Oxford Centre for Evidence-Based Medicine 2011) in order to develop concrete conclusions based on the best available evidence. This removed 2 potential studies(20, 56) based on inclusion criterion #5.

Meta-Analysis

Data Extraction. For each study, the primary author (NM) extracted both pretest and posttest means and standard deviations (SD). If pretest and posttest data were not available the article was excluded from the analysis. Three articles included bar graph representation of the pretest and posttest means and SD,(27, 28, 32) in which case a hand measurement was taken using a Digimatic Caliper (Mitutoyo, Kawasaki, Kanagawa Japan) measuring the graph in millimeters. A ratio was then established depending on the increments presented on the y-axis of the charts. Means and SD of pretest and posttest serve/ball velocities were calculated using the ratio.

Quality of Assessment: The Physiotherapy Evidence Database (PEDro) scale was used to rate the quality of all the articles used in the final analysis.(33) The PEDro is comprised of 11 questions but is scored on a ten-point scale with ten indicating a perfect score (question 1 does not count towards the final score). To be considered high quality evidence a study must score ≥6. (1) Two authors independently rated each article that met the specified inclusion criteria. Upon completion of all appraisals, the two authors met to deliberate their results. If authors disagreed on a score those specific inconsistencies were discussed. Following the critical appraisal, the appropriate strength of recommendation was selected using the Strength of Recommendation of Taxonomy (SORT), which includes ratings A, B, or C. (11) An "A" is received if the evidence is consistent and of good-quality patient-oriented outcomes, a "B" if the evidence is inconsistent and of limited-quality patient-oriented outcomes, and a "C" if evidence is based on studies of diagnosis or screening, expert opinion, disease-oriented outcomes, or case series.(11)

Statistical Methods: All pretest and posttest means and SDs of ball/serve velocities, group sample size, and the pre and post correlation were input into the Comprehensive Meta-Analysis Software (version 2.2.064; BioStat, Englewood , NJ). Using these statistics, the CMA software can compute the sample means of the pre/post differences for each group, along with the pooled SD of the change from pre to post. These statistics on the differences are then used to compute Hedges's g, which is an effect size to determine the differences between the group changes. We note that a pre and post correlation was the only value that could not be directly extracted from the majority of the articles. However, two articles provided pertinent information needed to calculate the pre post correlation.(6, 38) Both of these articles had high correlation values ranging between 0.86-0.97(6, 38); thus the authors decided that it would be reasonable to use 0.85 as the pre post correlation value for each of the 13 articles. We note that results will therefore be slightly conservative with respect to the two articles.(6, 38)

Seven of the 13 articles had more than one experimental group in which case each group was compared separately to the control group. Effect sizes for each article in this analysis were included even if the original paper reported the effect sizes. This ensured consistency in the reported effect sizes. The software calculated 95% confidence intervals (CIs) for each effect size. The upper and lower limit of the CI helps the reader interpret the precision of the training effect estimate. If the CI crosses zero, the reader should consider if the training truly had a meaningful effect on ball velocity. However, if the CI did not cross zero, the training had a meaningful effect on ball velocity. Cohen(9) suggests Hedges's g effect size can be interpreted similarly to Cohen's convention of small 0.2, moderate 0.5, or large 0.8; therefore, this effect size scale was used to interpret the results presented in this meta-analysis.(16)

Bias Assessment: Publication bias occurs when published studies report results that are unrepresentative of the majority of the research done within a particular area of interest.(47) This could be due to the simple fact that research that does not approach or obtain statistical significance goes unpublished. In this study, bias was evaluated using two different methods: a funnel plot assessing the relationship between effect size and study size, and Orwin's Fail-safe N, which allows the researcher to select a small hedges's g effect size in order to determine how many missing articles it would take to bring the effect size below the selected hedges's g.(7) Both appraisals of bias were assessed and created in the Comprehensive Meta-Analysis Software.

RESULTS

The methodological qualities of the 13 studies included in this review are provided in Table 2. The quality of the articles had an average score of 6±0.5 out of 10 points. Full overviews of the 13 articles identified in this analysis are provided in Table 3. The specific parameters involved within each intervention are provided in Table 4. All of the studies in this analysis conducted a randomized control trial and were considered level 2 evidence according to the Oxford Centre for Evidence-Based Medicine 2011 table.

Of the 13 studies one included isokinetic training,(38) one included multimodal training,(19) three included plyometric training,(6, 18, 39) 10 included resistance training,(6, 17, 18, 27, 28, 30, 32, 39, 41, 53) and one included weighted ball training.(10) Half of all the studies in this analysis had a meaningful training effect on ball/serve velocity, as the effect sizes ranged from 0.95 to 3.45, and the CIs did not cross zero.(6, 10, 19, 27, 28, 30, 38, 39, 41, 53)

Isokinetic Training. One study in this analysis evaluated serve velocity prior to and following either a concentric or eccentric isokinetic glenohumeral internal and external rotation workout (Table 3).(38) The isokinetic velocities were performed in a pyramidal scheme (90, 120, 150, 180, 180, 180, 120, 90°/sec) (Table 4). Compared to the control group, both the eccentric and concentric groups significantly improved their serve velocity by eight miles per hour (mph). The effect sizes demonstrate clinical meaningfulness from pre to post improvement in serve velocity (Figure 2) indicating that both concentric and eccentric isokinetic training are clinically beneficial for improving serve velocity in elite tennis players.

Multimodal Training. Only one study examined the effectiveness of multimodal training on serve velocity.(19) Nationally ranked junior tennis players were randomly assigned to an experimental group undergoing multimodal training that consisted of both single and multi-planar elastic tubing shoulder exercises, trunk, and medicine ball training (Table 3). Compared to the control group the experimental group significantly improved their serve speed by 4 mph. The effect size from pre to post improvement in serve velocity were >1 indicating that multimodal training is clinically beneficial for improving serve velocity in youth tennis players (Figure 3).

Plyometric Training. Plyometric training was implemented in two baseball studies and one tennis study. A large training effect was observed in junior tennis players (6) (Figure 4) undergoing a series of both upper and lower body exercises (Table 3). Compared to the control group, the plyometric group significantly improved their serve speed by 7 mph; however, the control group decreased in speed by 4 mph making it difficult to conclude if there was a true training effect.(6) In the remaining two studies both youth(18) and nationally ranked baseball players(39) underwent ball velocity testing prior to and following plyometric exercise. However effect sizes within both studies were moderate with the CI crossing zero (Figure 4), as ball velocity did not increase compared to that of the control groups.

