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The effect of physical training on hitting performance in sport: A systematic review

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Abstract

Physical training is being used to improve hitting performance in sports such as golf, baseball and tennis. Despite close correlations between physical capacities and hitting performance the most effective way to train for performance, remains unclear, with interventions ranging from whole body resistance training to ballistic training, to specific training. The aim is to review studies which have used these three interventions which vary in exercise selection, length of intervention, intensity of training and population, and to comment on how successful they were in improving hitting performance. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were used to perform a systematic search to identify eligible articles through PubMed, Sports discuss and PROQUEST. The search returned 2183 articles with 19 meeting the eligibility criteria from three different sports (golf, baseball, and tennis). Whole body resistance and ballistic training had 10 intervention articles each, with specific training having 3 interventions that were included. Whole body interventions which lasted more than 12 weeks with 2 sessions or more per week showed an increase of 28% in tennis serve speed over 36 weeks. Ballistic training involving throwing of medicine balls at high velocities, yielded an increase of 15% in golf clubhead speed. Specific training using over and under weighted bats across 6 weeks increased bat velocity by 8–13% in baseball. Practitioners could use all 3 intervention types to improve hitting performance but should consider the key role that each intervention can play in optimizing a player's hitting performance.

Keywords

Ballistic movement, baseball, golf, resistance exercise, tennis

Introduction

Hitting sports are sports in which an implement strikes a ball, characterised by five distinct phases: the preparatory phase, stance phase, drive phase, implement acceleration phase, and follow-through phase. These phases are evident in golf, baseball, cricket, tennis, field and ice hockey, badminton and squash.[1] To enhance skill execution and on-field performance, strength and conditioning practitioners have been employed in these sports to develop the physical capacities associated with hitting performance.[2–4] Improvement in hitting performance can be attributed to outcomes such as higher club head speed (CHS) in golf, greater serve speed in tennis, and greater bat speed in baseball.

Numerous studies in hitting sports have demonstrated the ability to increase the distance the ball travels after impact and/or increase ball speed to improve individual performance and/ or team success.[5–8] For example, increases in

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driving distance are associated with improved on-course performance in golf[9,10] and higher serve speeds are associated with better university tennis rankings ($r = 0.90$).[11] In baseball, a positive relationship exists between bat velocity and batted ball velocity. Nakashima[12] conducted a regression analysis between initial batted ball velocity and carry distance, the analysis demonstrated a linear relationship between initial ball velocity and flight distance highlighting the importance of generating higher exit velocities to maximise carry distance. Additionally, strength training and peak force has been shown to increase bat speed, leading to improved home run performance (30). Therefore, drive distance, bat speed and serve speed all influence the outcome of sports performance. Thus, it is important to understand the physical capacities that underpin the execution of these skills, so they can be appropriately trained and enhanced over time.

Several studies[13–15] have reported positive associations between physical tests, focusing on lower- and upper-limb strength qualities, and representative measures of hitting performance. For example, a longitudinal study in baseball by Hornsby et al. showed an increase in isometric mid-thigh pull peak force[15] and an improved home run performance across first two seasons, but the link between the two was not assessed (24). In both tennis and golf, lower-limb strength, measured with isometric mid-thigh pull, has demonstrated a strong correlation between peak force and serve speed ($r = 0.87$)[13] and a significant positive relationship with rate of force development and CHS ($r = 0.40$).[14] Additionally, general lower body and upper body strength scores, consisting of back squat, deadlift, and bench press one-repetition maximum (1RM) strength, have been shown to be moderately correlated with CHS in golfers ($r = 0.61$).[9,16] Ballistic performance tests (i.e., the countermovement jump test), which utilise a slow stretch shortening cycle (SSC) have demonstrated a moderate to large correlation with serve speed in tennis players ($r = 0.77$).[13] Therefore, hitting sport athletes should focus on maximum force production and rate of force development in their training to enhance hitting performance.[17]

Investigations into the effects of various training interventions have been conducted across multiple hitting sports, but the optimal type of physical training intervention remains unclear. In accordance with the principle of specificity, improving strength qualities related to hitting performance requires training stimuli that incorporate exercises performed over short durations and involving multiple joints and ranges of motion reflective of the hitting action. There is evidence to link plyometric training to improved hitting performance, with increases in serve speed in tennis[18] and CHS in golf players.[18,19] An 8 week programme of plyometric training showed a 3.2% increase in average CHS in collegiate golfers.[20] In addition, a combination of training methods involving 8 weeks of plyometric and weight training has demonstrated a 4.2% increase in drive distance for golfers who possessed an average handicap of 5.5 ± 3.7.[21]

