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

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Abstract

Myers, NL, Sciascia, AD, Westgate, PM, Kibler, WB, and Uhl, TL. Increasing ball velocity in the overhead athlete: a meta-analysis of randomized controlled trials. *J Strength Cond Res* 29(10): 2964–2979, 2015—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 mean and *SD*s of both pretest and posttest ball velocities in both the experimental and the control groups. The outcome of interest was ball/serve velocity in baseball, tennis, or softball athletes. Level 2 evidence or higher was investigated to determine the effect different training interventions had on velocity. Pretest and posttest data were extracted to calculate Hedges's *g* effect sizes with 95% confidence intervals (CIs). Methodological qualities of the final 13 articles within the analysis were assessed using the Physiotherapy Evidence Database 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, multimodal training, and periodization training are clinically beneficial at increasing velocity in the overhead athlete over different windows of time.

Key Words training interventions, speed, performance, tennis, baseball

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, whereas tennis players strive to improve serve velocity 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 to prescribe an appropriate resistance training program aimed at increasing velocity.

Resistance training has grown in popularity over the past 30 years (28). A successful resistance program should incorporate proper exercise prescription and appropriate methods of progression (28). 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

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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: first, to update the current body of literature on interventions that improve ball and serve velocity in the overhead athlete, and second, 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 by the search strategy. The search strategy was conducted in 5 stages (Figure 1). Stage 1 consisted of an Internet search through 4 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 because of 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 to perform an exhaustive search and identify any other potential articles. The 2 independent reviewers were in total agreement on the final 13 articles included in this 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

*Captures both singular and plural form of the search term.