Resistance Training. Different variations of strength training protocols were implemented in ten studies within this analysis.(6, 17, 18, 27, 28, 30, 32, 39, 41, 53) Out of the ten, 6 studies were shown to have a large training effect on ball velocity.(27, 28, 30, 39, 41, 53) All studies incorporated some form of upper extremity resistance training and, all but one study(39) included collegiate level athletes as part of the test population. Different levels of baseball players undergoing basic weight training programs (Table 3) all had >1 effect sizes significantly increasing their throwing velocity by three to four mph compared to the control group.(30, 39, 41) A study incorporating periodized training (Table 3) increased serve velocity by 20 mph compared to the control group.(28) Another study found that collegiate tennis players assigned to a periodized training program (Table 3) increased serve speed by 21 mph compared to the control group; however the control group decreased in their serve speed by 5 mph which increased the change between the two groups.(27) Within the same study, individuals in the non-periodized training group also significantly increased serve speed (14 mph) compared to the control group. The effect size from pre to post improvement in serve velocity was >1 for both the periodized and non-periodized group (Figure 5).(27) Treiber et al.(53) measured serve velocity prior to and following elastic tubing and dumbbell shoulder rotation training in college tennis players (Table 3). Compared to the control group, the experimental group significantly increased serve velocity by nine mph, but the control group dropped in their serve speed by 2 mph, which inflated the change between the two groups.(53) Four studies had moderate effect sizes ranging from .047-.064 with the CI crossing zero.(6, 17, 18, 28, 32) Small effect sizes with CI crossing zero were seen in two articles (Figure 5).(18, 28, 32)

Weighted Ball Training. One study included an overweight baseball training protocol and an underweight baseball training protocol (Table 3).(10) Compared to the control group, individuals training with overweight baseballs significantly improved their throwing speed by 3 mph while individuals in the underweight group improved their throwing speed by 4 mph. The effect sizes from pre to post improvement in ball velocity were > 1 (Figure 6) indicating that both overweight and underweight training are clinically beneficial for improving throwing velocity in high school baseball players**.**

Assessment of Bias: The authors did not detect any publication bias or heterogeneity in this meta-analysis. A funnel plot reveals that the majority of data points within the plot are within the funnel, indicating that bias and between study heterogeneity does not exist (Figure 7).(49) If bias did exist the data points would be congregated outside of the reverse funnel denoting asymmetry and bias by unpublished or inaccessible studies. Orwin's fail-safe N algorithm confirmed that publication bias was no concern in this analysis, as an additional 165 articles would need to be found to lower the effect size to under 0.2. An effect size of 0.2 was chosen as anything ≤ 0.4 can be interpreted as weak.

DISCUSSION

This meta-analysis on ball velocity indicates that multiple forms of training are associated with improvement in throwing and serve velocity. Following the critical appraisal, the overall strength of recommendation of this analysis was considered. The SORT emphasizes patient-oriented outcomes(11); however, in this analysis healthy athletes encompassed the study population instead of patients. Therefore, we modified the patient-oriented outcome to the "individual-oriented" outcome, as ball/serve velocity is an important performance variable to an overhead athlete. Eight of the articles in this analysis are considered high quality evidence scoring ≥6 out of 10 on the PEDro scale(6, 17-19, 27, 38, 39, 53) while the remaining five articles are considered moderate in quality.(10, 28, 30, 32, 41) Although all of the studies failed to report methods of concealment and blinding, the evidence across all the studies is consistent, and over half of the studies are of high quality according to the PEDro scale, indicating the strength of recommendation to be "A". The remainder of this paper will discuss the findings of the studies based on the type of training programs.

Isokinetic strength of the rotator cuff has been investigated in the overhead athlete (3, 4, 13, 40, 55); however, less attention has been put on isokinetic training as a protocol for enhancing functional performance outcomes such as velocity. Previous research done on college tennis players investigated the effectiveness of a concentric and eccentric isokinetic protocol. (12) The results suggested that concentric isokinetic training improved throwing velocity.(12) Our review provides evidence to suggest that both eccentric and concentric isokinetic training protocols are clinically beneficial for improving serve velocity in tennis players. Professionals that have isokinetic equipment available to them may consider implementing such protocols into their training regimes. However in some cases coaches, clinicians, and strength and conditioning professionals may not have such equipment available to them making this type of training unrealistic. Not only is availability of concern, but also the time needed for patient set up, and the implementation of the training protocols for each patient may not be realistic for a large group of athletes. Thus, other approaches to training that are more readily implemented and can be performed by multiple athletes at the same time may be more efficient.

Periodization training has been shown to be an effective intervention, improving strength, power, speed, and functional performance.(27, 28, 36, 51) Periodization resistance training incorporates variation in specific training variables such as volume, intensity, and frequency.(44) It is a frequently discussed topic within weight training, and is thought to eliminate boredom while training, decrease the risk of overtraining, and avoid plateaus via training progression.(28, 44) Previous research has shown that changes in volume and intensity will increase muscular strength in the 1-repetition maximum squat when compared to a protocol incorporating specific volume and intensity parameters.(51) Another study investigated the effects of a periodized multiple-set training regime on upper and lower body muscular strength, power, and speed.(36) The results suggested improvements in muscular performance in untrained but active young adult women.(36) Superior performance gains were found in training protocols ranging from 12 to 24 weeks long.(36, 51) Not only does periodized training increase muscular performance in active adults, but superior functional gains are being seen in an athletic population as well. Although, two different populations these findings imply the importance periodization training has on muscle and sport performance variables. Two studies in this analysis utilized the periodization model of training in female tennis players. Both studies suggest that the greatest velocity changes are found in overhead athletes partaking in a 9 month periodized upper and lower body resistance training protocol.(27, 28) Although not part of this meta-analysis, these two articles also measured velocity changes at 4 months, and interestingly enough the speeds measured at 4 months were very similar to what was measured at the end of the 9-month protocols.(27, 28) The differences in serve velocity between 4 and 9 months ranged between 3-5mph for both the periodized groups and the nonperiodized group, indicating that a 4-month training regime may be as beneficial as a 9-month regime.(27, 28)

Incorporating lumbo-pelvic hip exercises may help to increase ball velocities in the overhead athlete.(35, 50) Fernandez-Fernandez et al.(19) investigated multi-modal training for 6 weeks in a group of elite tennis players. Multi-modal training incorporated both single and multi-planar core exercises, shoulder theraband exercises, and plyometric exercises. An electromagnetic study identified muscle activation patterns during overarm throwing to progress to the arm through the trunk;(25) thus, validating the need for integrated movement patterns when trying to improve velocity. This meta-analysis suggests that training interventions may need to incorporate multimodal training as serve velocity was shown to increase compared to the control group.(19) Multimodal training interventions may be a viable option for overhead athletes as experts suggest these athletes utilize the entire kinetic chain combining multiple anatomical segments and regions in order to generate force in a proximal to distal fashion.(14, 15, 43)

Conflicting results exist when discussing the effectiveness of training with overweight balls in an overhead population.(54) A few studies have shown increases in throwing velocity following overweight ball training in baseball and handball athletes;(8, 10) however, when ball velocity was compared to a control group of baseball players no significant differences were found following overweight ball training. (5, 8, 54) Limited literature is available on overloading interventions in tennis players, although one crossover design study investigated the effects of light and heavy load ball throwing on the tennis serve.(20) Neither of these two interventions in this study were shown to be effective when compared to the control group, and the heavier load intervention negatively effected serve velocity.(20) On the contrary, underweight training has shown more consistent results in baseball players.(54) A recent study on youth baseball players investigated throwing velocity following a 10 week training protocol using lightweight baseballs or regulation-weight baseballs.(56) Throwing lightweight baseballs significantly increased throwing velocity when compared to individuals throwing regulation-weight baseballs. (56) These results are similar to the findings of DeRenne et al. who found lightweight interventions to yield greater improvements in velocity compared to a control group.(10) Despite the clinically irrelevant differences in speed between the two groups, several authors suggest that the underweight group may undergo greater neural adaptations such as higher firing frequencies.(10, 54) Improvements in throwing velocity using lightweight training interventions could also be due to an increase of glenohumeral rotation and velocity over time. Thus resulting in greater external rotation allowing for a larger window of acceleration permitting for more force generation.