Specific training that manipulates movement demands to mirror the skill (e.g., weighted bats) has been associated with improved performance.[22,23] In collegiate baseball, a six-week programme combining overweight and underweight bats with standard bats, increased bat speed by 3.4 m/s.[22] Hitting sports demand precise technical movements, so players require sufficient strength and an optimal strategy to execute them effectively.[24] However, improvements through technical adjustment alone may be limited if players lack the physical capacity to adopt the desired technique.[25,26] Task specific overload using heavier or lighter implements or medicine balls can target the biomechanical requirements of hitting and develop the requisite capacities. Consistent with this, adding weightlifting exercises increased average club head speed in golfers by 3.2% ($p = 0.02$), an adaptation aligned with the need to generate high forces in short time frames.[20] Collectively, these findings support a targeted, task specific strength approach to enhance hitting performance across striking sports.

To date, there are a limited number of investigations comparing the effectiveness of general and specific exercise programmes on hitting performance in cricket, field and ice hockey, squash and badminton. In hitting sports (golf, baseball and tennis) which have greater evidence base as to the effect of different types of physical training intervention on hitting performance it remains unclear as to which is optimal for performance. The main objective of this review is to compare the effects of various training methods on hitting performance variables across a range of hitting sports. We aim to review these studies and subsequently offer appropriate training recommendations to inform training strategies to improve hitting performance.

Methods

The present study adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[27]

Eligibility criteria

Studies that met the following inclusion criteria were included within the review: (i) healthy participants of any age, sex, or activity level; (ii) a physical training intervention lasting ≥6 weeks in a hitting-based sport aimed at improving physical capacities; (iii) measure outcomes related to bat speed, club head speed (CHS), racket speed prior to impact, and peak ball speed post-impact. Exclusion criteria included: (i) single-group study designs; (ii) no additional training outside the normal training regimen for the control group; (iii) reported no significant improvement in the measured physical capacity between pre- and post-test measures; (iv) non-English publications, non-peer reviewed documents, review articles, observational studies, conference abstracts or theses.

Information sources

An electronic search of the literature was conducted in the following databases from inception until 4th September 2024 PubMed, SPORTDiscus, and ProQuest. To ensure comprehensive coverage, a final search was performed using Google Scholar by all authors, utilising relevant keywords (described in detail later). Additionally, the reference lists of included studies meeting the inclusion criteria after title and abstract screening were examined for additional relevant papers.

Search strategy and selection process

An extensive literature search of three electronic databases was conducted using a list of pre-defined key terms and their associated synonyms. These terms are outlined in Table 1. The search results were compiled into a tailored Microsoft Excel document (Microsoft Excel, Version 16.55) to facilitate screening. Initial screening was performed by two authors (TB and AW). Both authors independently evaluated the titles and abstracts of the remaining articles. Following the evaluation of titles and abstracts, a full-text review of the agreed, included articles that appeared to meet the inclusion criteria was performed. A final decision regarding the inclusion of articles was made following the independent full-text review of articles by two authors (TB and AW). Any disparities regarding study inclusion were addressed through discussion among the authors (TB and AW). In instances of disagreement, all authors convened to arrive at a final decision regarding study inclusion or exclusion.

Data collection process and data items

Two authors (TB and JT) extracted data from the included studies and recorded it using a customised Microsoft Excel document. The extracted information included study design, details of the intervention, participant demographics, measured physical capacities, and study outcomes. Mean values and standard deviations for each outcome measure, including bat speed, serve speed, club head speed (CHS), ball speed, and strength measures, were collected for both pre- and post-intervention periods in both experimental and control groups. Subsequently, the extracted data underwent independent verification by the same authors (TB and JT) to ensure accuracy.

Study quality assessment

Two authors (TB and AW) evaluated the quality of the studies included in the analysis using a modified Downs and Black checklist.[28] The following items from the checklist were excluded: 8, 9, 13, 24, and 27. Similar modified versions have been used in previous systematic reviews and meta-analyses.[29–31] The modified version that was employed in this study had a maximum score of 23. Each paper was assigned a grade of "excellent" (19–23 points), "good" (15–18 points), "fair" (11–14 points) or "poor" (<11 points) in line with previous research using the modified Downs and Black.[30]

Results

Study selection

The PRISMA Flowchart (Figure 1) illustrates the process of study identification, screening, and evaluation of eligible studies. The initial search yielded 2183 articles from electronic databases, and an additional 14 articles obtained from other sources. After removing duplicates, the total number of articles was reduced to 2047. Further screening of titles and abstracts resulted in 55 full-text articles remaining. Following analysis of full-text articles, 36 papers were excluded from the initial 55 based on the inclusion criteria, leaving a final sample of 19 articles for inclusion in this review.