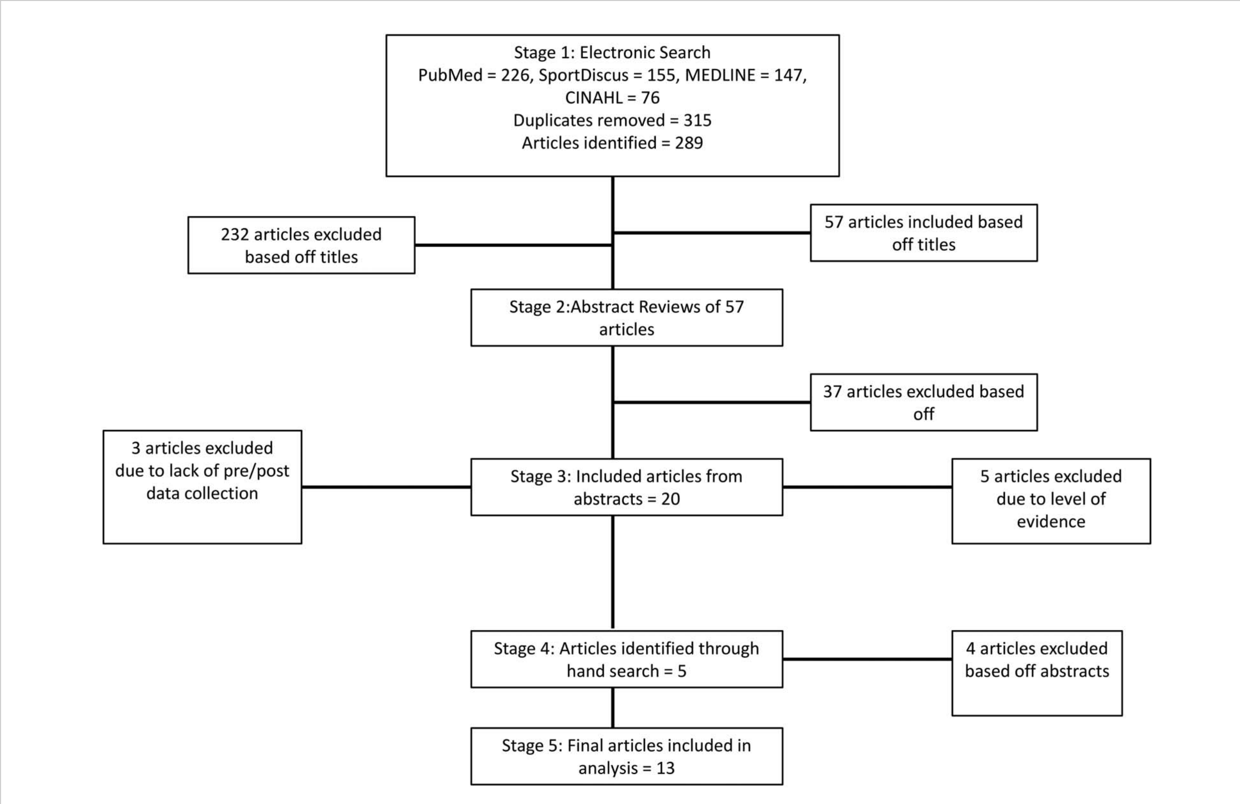

Figure 1. Flow chart for selecting articles to be included into the meta-analysis.

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

- Articles were in the English language and published between January 1970 and February 2014.
- Abstracts were available upon literature search.
- The authors examined the effectiveness of an intervention on ball or serve velocity.
- The authors compared interventions with a control group using a randomized control trial design.
- Prospective cohort designs assessed ball/serve velocity as the final outcome.
- The authors presented both pretest and posttest ball/serve velocity mean and *SD*s or *SE*. This information was necessary to calculate effect sizes for the meta-analysis.
- 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 mean and *SD*s 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) 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 (NLM) extracted both pretest and posttest mean and *SD*s. 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 mean and *SD* (27,29,32), in which case a hand measurement was taken using a Digimatic Caliper (Mitutoyo, Kawasaki, Japan) measuring the graph in millimeters. A ratio was then established depending on the increments presented on the y-axis of the charts. Mean 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 10-point scale, with 10 indicating a perfect score (question 1 does not count toward 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 2 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 mean and *SD*s 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, USA). Using these statistics, the CMA software can compute the sample mean 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, 2 articles provided pertinent information needed to calculate the pre-post correlation (6,38). Both these articles had high correlation values ranging between 0.86 and 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 2 articles (6,38).

Seven of the 13 articles had more than 1 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 article 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 that 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 because of the simple fact that research that does not approach or obtain statistical significance goes unpublished. In this study, bias was evaluated using 2 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 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

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 (19)	✓	✓		✓				✓	✓	✓	✓	6/10
Behringer et al. (6)	✓	✓		✓				✓	✓	✓	✓	6/10
Kraemer (27)	✓	✓		✓				✓	✓	✓	✓	6/10
Treiber (53)	✓	✓		✓				✓	✓	✓	✓	6/10
Kraemer (29)	✓	✓		✓				✓	✓		✓	5/10
Mont (38)	✓	✓		✓				✓	✓	✓	✓	6/10
Newton (39)		✓		✓				✓	✓	✓	✓	6/10
Escamilla (18)	✓	✓		✓				✓	✓	✓	✓	6/10
Escamilla (17)	✓	✓		✓				✓	✓	✓	✓	6/10
Potteiger (41)		✓						✓	✓	✓	✓	5/10
DeRenne (10)		✓						✓	✓	✓	✓	5/10
Maddigan (32)		✓						✓	✓	✓	✓	5/10
Lachowetz (30)		✓						✓	✓	✓	✓	5/10

*The PEDro is scored on a 10-point scale. Question 1 is not included into the total score. "✓" indicates criteria met.