The majority of the remaining training regimes in this meta-analysis produced large effect sizes;(6, 10, 30, 39, 41, 53) however, there were several training protocols that did not significantly effect ball/serve velocity.(6, 17, 18, 32, 39) The seven training programs that did not find significant increases in ball/serve velocity lacked a variation in program design and intensity, and frequency periodization. The majority of these protocols only incorporated upper body exercises utilizing therabands and machine-based equipment.(6, 17, 18, 32, 39) Previous research states that in an appropriately functioning kinetic chain the legs and the trunk develop 51-55% of the kinetic energy and force distributed to the hand,(21, 26) while the shoulder has been thought to contribute around 13% of the total kinetic energy.(31) This kinetic chain phenomena is seen in this analysis as interventions utilizing both lower and upper extremity and trunk exercises(6, 10, 19, 27, 28, 41) had larger effect sizes than those employing only upper extremity joint motion with the exception of the isokinetic training intervention in male tennis and baseball players,(30, 38) glenohumeral rotational training in male and female tennis players,(53) and upper extremity weight training in nationally ranked baseball players.(39) Methodological flaws could be responsible for the moderate effect sizes seen in plyometric training studies.(18, 39) Participants in the Newton et al.(39) study had no previous history of strength training while Escamilla utilized young adolescents participating in high school baseball. Both groups of participants may not have had the fundamental strength base needed to partake in explosive activities such as plyometrics. In order to improve power output there needs to be a strength base, which is dependent on many factors with one being muscle fiber size.(23, 52) Smaller muscle fibers result in smaller cross-sectional area of the muscle making it difficult to generate maximal force.

The data presented in this meta-analysis suggests that increasing ball/serve velocity in the overhead athlete can be accomplished in more than one way. The most effective approaches are time and equipment dependent which are variables that should be considered. Periodization training increases serve speed by 17 mph following a 4-month training regime and 20 mph following a 9-month training protocol. However, 4 to 9 months may be an unrealistic window of time for many health care professionals. Thus, shorter 6-week protocols incorporating multi-modal or isokinetic training may be more realistic and convincing to the athlete.

Several areas of future research have been identified from this review that are worthy of investigation. 1) Investigating periodization programs shorter than 9 months in a male athletic population as participants in this review undergoing periodized training were all women tennis players.(27, 28) 2) Investigate the benefits of plyometric training in previously trained overhead athletic population to see if there is stronger training effect in throwing velocity in individuals with resistance training experience as to date the studies have only investigated individuals without previous training experience. 3) Further research is needed to investigate the conflicting results on the use of underweight and overweight baseball training regimes and the effects these interventions have on ball velocity.

This meta-analysis is not without limitations. First, this analysis did not include athletes participating in all overhead sports. The analysis was also very specific with the type of study warranted for this review. For example, there are several different study designs available on this topic, but they did not meet the inclusion criteria of this particular analysis.(20, 22, 37, 42, 56) However, making the inclusion criteria for the level of evidence more stringent only provides the readers with more concrete implications for practice. Only randomized control trials were used in order to draw strong conclusions on causality. Other reliable and valid assessment tools to rate the quality of evidence are available but were not utilized within this analysis. The PEDro scale offers ease of use compared to other assessment measures. Lastly, the pre post correlation values were not calculated for all of the 13 articles due to a lack or reported information from 11 articles. However, the authors were able to calculate the correlation values from two articles(6, 38), which suggested that a correlation value of 0.85 might be reasonable to use.

PRACTICAL APPLICATIONS

This analysis suggests that the most effective way to increase velocity over a 9-month period would be to incorporate periodized resistance training for both the upper and lower extremity. However, an effective 6-week intervention would incorporate multi-modal training. If available, isokinetic equipment incorporating concentric and eccentric external and internal rotation has also been shown to be effective at increasing ball velocity following a 6-week training regime. Coaches, clinicians, and strength and conditioning professionals that utilize one or both of the above training protocols should see not only muscular improvements but functional performance improvements as well.

References

1. http://www.pedro.org.au/english/downloads/pedro-statistics/.
2. Abrams GD, Sheets AL, Andriacchi TP, and Safran MR. Review of tennis serve motion analysis and the biomechanics of three serve types with implications for injury. *Sports Biomech* 10: 378-390, 2011.
3. Alderink GJ and Kuck DJ. lsokinetic Shoulder Strength of High School and College-Aged Pitchers. *J Orthop Sports Phys Ther* 7: 163-172, 1986.
4. Andrade Mdos S, Fleury AM, de Lira CA, Dubas JP, and da Silva AC. Profile of isokinetic eccentric-to-concentric strength ratios of shoulder rotator muscles in elite female team handball players. *J Sports Sci* 28: 743-749, 2010.
5. Barata J. Changes in ball velocity in the handball free throw, induced by two different speed-strength training programs. *Portug J Human Perform* 8: 45-45, 1992.
6. Behringer M, Neuerburg S, Matthews M, and Mester J. Effects of Two Different Resistance-Training Programs on Mean Tennis-Serve Velocity in Adolescents. *Pediatr Exerc Sci* 25: 370-384, 2013.
7. Borenstein D HL, Higgins J, Rothstein H. *Introduction to Meta-Analysis.* West Sussex, United Kingdom: A John Wiley and Sons, Ltd., 2009.
8. Brose DE and Hanson DL. Effects of overload training on velocity and accuracy of throwing. *Res Q* 38: 528-533, 1967.
9. Cohen J. *Stastical Power Analysis for the Behavioral Sciences, 2nd Edition.* Hillsdale: Lawrence Erlbaum, 1988.
10. DeRenne C, Ho K, and Blitzblau A. Effects of weighted implement training on throwing velocity. *J of Appl Sport Sci Res* 4: 16-19, 1990.
11. Ebell MH, Siwek J, Weiss BD, Woolf SH, Susman J, Ewigman B, and Bowman M. Strength of recommendation taxonomy (SORT): a patient-centered approach to grading evidence in the medical literature. *J Am Board Fam Pract* 17: 59-67, 2004.
12. Ellenbecker TS, Davies GJ, and Rowinski MJ. Concentric versus eccentric isokinetic strengthening of the rotator cuff. Objective data versus functional test. *Am J Sports Med* 16: 64-69, 1988.
13. Ellenbecker TS and Mattalino AJ. Concentric isokinetic shoulder internal and external rotation strength in professional baseball pitchers. *J Orthop Sports Phys Ther* 25: 323-328, 1997.
14. Elliott B. Biomechanics and tennis. *Br J Sports Med* 40: 392-396, 2006.
15. Elliott BC. Biomechanics of the serve in tennis. A biomedical perspective. *Sports Med* 6: 285-294, 1988.
16. Ellis, P.D. 2009 http://www.polyu.edu.hk/mm/effectsizefaqs/thresholds_for_interpreting_effect_sizes2.html. Accessed January 26th /2015.
17. Escamilla RF, Fleisig GS, Yamashiro K, Mikla T, Dunning R, Paulos L, and Andrews JR. Effects of Aa 4-week Youth Baseball Conditioning Program on Throwing Veolocity. *J Strength Cond Res* 24: 3247-3254, 2010.