Population

The studies within this review contained a wide range of participant demographics. This review was dominated by three sports; golf, tennis and baseball, with varying levels of participant ages ranging from 11 years to a mean of 36 years. The review contained both male and female participants, although it was heavily dominated by male participants in sixteen of the nineteen studies, with only three studies containing female participants as outlined in Tables 1, 2 and 3. The participants' playing levels are shown in Tables 1, 2 and 3, there are varying levels of performance from recreational golfers to county level tennis athletes, with the highest performance level included in this study viewed as collegiate level baseball and tennis athletes. Physical training history information is sparsely talked about in this review with only ten studies including some mention of physical training programmes prior to the commencement of training interventions.

Study characteristics

Due to variations in the training interventions, training methods were categorized into three distinct groups: whole body resistance (Table 2), ballistic (Table 3), and specific training (Table 4), defined as follows: Whole body resistance training

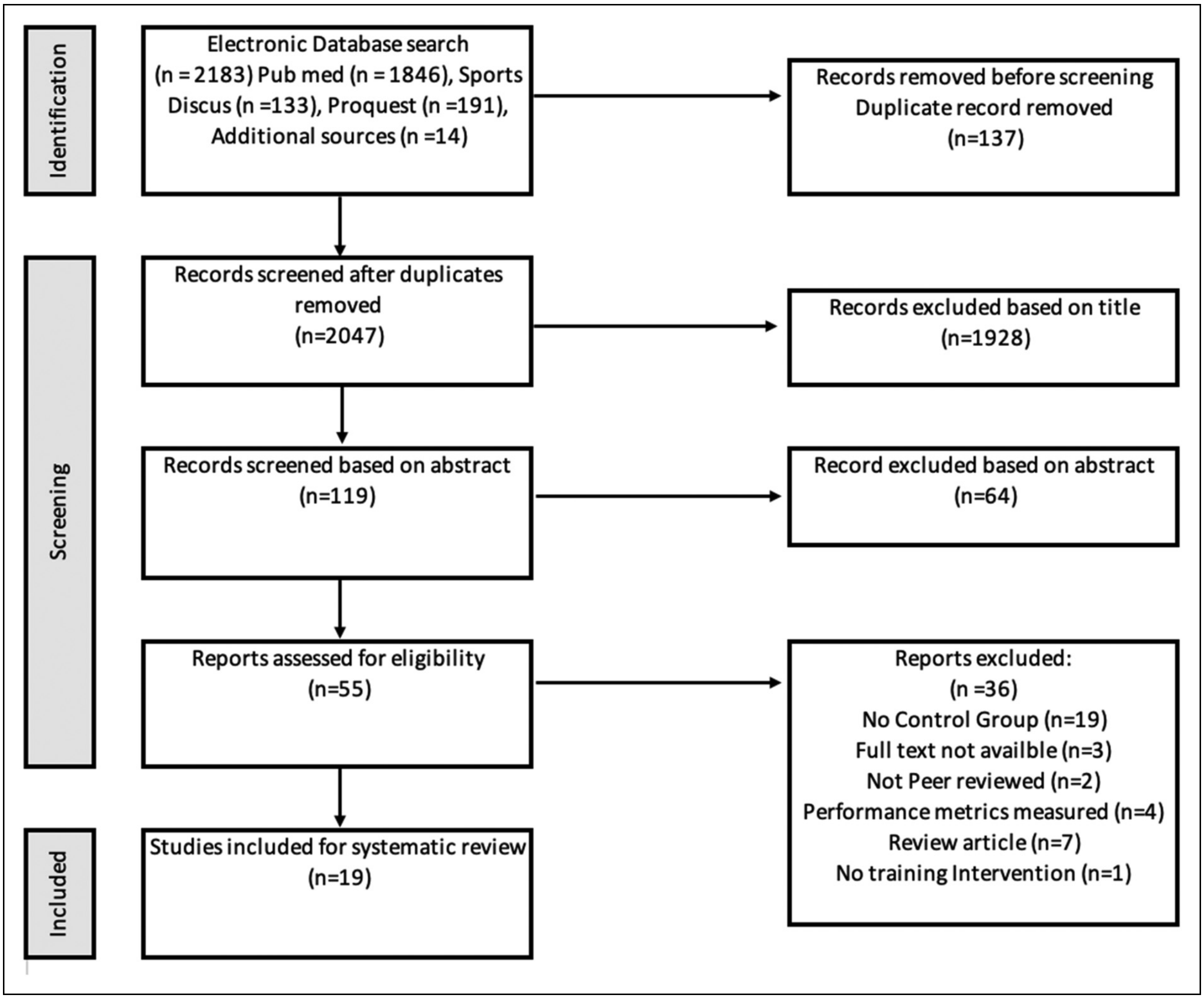

Figure 1. Selection process for articles included in this article.