Table 3. Summary of articles included in the analysis.*

Study	Population	Intervention	Outcome
Mont (38)	30 male tennis players	Eccentric internal and external rotator training: $n = 8$; isokinetic dynamometer	Serve velocity measured with radar gun in miles per hour
	33 y (range, 18–42 y)	Concentric internal and external rotator training: $n = 9$; isokinetic dynamometer	Radar gun at opposite service line
		CG: $n = 13$	Mean of 4 serves
Fernandez-Fernandez (19)	30 nationally ranked elite male tennis players split into 2 groups	EG: $n = 15$; regular tennis activity plus multimodal training	Serve velocity measured with radar gun in kilometer per hour
	14.2 ± 0.5 y	CG: $n = 15$; regular tennis activity only	Radar gun positioned 4 m behind the server aligned with height of ball contact Highest speed from 8 serves
Behringer et al. (6)	36 youth male tennis players	PG: $n = 10$; regular tennis activity plus upper- and lower-body plyometric training	Serve velocity measured with radar gun in kilometer per hour
	15.03 ± 1.64 y	RG: $n = 13$; regular tennis activity plus UE, LE, and trunk machine-based exercises	Radar gun positioned 20 cm behind the net in the center of the court
		CG: $n = 10$; regular tennis activity	Mean of 20 serves
Escamilla (18)	68 high school baseball players	TT group: $n = 14$; UE resistance training with theraband, free weight, and body weight plus summer league baseball	Throwing velocity measured with a radar gun in meter per second
	TT group: 14.2 ± 1.1 y	KP group: $n = 15$; UE resistance training with pulley system plus summer league baseball	Subjects threw from a distance of 22.9 m
	KP group: 15.4 ± 1.3 y	PG: $n = 14$; UE with some trunk plyometric exercises plus summer league baseball	Radar gun position next to the subject
	PG: 15.8 ± 0.8 y	CG: $n = 15$; summer league baseball	Peak velocity of first 5 ball thrown through a circular target zone
	CG: 15.8 ± 1.4 y		Note: all subjects were allowed a 2-step throw
Newton (39)	24 baseball players recruited from national league	MB: $n = 8$ exercises included explosive 2-hand chest pass and 2-hand overhead throw with both feet held in place plus normal baseball activity	Throwing velocity measured with a radar gun in meter per second
	18.6 ± 1.9 y	WT: $n = 8$; exercises included barbell bench press and barbell pullover plus normal baseball activity	Subjects threw from pitcher's mound to home plate (18.44 m)
		CG: $n = 8$; normal baseball routine	Radar gun position 2 m behind home plate and held at chest height First 5 balls thrown through the strike zone
Escamilla (17)	34 youth baseball players	RG: $n = 17$; 17 UE exercises performed with elastic tubing and long toss drills plus normal physical and school activity other than baseball	Throwing velocity measured with a radar gun in meter per second
	12.5 ± 1.5 y	CG: $n = 17$; normal physical and school activity other than baseball	Subjects threw from a distance of 13.7 m Radar gun position next to the subject 5 throws were performed and recorded

Kraemer (29)	24 collegiate women tennis players	Periodized training group (P): $n = 8$; regular tennis activity and UE, LE, and trunk resistance training (see parameters for specifics)	Serve velocity measured with 2 Panasonic video cameras in meter per second
	Periodized training group (PG): 19.0 ± 0.9 y	SSTG: $n = 8$; regular tennis activity and UE, LE, and trunk resistance training (see parameters for specifics)	The 2 cameras faced each other on the baseline of the testing court
	SSTG: 18.9 ± 1.2 y CG: 19.8 ± 1.7 y	CG: $n = 8$; regular tennis activity	Mean of 3 serves
Kraemer (27)	27 women collegiate tennis players	P: $n = 9$; regular tennis activity plus upper- and lower-body resistance training (see parameters for specifics)	Serve velocity measured with 2 Panasonic video cameras in meter per second
	P: 19.2 ± 1.1 y	NV: $n = 10$; regular tennis activity plus upper- and lower-body resistance training (see parameters for specifics)	The 2 cameras faced each other on the baseline of the testing court
	NV: 18.6 ± 1.3 y CG: 19.3 ± 1.6 y	CG: $n = 8$; regular tennis activity	Mean of the top 3 serves out of 10
Lachowetz (30)	22 college baseball players	Training group: $n = 12$; 11 UE strength training with free weights, cybex, nautilus, and cybex pulley system plus throwing program	Throwing velocity measured with radar gun in miles per hour
	Range, 18–22 y	CG: $n = 10$; throwing program only	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 (32)	13 female college softball players	EG: $n = 7$; endurance shoulder training in one position (throwing position) using a elastic band with the stance foot stationary	Throwing velocity measured with radar gun in kilometer per hour
	21.9 ± 2.6 y	CG: $n = 6$; no training	Throw into net that was positioned 4.5 m from the thrower Mean of 3 throws
Potteiger (41)	21 collegiate baseball players	RG: $n = 10$; 3 LE exercises, 5 UE exercises, and sprints plus normal baseball activity	Throwing velocity measured with a radar gun miles per hour
		Aerobic dance (CG): $n = 11$; dance training	Mean of 4 throws
Treiber (53)	22 collegiate tennis players	SRG: $n = 11$; regular tennis activity, shoulder theraband exercises, and shoulder dumbbell training	Serve velocity measured with a radar gun in miles per hour
	Male: $n = 12$	CG: $n = 11$; regular tennis activity	Radar gun positioned 1.8 m behind the server and at equal height to the center of the racket head during ball contact
	Female: $n = 13$ 21.2 y (range, 18–29 y)		Mean of 8 serves
DeRenne (10)	30 high school baseball players	OITG: 10-min controlled lesson plan of 50 pitches (see parameters)	Throwing velocity measured with electromagnetic radiation radar in miles per hour
	Range, 16–18 y	UITG: 10-min controlled lesson plan of 50 pitches (see parameters)	Radar gun located behind the catcher
		CG: 50 pitches with 5-oz baseball	Mean of 10 consecutive pitches