18. Escamilla RF, Ionno M, Demahy S, Fleisig GS, Wilk KE, Yamashiro K, Mikla T, Paulos L, and Andrews JR. Comparison of Three Baseball-Specific Six-Week Training Programs on Throwing Velocity in High School Baseball Players. *J Strenght Cond Res 2012*.
19. Fernandez-Fernandez J, Ellenbecker T, Sanz-Rivas D, Ulbricht A, and Ferrautia L. Effects of a 6-week junior tennis conditioning program on service velocity. *J Sports Sci Med* 12: 232-239, 2013.
20. Ferrauti A and Bastiaens K. Short-term effects of light and heavy load interventions on service velocity and precision in elite young tennis players. *Br J Sports Med* 41: 750-753, 2007.
21. Fleisig G, Nicholls R, Elliott B, and Escamilla R. Kinematics used by world class tennis players to produce high-velocity serves. *Sports Biomech* 2: 51-64, 2003.
22. Gelen E, Dede M, Bingul BM, Bulgan C, and Aydin M. Acute effects of static stretching, dynamic exercises, and high volume upper extremity plyometric activity on tennis serve performance. *J Sports Sci Med* 11: 600-605, 2012.
23. Gollnick PD, Timson BF, Moore RL, and Riedy M. Muscular enlargement and number of fibers in skeletal muscles of rats. *J Appl Physiol Respir Environ Exerc Physiol* 50: 936-943, 1981.
24. Gorostiaga EM, Izquierdo M, Ruesta M, Iribarren J, Gonzalez-Badillo JJ, and Ibanez J. Strength training effects on physical performance and serum hormones in young soccer players. *Eur J Appl Physiol* 91: 698-707, 2004.
25. Hirashima M, Kadota H, Sakurai S, Kudo K, and Ohtsuki T. Sequential muscle activity and its functional role in the upper extremity and trunk during overarm throwing. *J Sports Sci* 20: 301-310, 2002.
26. Kibler WB. Clinical biomechanics of the elbow in tennis: implications for evaluation and diagnosis. . *Med Sci Sports Exerc* 26: 1203-1206, 1994.
27. Kraemer WJ, Hakkinen K, Triplett-Mcbride NT, Fry AC, Koziris LP, Ratamess NA, Bauer JE, Volek JS, McConnell T, Newton RU, Gordon SE, Cummings D, Hauth J, Pullo F, Lynch JM, Fleck SJ, Mazzetti SA, and Knuttgen HG. Physiological changes with periodized resistance training in women tennis players. *Med Sci Sports Exerc* 35: 157-168, 2003.
28. Kraemer WJ, Ratamess N, Fry AC, Triplett-McBride T, Koziris LP, Bauer JA, Lynch JM, and Fleck SJ. Influence of resistance training volume and periodization on physiological and performance adaptations in collegiate women tennis players. *Am J Sports Med* 28: 626-633, 2000.
29. Kraemer WJ and Ratamess NA. Fundamentals of resistance training: progression and exercise prescription. *Med Sci Sports Exerc* 36: 674-688, 2004.
30. Lachowetz T, Evon J, and Pastiglione J. The effect of an upper body strength program on intercollegiate baseball throwing velocity. *J Strength Cond Res* 12: 116-119, 1998.
31. Lintner D, Noonan TJ, and Kibler WB. Injury Patterns and Biomechanics of the Athlete's Shoulder. *Clin Sports Med* 27: 527-551, 2008.
32. Maddigan ME, Behm DG, and Belfry GR. High-Intensity Interval Training for Improvement of Overhand Throwing Velocity. *Int J Athl Ther Train* 19: 36-40, 2014.

33. Maher CG, Sherrington C, Herbert RD, Moseley AM, and Elkins M. Reliability of the PEDro scale for rating quality of randomized controlled trials. *Phys Ther* 83: 713-721, 2003.
34. Marshall RN and Elliott BC. Long-axis rotation: the missing link in proximal-to-distal segmental sequencing. *J Sports Sci* 18: 247-254, 2000.
35. Martin C, Kulpa R, Ropars M, Delamarche P, and Bideau B. Identification of temporal pathomechanical factors during the tennis serve. *Med Sci Sports Exerc* 45: 2113-2119, 2013.
36. Marx JO, Ratamess NA, Nindl BC, Gotshalk LA, Volek JS, Dohi K, Bush JA, Gomez AL, Mazzetti SA, Fleck SJ, Hakkinen K, Newton RU, and Kraemer WJ. Low-volume circuit versus high-volume periodized resistance training in women. *Med Sci Sports Exerc* 33: 635-643, 2001.
37. McEvoy KP and Newton RU. Baseball throwing speed and base running speed: the effects of ballistic resistance training. *J Strength Cond Res* 12: 216-221, 1998.
38. Mont MA, Cohen DB, Campbell KR, Gravare K, and Mathur SK. Isokinetic concentric versus eccentric training of shoulder rotators with functional evaluation of performance enhancement in elite tennis players. *Am J Sports Med* 22: 513-517, 1994.
39. Newton RU and McEvoy KP. Baseball throwing velocity: a comparison of medicine ball training and weight training. *J Strength Cond Res* 8: 198-203, 1994.
40. Ng LR and Kramer JS. Shoulder rotator torques in female tennis and nontennis players. *J Orthop Sports Phys Ther* 13: 40-46, 1991.
41. Potteiger JA, Williford HN, Blessing DL, and Smidt J. Effect of two training methods on improving baseball performance variables. *J Appl Sport Sci Res* 6: 2-6, 1992.
42. Prokopy MP, Ingersoll CD, Nordenschild E, Katch FI, Gaesser GA, and Weltman A. Closed-kinetic chain upper-body training improves throwing performance of NCAA Division I softball players. *J Strength Cond Res* 22: 1790-1798, 2008.
43. Putnam CA. Sequential motions of body segments in striking and throwing skills: Description and explanations. *J Biomech* 26: 125-135, 1993.
44. Rhea MR and Alderman BL. A meta-analysis of periodized versus nonperiodized strength and power training programs. *Res Q Exerc Sport* 75: 413-422, 2004.
45. Rhea MR, Ball SD, Phillips WT, and Burkett LN. A comparison of linear and daily undulating periodized programs with equated volume and intensity for strength. *J Strength Cond Res* 16: 250-255, 2002.
46. Roig M, O'Brien K, Kirk G, Murray R, McKinnon P, Shadgan B, and Reid WD. The effects of eccentric versus concentric resistance training on muscle strength and mass in healthy adults: a systematic review with meta-analysis. *Br J Sports Med* 43: 556-568, 2009.
47. Rothstein H SA, Borenstien M. *Publication Bias in Meta-Analysis: Prevention, Assessment and Adjustments.* John Wiley & Sons, Ltd., 2005.