included general resistance programmes involving multi and singular joint exercises, such as back squats and bench press, while excluding movements biomechanically similar to the sporting skill.[32] Ballistic training involved accelerating through a full range of motion to the point of projection, including plyometric exercises, medicine ball throws, ballistic push-ups, bounding, hopping, and jumping variations.[33,34] Specific training involved movements closely resembling the biomechanics of the hitting action, such as utilizing weighted implements like golf clubs or baseball bats to improve hitting performance.[32,35]

Table 1. Search terms.

TERM	Search Strategy
OR	1. "Strength training" OR "power training" OR "resistance training" OR "weight training" OR "circuit training" OR "Olympic lifting" OR "weightlifting" OR "ballistic training" OR "plyometric training" OR "jump training"
WITH	2. "Bat velocity" OR "clubhead speed" OR "ball velocity" OR "carry distance" OR "handicap"

Unless otherwise stated, all results displayed represent the change in a metric are from pre to post testing for the intervention groups (Tables 2, 3 and 4). There were eleven studies which investigated whole body resistance training ranging from 6-week interventions to 36 weeks.[2136–45] Of these investigations, one study investigated the effect of whole-body resistance training on serve speed in tennis and found an increase of 29% from pre to post intervention.[42] Static and dynamic core training showed improvement in serve velocity in youth male and female tennis players of 6%.[45] In golf there was a significant increase in youth golfers peak CHS of 4.6% after 12-week whole body training intervention.[44] The other eight studies reported a mean range of −4% to +5% in pre to post hitting performance variables after whole-body resistance training intervention (Table 2).

Seven studies investigated the effect of ballistic training.[18,19,23,3746–48] The training intervention periods across

Table 2. Overview of studies reporting changes in hitting performance following whole body resistance training.

Study	Participants	Training Intervention	Relevant Findings	D&B Grade
Coughlan et al. 2020	39 male county squad golfers Physical training history not stated	12 weeks, 1 session per week; EXP group completed whole body resistance training, Sets 1–6, reps 2–12. CON completed normal golf regime.	CHS: CON 2%↓ EXP 2.5%↑ BS: CON - EXP 3.2%↑	FAIR 14/23
Behringer et al. 2013	36 male youth tennis players Physical training history not stated	8 weeks, 2 sessions per week; EXP(1) group completed whole body resistance training programme progression from 65% to 85% 1RM. Sets 2, reps 10–15; EXP(2) group completed upper and lower body plyometric training; CON group completed normal tennis training regime.	SV: CON 5% EXP -	GOOD 15/23
Shaw 2024 et al.	18 male youth golfers No experience in physical training programme	12 weeks, 2 sessions per week; EXP completed whole body resistance training programme of Sets 2–4, reps 3–10 dependant on exercise; CON followed their normal golf routine	CHS CON 1.9% ↑ *EXP 4.57% *	GOOD 15/23
Alvarez et al. 2012	10 male right-handed amateur golfers 2× physical training per week Physical training history not stated	6 weeks, 2 sessions per week; EXP completed whole body resistance training at 85% 1RM. Sets 3, reps 5; CON followed normal golf and resistance training regime.	BS: CON 1% ↑ EXP ↑ 4%	GOOD 16/23
Lamberth et al. 2013	10 male college golfers Not involved in physical training 8 weeks prior	6 weeks 2 sessions per week; EXP completed lower and upper body strength training. Sets 2–4, reps 6–12; CON Followed their normal training regime	CHS: CON 2% ↓ EXP 4% ↓	GOOD 15/23
Hughes et al. 2004	23 male college golfers Involved in college physical training programme 3× per week	6 weeks, 3 sessions per week; EXP group completed wrist and fore arm strengthening exercises. Sets 3, reps 10 ; CON group followed normal training programme	CHS: CON 1.5% ↑ EXP 5% ↑	GOOD 16/23
Fletcher 2004	11 male amatuer golfers <6 months of physical training history	8 weeks, 2 session per week; EXP followed a combined whole body resistance training programme. Sets 3, reps 10; CON group followed normal training routine	CHS: CON - EXP: 1.5% ↑	GOOD 15/23
Weston 2013 et al.	36 male amateur golfers Physical training history not stated	8 weeks, 3 sessions per week; EXP completed a core an isolated core training programme; CON followed their normal golf regime	CHS: CON 1.5% ↓ EXP 2% ↑	GOOD 16/23
Kraemer 2003 et al.	27 female college tennis players Not involved in any resistance training programme	36 weeks, 2–3 sessions per week; EXP (1) completed single set of whole body resistance training. Sets 1 reps 8–10; EXP (2) completed 2–4 sets of whole body resistance of whole body resistance. Sets 2–4, reps 4–15; CON followed normal tennis programme	SV: CON 7% ↓ EXP (1) 16% ↑ *EXP (2) 29% ↑*	GOOD 16/23
Canòs 2022 et al.	24 male youth tennis Not involved in physical training 2 weeks prior <6 months of physical training history	8 weeks, 2 sessions per week; EXP (1) completed machine based whole body resistance training; EXP (2) completed whole body flywheel neuromuscular based training; CON followed normal tennis regime	SV: CON 1% ↓ FG 2.2% I FG 1% I	GOOD 17/23
Egesoy 2021 et al.	36 male and female youth tennis players Physical training history not stated	8 weeks, 2 sessions per week; EXP (1) completed isolated static core training. 2 sets of 20–40 s progressively increasing over 8 weeks; EXP (2) completed dynamic core exercises with same loading as EXP (1). CON followed normal tennis regime	SV: CON 1% ↑ EXP (1) 6% ↑ *EXP (2) 6% ↑*	Good 16/23