*CG = control group; EG = experimental group; PG = plyometric group; RG = resistance group; TT group = throwers ten group; UE = upper extremity; LE = lower extremity; KP group = Keiser pneumatic group; MB = medicine ball training program; WT = weight training program; SSTG = single-set training group; P = periodized resistance training; NV = nonperiodized resistance training group; SRG = shoulder resistance training group; OITG = overweight implement training group; UITG = underweighted implement training group.

Table 4. Study parameters for each intervention included in the analysis.*†

Study	Group 1 intervention parameters	Group 2 intervention parameters	Control group
Mont (38)	3 times a week for 6 wk Eccentric and Concentric Training: • 8 × 10 • Training velocity as follows: 90, 120, 150, 180, 180, 120, $90^\circ \cdot s^{-1}$	NA	No training
Fernandez-Fernandez (19)	Regular tennis activity: 8–10 h a week Experimental group: 3 times a week for 6 wk • Core exercises: 2/3 × 20 reps • Shoulder elastic tubing: 2 × 20 reps 45 s rest between sets • Medicine ball training: 2 × 8 reps 2-kg ball 1-min rest between sets	NA	Regular tennis activity
Behringer et al. (6)	Regular tennis activity: 2 times a week ≈ 1–1.5 h a session Plyometric group: 2 times a week for 8 wk • Wk 1: 2 × 20 reps • Wk 2: 2/3 × 20 reps • Wk 3–4: 3 × 10/12 reps • Wk 4–5: 3 × 12/15 reps • Wk 6–7: 4 × 10/12 reps • Wk 7–8; 4 × 12/15 reps 1-min rest between sets	Resistance group: 2 times a week for 8 wk • Wk 1–2: 65% 1RM; 2 × 15 reps • Wk 3–8: 85% 1RM; 2 × 15 reps 1-min rest between sets	Regular tennis activity
Escamilla (18)	3 times a week for 6 wk Throwers ten and Keiser pneumatic groups: • Wks 1 and 4: 2 × 12RM • Wks 2 and 5: 2 × 10RM • Wks 3 and 6: 2 × 6RM 1- to 2-min rest between sets	Plyometric group: • Wks 1 and 4: 2 × 10 • Wks 2 and 5: 2 × 8 • Wks 3 and 6: 2 × 6 1- to 2-min rest between sets Load = between 1.8 and 3.6 kg	Summer league baseball
Newton (39)	2 times a week for 8 wk Medicine ball group: • Wk 1–4: 3 × 8 reps • Wk 4–8: 3 ×10 reps 3-min rest between sets Load = 3 kg	Weight training group: • Wk 1–4: 3 × 8–10RM • Wk 4–8: 3 × 6–8RM 3-min rest between sets	Normal baseball routine
Escamilla (17)	2 times a week for 4 wk Resistance group:	NA	Normal physical and school activity other than baseball