48. Sheppard JM, Cronin JB, Gabbett TJ, McGuigan MR, Etxebarria N, and Newton RU. Relative importance of strength, power, and anthropometric measures to jump performance of elite volleyball players. *J Strength Cond Res* 22: 758-765, 2008.
49. Sterne JA, Sutton AJ, Ioannidis JP, Terrin N, Jones DR, Lau J, Carpenter J, Rucker G, Harbord RM, Schmid CH, Tetzlaff J, Deeks JJ, Peters J, Macaskill P, Schwarzer G, Duval S, Altman DG, Moher D, and Higgins JP. Recommendations for examining and interpreting funnel plot asymmetry in meta-analyses of randomised controlled trials. *BMJ* 343: d4002, 2011.
50. Stodden DF, Campbell BM, and Moyer TM. Comparison of trunk kinematics in trunk training exercises and throwing. *J Strength Cond Res* 22: 112-118, 2008.
51. Stone MH, Potteiger JA, Pierce KC, Proulx CM, O'Bryant HS, Johnson RL, and Stone ME. Comparison of the effects of three different weight-training programs on the one repetition maximum squat. *J Strength Cond Res* 14: 332-337, 2000.
52. Thorstensson A, Hulten B, von Dobeln W, and Karlsson J. Effect of strength training on enzyme activities and fibre characteristics in human skeletal muscle. *Acta Physiol Scand* 96: 392-398, 1976.
53. Treiber FA, Lott J, Duncan J, Slavens G, and Davis H. Effects of theraband and lightweight dumbbell training on shoulder rotation torque and serve performance in college tennis players. *Am J Sports Med* 26: 510-515, 1998.
54. Van Den Tillaar R. Effect of different training programs on the velocity of overarm throwing: a brief review. *J Strength Cond Res* 18: 388-396, 2004.
55. Wang HK, Macfarlane A, and Cochrane T. Isokinetic performance and shoulder mobility in elite volleyball athletes from the United Kingdom. *Br J Sports Med* 34: 39-43, 2000.
56. Wen-Wen Y, Ya-Chen LIU, Lee-Chang LU, Hsiao-Yun C, Chou PP-H, and Chiang LIU. Performance Enhancement Among Adolescent Players After 10 Weeks of Pitching Training with Appropriate Baseball Weights. *J Strength Cond Res* 27: 3245-3251, 2013.
57. Wilk KE, Meister K, and Andrews JR. Current concepts in the rehabilitation of the overhead throwing athlete. *Am J Sports Med* 30: 136-151, 2002.

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Figure Legend

Figure 1: Flow chart for selecting articles to be included into the Meta-Analysis

Figure 2: Hedges's g effect sizes with 95% Confidence Intervals for Improvements in ball velocity following an isokinetic training intervention. Interventions that Favours B support the intervention group. Interventions that Favours A support the control group.

Figure 3. Hedges's g effect sizes with 95% Confidence Intervals for Improvements in ball velocity following a multimodal training intervention. Interventions that Favours B support the intervention group. Interventions that Favours A support the control group.

Figure 4. Hedges's g effect sizes with 95% Confidence Intervals for Improvements in ball velcoity following plyometic training interventions. Interventions that Favours B support the intervention group. Interventions that Favours A support the control group.

Figure 5. Hedges's g effect sizes with 95% Confidence Intervals for Improvements in ball velocity following resistance training interventions. Interventions that Favours B support the intervention group. Interventions that Favours A support the control group.

Figure 6. Hedges's g effect sizes with 95% Confidence Intervals for Improvements in ball velcoity following weighted ball training. Interventions that Favours B support the intervention group. Interventions that Favours A support the control group.

Figure 7. Funnel plot with Hedges's g plotted against the standard error. Circles indicate studies within analysis.

Table 1. Systematic Search Strategy with number of studies identified for each key term/s

Step	Strategy	PubMed	SportDiscus	MEDLINE	CINAHL
#29	S7 AND S18 AND S28	226	155	147	76
#28	S19 OR S20 OR S21 OR S22 OR S23 OR S24 OR S 25 OR S26 OR S27	20,450	2,223	21,330	588
#27	overhead velocity	64	9	9	3
#26	pitch velocity	505	50	121	14
#25	serve velocity	1,055	57	52	14
#24	throwing speed	173	118	46	11
#23	throwing velocity	255	195	97	51
#22	ball acceleration	268	46	36	6
#21	ball velocity	753	468	272	108
#20	ball speed	859	781	293	112
#19	(MH "Acceleration")	8,043	0	7,80	0
#18	S8 OR S9 OR S10 OR S11 OR S12 OR S13 OR S 14 OR S15 OR S16 OR S17	599,131	218,961	527,207	172,543
#17	exercise	272,039	166,312	239,884	75,915
#16	exercise training	60,648	10,905	14,556	3,692
#15	rehabilitation	355,742	55,962	268,412	95,002
#14	plyometric training	347	825	233	184
#13	overload training	1,195	395	152	46
#12	weight training	16,841	13,940	2,374	983
#11	overhead training	431	36	35	15
#10	(MH "Recreation Therapy")	34	0	34	0
#9	(MH "Athletic Performance")	37,185	0	4,068	2,549
#8	(MH "Exercise+")	114,175	5	114,075	50,028
#7	S1 OR S2 OR S3 OR S4 OR S5 OR S6	11,577	108,300	11,526	7,614
#6	throwing athlete*	362	484	185	92
#5	overhead athlete*	251	337	393	241
#4	softball	2,401	4,630	295	174
#3	baseball	2,315	66,858	2,312	1,308
#2	tennis	5,852	38,872	5,837	1,538
#1	(MH "Athletes")	3,254	1	3,243	4,769

Table 2. Validity Scores for Randomized Control Trials

PEDro Scores	1	2	3	4	5	6	7	8	9	10	11	Total Score
Fernandez-Fernandez (17)	¶	¶		¶				¶	¶	¶	¶	6/10
Behringer (6)	¶	¶		¶				¶	¶	¶	¶	6/10
Kraemer (25)	¶	¶		¶				¶	¶	¶	¶	6/10
Treiber(50)	¶	¶		¶				¶	¶	¶	¶	6/10
Kraemer(26)	¶	¶		¶				¶	¶		¶	5/10
Mont (35)	¶	¶		¶				¶	¶	¶	¶	6/10
Newton (36)		¶		¶				¶	¶	¶	¶	6/10
Escamilla (16)	¶	¶		¶				¶	¶	¶	¶	6/10
Escamilla (15)	¶	¶		¶				¶	¶	¶	¶	6/10
Potteiger (38)		¶						¶	¶	¶	¶	5/10
DeRenne (9)		¶						¶	¶	¶	¶	5/10
Maddigan(30)		¶						¶	¶	¶	¶	5/10
Lachowetz(28)		¶						¶	¶	¶	¶	5/10

¶ = criteria met

The PEDro is scored on a ten-point scale. Question 1 is not included into the total score

Table 3. Summary of Articles Included in the Analysis

Study	Population	Intervention	Outcome
Mont(35)	30 male tennis players 33 yrs (range 18-42)	**Eccentric internal & external rotator training:** n=8; isokinetic dynamometer **Concentric internal & external rotator training:** n=9; isokinetic dynamometer **Control Group:** n=13	Serve velocity measured with radar gun in mph Radar gun at opposite service line Mean of 4 serves
Fernandez-Fernandez (17)	30 nationally ranked elite male tennis players split into 2 groups 14.2±0.5 yrs	**Experimental Group (EG):** n=15; regular tennis activity plus multimodal training **Control Group (CG):** n= 15; regular tennis activity only	Serve Velocity measured with radar gun in km/h Radar gun positioned 4 m behind the server aligned with height of ball contact Highest speed from 8 serves
Behringer (6)	36 youth male tennis players 15.03±1.64 yrs	**Plyometric Group (PG):** n=10; regular tennis activity plus upper and lower body plyometric training **Resistance Group (RG):** n=13; regular tennis activity plus UE, LE, and trunk machine based exercises **Control Group (CG):** n=10; regular tennis activity	Serve Velocity measured with radar gun in km/h Radar gun positioned 20 cm behind the net in the center of the court Mean of 20 serves
Escamilla (16)	68 high school baseball players	**TT Group:** n=14; UE resistance training with	Throwing velocity measured with a radar gun in $m \cdot s^{-1}$

	Throwers ten group (TT) 14.2±1.1 yrs Keiser pneumatic (KP) group 15.4±1.3 yrs Plyometric Group (PG) 15.8±0.8 yrs Control Group (CG) 15.8±1.4 yrs	theraband, free weight, & body weight plus summer league baseball **KP Group:** n=15; UE resistance training with pulley system plus summer league baseball **PG:** n=14; UE with some trunk plyometric exercises plus summer league baseball **CG:** n=15; summer league baseball	Subjects threw from a distance of (22.9 m). Radar gun position next to the subject Peak velocity of 1st 5 ball thrown through a circular target zone **Note: all subjects were allowed a 2 step throw**
Newton (36)	24 baseball players recruited from national league 18.6±1.9 yrs	**Medicine ball training program (MB):** n=8 exercises included explosive two-hand chest pass and two-hand overhead throw with both feet held in place plus normal baseball activity **Weight training program (WT):** n=8; exercises included barbell bench press and barbell pullover plus normal baseball activity **Control group:** n=8; normal baseball routine	Throwing velocity measured with a radar gun in $m \cdot s^{-1}$ Subjects threw from pitcher's mound to home plate (18.44 m). Radar gun position 2 m behind home plate and held at chest height First 5 balls thrown through the strike zone
Escamilla (15)	34 youth baseball players 12.5±1.5 yrs	**Resistance Group:** n=17; 17 UE exercises performed with elastic tubing and long toss drills plus normal physical	Throwing velocity measured with a radar gun in $m \cdot s^{-1}$ Subjects threw from a

		and school activity other than baseball **Control Group:** n=17; Normal physical and school activity other than baseball	distance of (13.7 m). Radar gun position next to the subject 5 throws were performed and recorded
Kraemer (26)	24 collegiate women tennis players Periodized Training Group (PG): 19.0±0.9 yrs Single-Set Training Group: 18.9±1.2 yrs Control Group 19.8±1.7 yrs	**Periodized training group (PG):** n=8; regular tennis activity and UE, LE, and trunk resistance training (see parameters for specifics) **Single-set training group (SSTG):** n=8; regular tennis activity and UE, LE, and trunk resistance training (see parameters for specifics) **Control group:** n=8; regular tennis activity	Serve velocity measured with 2 panasonic video cameras in $m \cdot s^{-1}$ The 2 Cameras faced each other on the baseline of the testing court. Mean of 3 serves
Kraemer (25)	27 women collegiate tennis players Periodized Resistance Training (P): 19.2±1.1 yrs Nonperiodized Resistance Training Group (NV): 18.6±1.3 yrs Control Group (CG): 19.3±1.6 yrs	**P:** n=9; regular tennis activity plus upper and lower body resistance training (see parameters for specifics) **NV:** n=10; regular tennis activity plus upper and lower body resistance training (see parameters for specifics) **CG:** n=8; regular tennis activity	Serve velocity measured with 2 Panasonic video cameras in $m \cdot s^{-1}$ The 2 Cameras faced each other on the baseline of the testing court. Mean of the top 3 serves out of 10

Lachowetz (28)	22 college baseball players range 18-22 yrs	**Training group:** n=12; 11 UE strength training with free weights, cybex, nautilus, and cybex pulley system plus throwing program **Control group:** n=10; throwing program only	Throwing velocity measured with radar gun in mph Subjects threw from pitcher's mound to home plate (18.44 m). Radar gun position 2 m behind home plate and held at chest height Maximum of 5 throws
Maddigan (30)	13 female college softball players 21.9±2.6 yrs	**Experimental group:** n=7; endurance shoulder training in one position (throwing position) using a elastic band with the stance foot stationary **Control group:** n=6; no training	Throwing velocity measured with radar gun in km/h Throw into net that was positioned 4.5m from the thrower Mean of 3 throws
Potteiger (38)	21 collegiate baseball players	**Resistance Group:** n=10; 3 LE exercises, 5 UE exercises, and sprints plus normal baseball activity **Aerobic Dance (Control group):** n=11; dance training	Throwing velocity measured with a radar gun mph Mean of 4 throws
Treiber (50)	22 collegiate tennis players Male: n=12 Female: n=13	**Shoulder Resistance Training Group (SRG):** n=11; regular tennis activity, shoulder theraband exercises,	Serve velocity measured with a radar gun in mph Radar gun positioned 1.8 m

	21.2 yrs (range 18-29 yrs)	and shoulder dumbbell training **Control Group (CG):** n=11; regular tennis activity	behind the server and at equal height to the center of the racket head during ball contact Mean of 8 serves
DeRenne (9)	30 high school baseball players range 16-18 yrs	**Overweight Implement Training Group (OITG):** 10 minute controlled lesson plan of 50 pitches (see parameters) **Under weighted implement training group (UITG):** 10 minute controlled lesson plan of 50 pitches (see parameters) **Control Group:** 50 pitches with 5 oz. baseball	Throwing velocity measured with electromagnetic radiation radar in mph Radar gun located behind the catcher Mean of 10 consecutive pitches

Abbreviations: Years=yrs, meters=m, kilometers per hours = km/h, meters per second = $m \cdot s^{-1}$, miles per hour = mph, Upper extremity = UE, Lower extremity = LE Months=mos, approximately = “≈”, ounce = oz.

Table 4. Study Parameters for Each Intervention Included in the Analysis

Study	Group 1 Intervention Parameters	Group 2 Intervention Parameters	Control Group
Mont (35)	3 x a wk for 6 wks Eccentric and Concentric Training: • 8x10 • Training velocity as follows: 90,120,150,180,180,120,90°/sec	NA	No training

Fernandez-Fernandez (17)	Regular tennis Activity: 8-10 hrs a wk
	Experimental Group: 3 x a wk for 6 wks
	• Core exercises:
	  o 2/3x20 reps
	• Shoulder elastic tubing:
	  o 2x20 reps
	  o 45 sec. rest between sets
	• Medicine Ball training:
	  o 2x8 reps
	  o 2kg ball
	  o 1 min. rest between sets
		NA	Regular tennis activity

Behringer (6)	Regular tennis activity: 2 x a wk ≈ 1 to 1.5 hrs a session
	Plyometric Group: 2 x a wk for 8 wks
	• Wk 1: 2x20 reps
	• Wk 2: 2/3x20 reps
	• Wk 3-4: 3x10/12 reps
	• Wk 4-5: 3x12/15 reps
	• Wk 6-7: 4x10/12 reps
	• Wk 7-8; 4x12/15 reps
	  o 1 min. rest between sets
		Resistance Group: 2 x a wk for 8 wks
		• Wk 1-2: 65% 1 RM; 2x15 reps
		• Wk 3-8: 85% 1 RM; 2x15 reps
		  o I min. rest between sets
			Regular tennis activity