	• 1 × 25 reps (1:2 tempo) • Long toss (no step aloud) 5-min warm-up at 50 ft 5-min throws at 60 ft 5-min throws at 75 ft 5-min throws at 100 ft • Long toss (1 step aloud) 5-min throws at 100 ft 2-min throws at 125 ft		
Kraemer (29)	2/3 times a week for 9 mo: same exercises different loads (2 times a week if matches scheduled) Periodized training group: 2/4 sets and reps varied each week • 4–6RM 2- to 3-min rest between sets • 8–10RM 1- to 2-min rest between sets • 12–15RM 1- to 2-min rest between sets	Single-set training group: • 1 set 8–10RM 1- to 2-min rest between sets	Regular tennis activity
Kraemer (27)	Periodized group: 3 times a week for 9 mo: same exercises different loads • Monday: 2/3 × 4–6RM • Wednesday 2/3 × 8–10RM • Friday 2/3 × 12–15RM	Nonperiodized group: Monday, Wednesday, Friday: 2/3 × 8–10RM	Regular tennis activity
Lachowetz (30)	Training group: 4 times a week for 8 wk • Wk 1: 3 × 10RM • Wk 2–8: 3 × 10RM followed by additional 5 reps 1-min rest between sets	NA	Throwing program only
Maddigan (32)	Experimental group: 3 times a week for 3 wk • 5 × 20 reps 4.5-min rest between sets • Wk 1: green band • Wk 2: blue band • Wk 3: black band	NA	No training
Potteiger (41)	Resistance group: 4 times a week for 10 wk • 3 × 12 reps 100% of 12RM • Sprint training Two 10-s sprints at 50% of maximum Three 10-s sprints at 100% maximum 30-s rest between each sprint	NA	Aerobic dance training
Treiber (53)	Shoulder resistance training group: 3 times a week for 4 wk • Elastic tubing (1:1 tempo): 2 × 20 reps	NA	Regular tennis activity

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	• Elastic tubing (Quick speed): 2 × 20 30- to 40-s rest between sets • Dumbbells: 4 × 20 (1:1 tempo); load 2.1 lbs (range 1–4 lbs) 30- to 40-s rest between sets	
DeRenne (10)	Overweight implement training group: 3 times a week for 10 wk • Wk 1–2: 5 oz • Wk 3–4: 5¼ oz • Wk 5–6: 5½ oz • Wk 7–8: 5¾ 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: 50 pitches with 5-oz baseball • Wk 1–2: 5 oz • Wk 3–4: 4¾ oz • Wk 5–6: 4½ oz • Wk 7–8: 4¼ oz • Wk 9–10: 4 oz 20 throws with standard baseball 20 throws with underweight baseball 10 throws with standard baseball

*reps = repetitions; RM = repetition maximum.
†Not all studies had 2 experimental groups; therefore, not applicable (NA) was placed in column 3 for studies only presenting with 1 experimental group.

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 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, 1 included isokinetic training (38), 1 included multimodal training (19), 3 included plyometric training (6,18,39), 10 included resistance training (6,17,18,27,29,30,32,39,41,53), and 1 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 1.05 to 3.45, and the CIs did not cross zero (6,10,19,27,29,30,38,39,41,53).

Isokinetic Training

One study in this analysis evaluated serve velocity before and after 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, $90^{\circ}\cdot s^{-1}$) (Table 4). Compared with the control group, both the eccentric and the concentric groups significantly improved their serve velocity by 8 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 1 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 with 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 2 baseball studies and 1 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 with 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 2 studies, both youth (18) and nationally ranked baseball players (39) underwent ball velocity testing before and after plyometric exercise. However, effect sizes within both studies were moderate with the CI crossing zero (Figure 4)

Study name	Subgroup within study	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
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

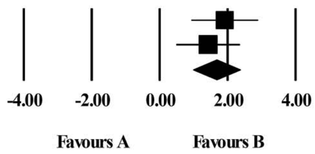

Figure 2. Hedges's *g* effect sizes with 95% confidence intervals for improvements in ball velocity following an isokinetic training intervention. Interventions that favours B support the intervention group. Interventions that favours A support the control group.

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

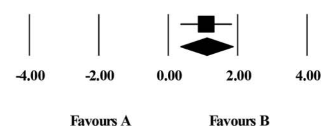

Figure 3. Hedges's *g* effect sizes with 95% confidence intervals for improvements in ball velocity following a multimodal training intervention. Interventions that favours B support the intervention group. Interventions that favours A support the control group.

Study name	Subgroup within study	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
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

Hedges's g and 95% CI

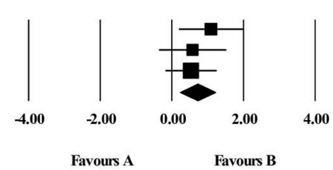

Figure 4. Hedges's *g* effect sizes with 95% confidence intervals for improvements in ball velcoity following plyometic training interventions. Interventions that favours B support the intervention group. Interventions that favours A support the control group.

because ball velocity did not increase compared with that of the control groups.