Escamilla (16)	3 x a wk for 6 wks Throwers ten and Keiser pneumatic groups: • Wks 1 & 4: 2x12 RM • Wks 2 & 5: 2x10 RM • Wks 3 & 6: 2x6 RM ○ 1-2 min. rest between sets	Plyometric Group: • Wks 1 & 4: 2x10 • Wks 2 & 5: 2x8 • Wks 3 & 6: 2x6 ○ 1-2 min. rest between sets Load = between 1.8-3.6 kg	Summer league baseball
Newton (36)	2 x a wk for 8 wks Medicine ball group: • Wk 1-4: 3x8 reps • Wk 4-8: 3 x10 reps ○ 3 min. rest between sets ○ Load = 3kg	Weight Training group: • Wk 1-4: 3x8-10 RM • Wk 4-8: 3x6-8 RM 3 min. rest between sets	Normal baseball routine
Escamilla (15)	2 x a wk for 4 wks Resistance Group: • 1x25 reps (1:2 tempo) • Long toss (no step aloud) ○ 5 min warm up at 50ft ○ 5 min throws at 60ft ○ 5 min throws at 75ft ○ 5 min throws at 100ft • Long toss (1 step aloud) ○ 5 min throws at 100ft ○ 2 min throws at 125ft	NA	Normal physical and school activity other than baseball
Kraemer (26)	2/3 x a wk for 9 mos: same exercises different loads (2 times a week if matches scheduled) Periodized Training Group: 2/4 sets and reps varied each wk • 4-6 RM	Single-Set Training Group: • 1 set 8-10 RM ○ 1-2 min rest between sets	Regular tennis activity

	○ 2-3 min. rest between sets • 8-10 RM ○ 1-2 min. rest between sets • 12-15 RM ○ 1-2 min. rest between sets		
Kraemer (25)	3 x a wk for 9 mos: same exercises different loads Periodized Group: • Monday: 2/3 x 4-6 RM • Wednesday 2/3 x 8-10 RM • Friday 2/3 x 12-15 RM	Nonperiodized Group: Monday, Wednesday, Friday: 2/3 x 8-10 RM	Regular tennis activity
Lachowetz (28)	4 x a wk for 8 wks Training Group: • Wk 1: 3x10 RM • Wk 2-8: 3x10 RM followed by additional 5 reps ○ 1 min rest between sets	NA	Throwing program only
Maddigan (30)	3 x a wk for 3 wks Experimental Group: • 5x20 reps ○ 4.5 min. rest between sets • Wk 1: green band • Wk 2: blue band • Wk 3: black band	NA	No training
Potteiger (38)	4 x a wk for 10 wks Resistance Group: • 3x12 reps ○ 100% of 12 RM	NA	Aerobic dance training

	• Sprint Training
	  ○ 2, 10 sec. sprints at 50% of maximum
	  ○ 3, 10 sec. sprints at 100% maximum
	    ▪ 30 sec. rest between each sprint		

Treiber (50)	3 x a wk for 4 wks
	Shoulder Resistance Training Group
	• Elastic Tubing (1:1 tempo): 2x20 reps
	• Elastic Tubing (Quick speed): 2x20
	  ○ 30-40 sec. rest between sets
	• Dumbbells: 4x20 (1:1 tempo); Load 2.1 lbs. (range 1-4 lbs)
	  ○ 30-40 sec. rest between sets
		NA	Regular tennis activity

DeRenne (9)	3 x a wk for 10 wks
	Overweight Implement Training Group:
	• Wk 1-2: 5 oz.
	• Wk 3-4: 5 ¼ oz.
	• Wk 5-6: 5 ½ oz.
	• Wk 7-8: 5 ¾ oz.
	• Wk 9-10: 6 oz.
	  ○ 20 throws with standard baseball
	  ○ 20 throws with overweight baseball
	  10 throws with standard baseball
		Underweight Implement Training Group:
		• Wk 1-2: 5 oz.
		• Wk 3-4: 4 ¾ oz.
		• Wk 5-6: 4 ½ oz.
		• Wk 7-8: 4 ¼ oz.
		• Wk 9-10: 4 oz.
		  ○ 20 throws with standard baseball
		  ○ 20 throws with underweight baseball
		  ○ 10 throws with standard baseball
			50 pitches with 5 oz. baseball

Not all studies had two experimental groups; therefore, not applicable (NA) was placed in column 3 for studies only presenting with one experimental group.
Abbreviations: Hours=hrs, week=wk, times=x, repetitions=reps, second=sec, minute=min, approximately = "≈", repetition maximum=RM, pounds = lbs., Kilograms = kg.

Figure 1

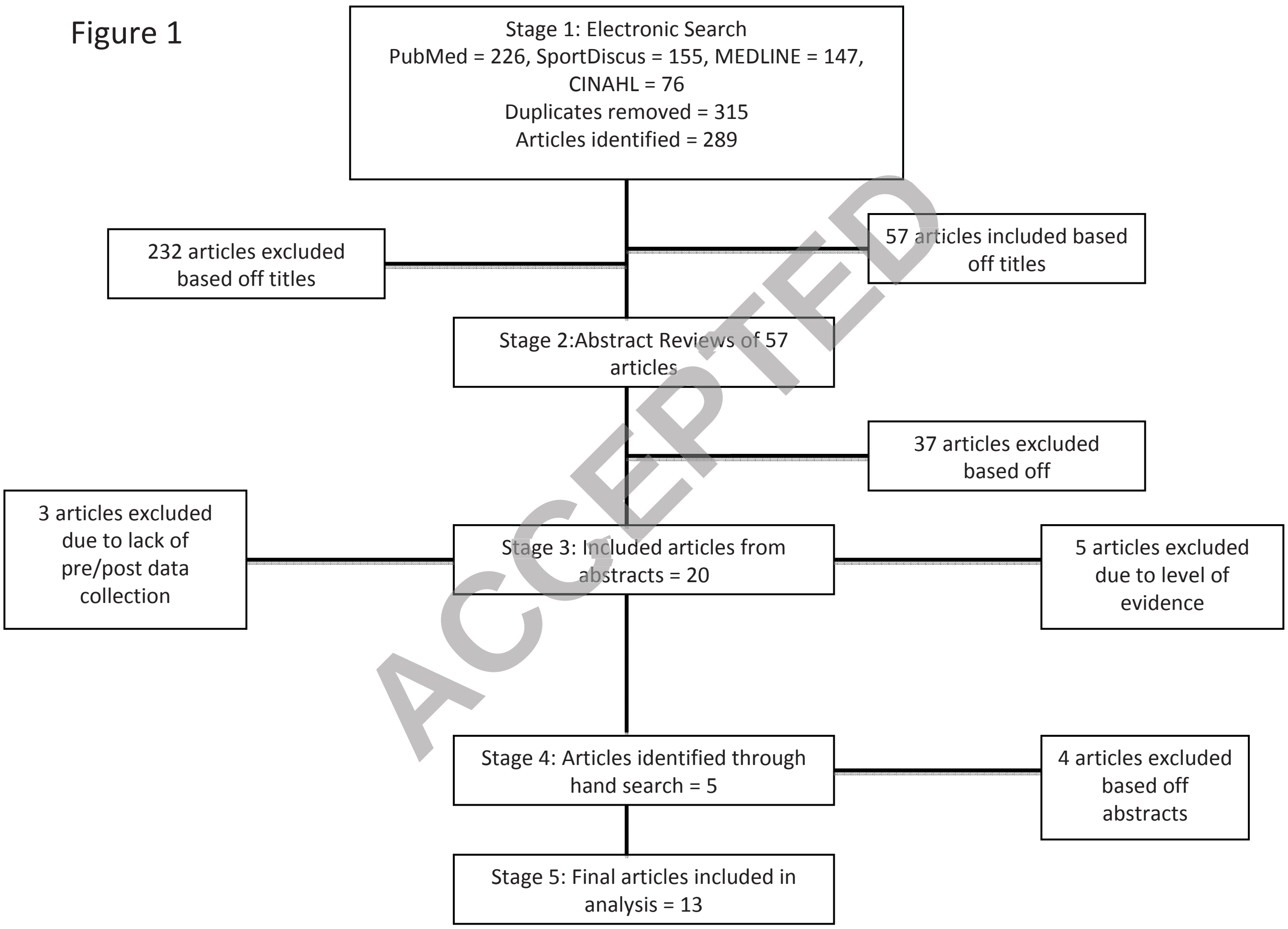

Stage 1: Electronic Search
PubMed = 226, SportDiscus = 155, MEDLINE = 147, CINAHL = 76
Duplicates removed = 315
Articles identified = 289
232 articles excluded based off titles
57 articles included based off titles
Stage 2:Abstract Reviews of 57 articles
37 articles excluded based off
3 articles excluded due to lack of pre/post data collection
Stage 3: Included articles from abstracts = 20
5 articles excluded due to level of evidence
Stage 4: Articles identified through hand search = 5
4 articles excluded based off abstracts
Stage 5: Final articles included in analysis = 13

Figure 2

Study name	Subgroup within study	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
		Statistics for each study						
Mont et al.	concentric isokinetics	1.917	0.507	0.258	0.922	2.912	3.777	0.000
Mont et al.	eccentric isokinetics	1.430	0.485	0.235	0.480	2.379	2.951	0.003
		1.662	0.350	0.123	0.975	2.349	4.743	0.000

Hedges's g and 95% CI

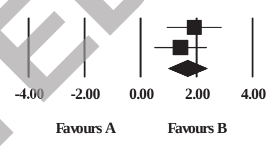


Figure 3

Study name	Subgroup within study	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Fernandez-Fernandez et al.	multimodal	1.095	0.382	0.146	0.345	1.844	2.863	0.004
		1.095	0.382	0.146	0.345	1.844	2.863	0.004

Hedges's g and 95% CI

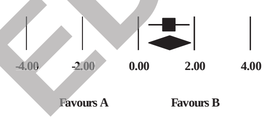


Figure 4

Study name	Subgroup within study	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
		Statistics for each study						
Behringer et al.	plyometric	1.093	0.462	0.213	0.188	1.998	2.366	0.018
Newton et al.	plyometric	0.579	0.484	0.234	-0.369	1.527	1.198	0.231
Escamilla et al 2012	plyometric	0.534	0.368	0.135	-0.187	1.255	1.452	0.146
		0.706	0.247	0.061	0.222	1.191	2.856	0.004

Figure 5

Study name	Subgroup within study	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Behringer et al.	resistance	0.494	0.412	0.170	-0.313	1.301	1.199	0.230
Kraemer et al. 2003	nonperiodized resistance	2.961	0.669	0.448	1.649	4.272	4.426	0.000
Kraemer et al. 2003	periodizied resistance	3.445	0.749	0.562	1.976	4.914	4.596	0.000
Treiber et al.	resistance	1.055	0.440	0.194	0.192	1.917	2.397	0.017
Kraemer et al. 2000	periodizied resistance	3.425	0.768	0.590	1.920	4.931	4.459	0.000
Kraemer et al. 2000	singleset resistance training	0.367	0.477	0.228	-0.569	1.302	0.768	0.442
Newton et al.	resistance	1.098	0.511	0.261	0.097	2.100	2.149	0.032
Escamilla et al. 2012	keiser pneumatic resistance	0.349	0.358	0.128	-0.353	1.051	0.974	0.330
Escamilla et al. 2012	throwers ten resistance	0.475	0.367	0.134	-0.243	1.193	1.296	0.195
Escamilla et al 2010	resistance	0.642	0.344	0.118	-0.032	1.316	1.868	0.062
Maddigan et al.	resistance	0.481	0.526	0.277	-0.550	1.512	0.914	0.361
Potteiger et al.	resistance	1.150	0.455	0.207	0.258	2.043	2.526	0.012
Lachowetz et al.	resistance	1.387	0.498	0.248	0.411	2.362	2.787	0.005
		1.163	0.242	0.059	0.689	1.638	4.808	0.000

Hedges's g and 95% CI

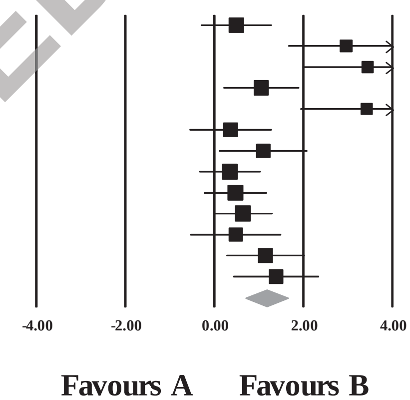


Figure 6

Study name	Subgroup within study	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
DeRenne et al.	overweight ball training	1.156	0.466	0.217	0.243	2.069	2.483	0.013
DeRenne et al.	underweighted ball training	1.629	0.500	0.250	0.649	2.608	3.259	0.001
		1.376	0.341	0.116	0.708	2.044	4.038	0.000

Statistics for each study

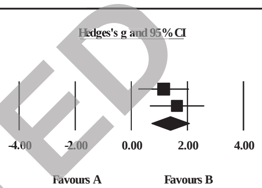
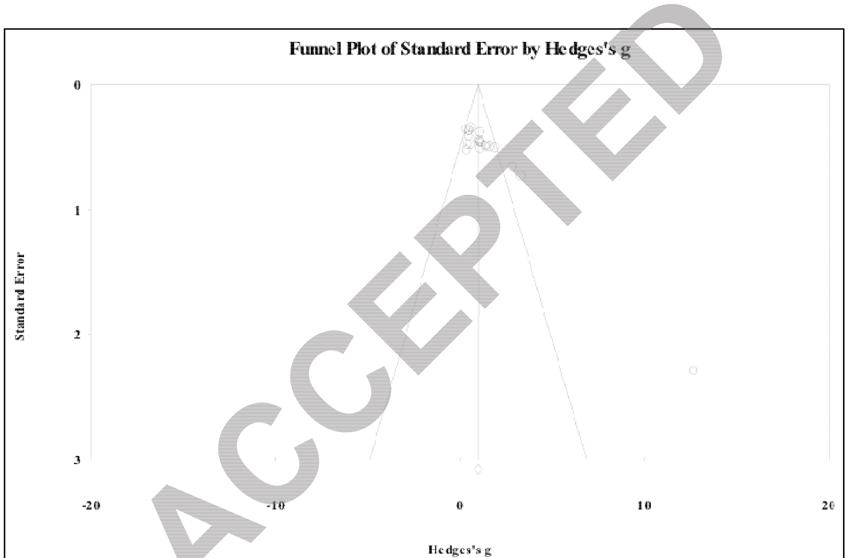


Figure 7


Funnel Plot of Standard Error by Hedges's g
Standard Error
0
1
2
3
-20
-10
0
10
20
Hedges's g