Resistance Training

Different variations of strength training protocols were implemented in 10 studies within this analysis (6,17,18,27,29,30,32,39,41,53). Of the 10 studies, 6 were shown to have a large training effect on ball velocity (27,29,30,39,41,53). 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 3–4 mph compared with the control group (30,39,41). A study incorporating periodized training (Table 3) increased serve velocity by 20 mph compared with the control group (29). Another study found that collegiate tennis players assigned to a periodized training program (Table 3) increased serve speed by 21 mph compared with the control group; however, the control group decreased in their serve speed by 5 mph, which increased the change between the 2 groups (27). Within the same study, individuals in the nonperiodized training group also significantly increased serve speed (14 mph) compared with the control group. The effect size from pre to post improvement in serve velocity was >1 for both the periodized and nonperiodized groups (Figure 5) (27). Treiber et al. (53) measured serve velocity before and after elastic tubing and dumbbell shoulder rotation training in college tennis players (Table 3). Compared with the control group, the experimental group significantly increased serve velocity by 9 mph, but the control group dropped in their serve speed by 2 mph, which inflated the change between the 2 groups (53). Four studies had moderate effect sizes ranging from 0.47–0.64, with the CI crossing zero (6,17,18,32). Small effect sizes with CI crossing zero were seen in 2 articles (Figure 5) (18,29).

Weighted Ball Training

One study included an overweight baseball training protocol and an underweight baseball training protocol (Table 3) (10). Compared with the control group, individuals training with overweight baseballs significantly improved their throwing speed by 3 mph, whereas 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

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

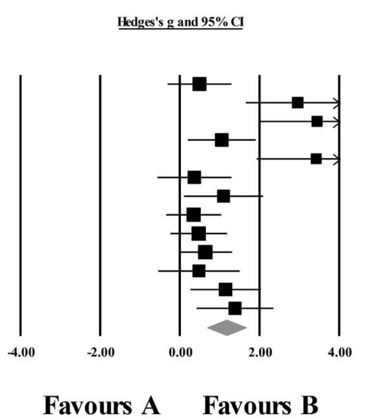

Figure 5. Hedges's *g* effect sizes with 95% confidence intervals for improvements in ball velocity following resistance training interventions. Interventions that favours B support the intervention group. Interventions that favours A support the control group.

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

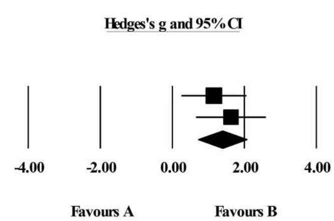

Figure 6. Hedges's *g* effect sizes with 95% confidence intervals for improvements in ball velcoity following weighted ball training. Interventions that favours B support the intervention group. Interventions that favours A support the control group.

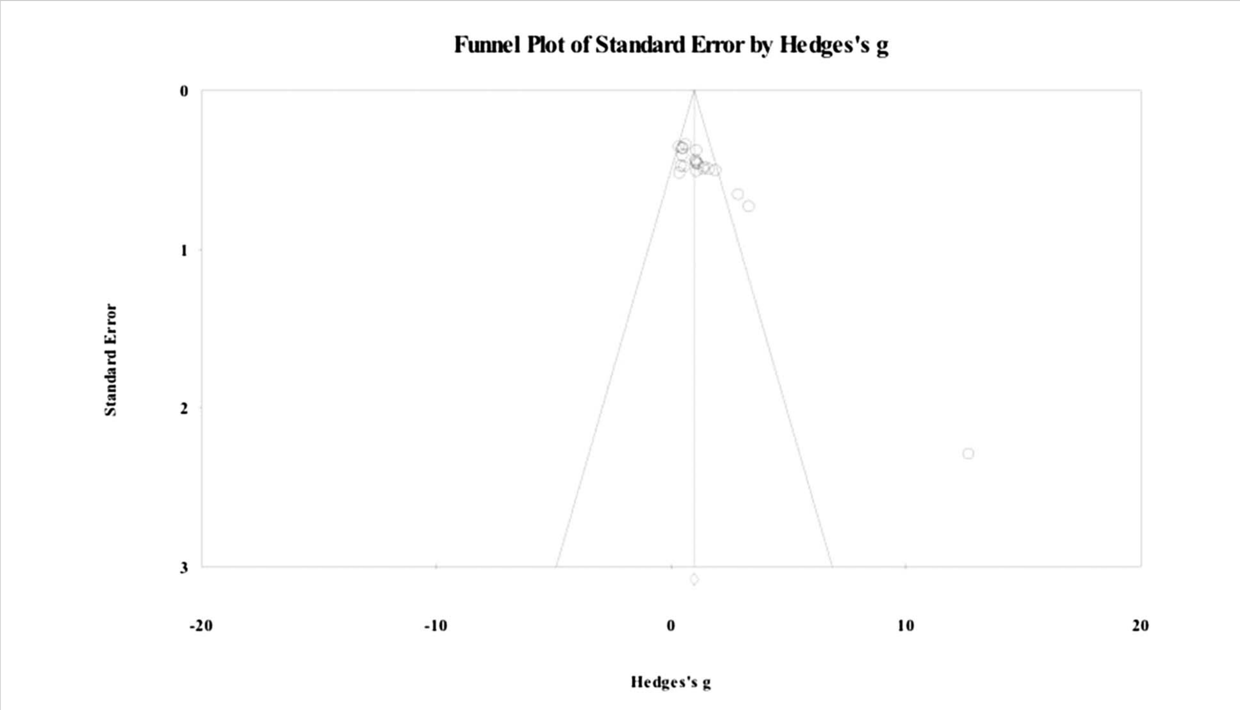

Figure 7. Funnel plot with Hedges's *g* plotted against the *SE*. Circles indicate studies within analysis.

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 do 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 because an additional 165 articles would need to be found to lower the effect size to <0.2. An effect size of 0.2 was chosen because 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 because 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 of 10 on the PEDro scale (6,17–19,27,38,39,53) while the remaining 5 articles are considered moderate in quality (10,29,30,32,41). Although all 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 article 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 who 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 (27,29,36,51). 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 by training progression (29,44). Previous research has shown that changes in volume and intensity will increase muscular strength in the 1 repetition maximum squat when compared with 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, 2 different populations, these findings imply the importance periodization training has on muscle and sport performance variables. Two studies in this analysis used 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 (27,29). Although not part of this meta-analysis, these 2 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 (27,29). The differences in serve velocity between 4 and 9 months ranged between 3 and 5 mph for both the periodized group and the nonperiodized group, indicating that a 4-month training regime may be as beneficial as a 9-month regime (27,29).

Incorporating lumbopelvic hip exercises may help to increase ball velocities in the overhead athlete (35,50). Fernandez-Fernandez et al. (19) investigated multimodal training for 6 weeks in a group of elite tennis players. Multimodal 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 with the control group (19). Multimodal training interventions may be a viable option for overhead athletes because experts suggest these athletes use the entire kinetic chain combining multiple anatomical segments and regions 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 with 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 1 crossover design study investigated the effects of light and heavy load ball throwing on the tennis serve (20). Neither of these 2 interventions in this study were shown to be effective when compared with the control group, and the heavier load intervention negatively effected serve velocity (20). In contrast, 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 with individuals throwing regulation-weight baseballs (56). These results are similar to the findings of DeRenne et al. (10) who found lightweight interventions to yield greater improvements in velocity compared with a control group. Despite the clinically irrelevant differences in speed between the 2 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 because of 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 7 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 using 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 phenomenon is seen in this analysis as interventions using both lower and upper extremity and trunk exercises (6,10,19,27,29,41) had larger effect sizes than those using 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 study by Newton and McEvoy (39) had no history of strength training while Escamilla (18) used 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. 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, 4–9 months may be an unrealistic window of time for many health care professionals. Thus, shorter 6-week protocols incorporating multimodal 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: (a) 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 (27,29). (b) 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. (c) 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 to draw strong conclusions on causality. Other reliable and valid assessment tools to rate the quality of evidence are available but were not used within this analysis. The PEDro scale offers ease of use compared with other assessment measures. Finally, the pre-post correlation values were not calculated for all the 13 articles because of a lack of reported information from 11 articles. However, the authors were able to calculate the correlation values from 2 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 the lower extremities. However, an effective 6-week intervention would incorporate multimodal 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 who use one or both of the above training protocols should see not only muscular improvements but functional performance improvements as well.

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