EXP: Experimental; CON: Control; RM: Repetition Max; CHS: Club Head Speed; SV: Serve velocity; ↑ indicates increase in mean score, ↓ indicates decrease in mean score * denotes statistical significance between pre and post test $p \leq 0.05$. D&B - Downs and Black quality assessment tool score. Items 8, 9, 13, 24, 27 omitted as not applicable.

Table 3. Overview of studies reporting changes in hitting performance following ballistic training.

Study	Participants	Training Intervention	Relevant Findings	D&B Grade
Fernandez-Fernandez et al. 2016	60 male youth tennis players Not involved in any physical training 4 weeks prior No experience in formalised physical training	8 weeks, 2 sessions per week; EXP group completed whole body plyometric training of 4–8 exercises. Sets 2–4 sets, reps 10–15; CON group completed normal tennis training regime	SV: CON 1% ↑ EXP 6% ↑ *	GOOD 15/23
Fernandez-Fernandez et al. 2013	30 male nationally ranked youth tennis players Not involved in any physical training 4 weeks prior No experience in formalised physical training	6 weeks, 3 sessions per week; EXP group completed whole body plyometric and med ball training. Sets 2, reps 8–20; CON group completed normal tennis training regime	SV: CON - EXP 5% ↑*	GOOD 16/23
Bliss et al. 2015	16 male amateur college golfers < 6months of physical training history	8 weeks, 2 sessions per week; EXP group completed whole body plyometric medicine ball training and golf swing derivative training. Sets 3–4, reps 5–6; CON group completed normal golf schedule.	CHS: CON 1% ↓ EXP 3% ↑ *BS: CON 1%↓ EXP 3% ↑*	FAIR 14/23
Choi et al. 2017	18 amateur golfers Physical training history not stated.	8 weeks, 3 sessions per week; EXP group performed golf swing med ball throws from various heights from waist to shoulder height. Medicine ball weight increased from 3 kg to 5 kg; CON completed normal golf regime	CHS: CON 1% ↑ EXP 15% ↑ *	GOOD 16/23
Kim et al. 2010	17 female golfers <5 months of physical training history	12 weeks 3 sessions per week; EXP group performed med ball training and core strengthening exercises at 60–70% 1 RM. Sets 3, reps 14; CON group followed normal golf training regime	CHS: CON 2% EXP 4% BS: CON - EXP 2.5%	GOOD 16/23
Behringer et al. 2013	36 youth male tennis players Physical training history not stated	8 weeks, 2 sessions per week; EXP group completed upper and lower body plyometric training. Sets 2–4, reps 10–20; CON group completed normal tennis training regime.	SV: CON 5% ↓ EXP 3%	GOOD 15/23
Genevois et al. 2013	44 male amateur tennis players Physical training history not stated	6 weeks, 2 sessions per week; EXP group completed heavy medicine ball training. Sets 6, reps 6 ; CON group followed their normal tennis regime	FHV: CON 4.5% ↓ EXP 8% ↑*	GOOD 16/23

EXP: Experimental; CON: Control; RM: Repetition max; CHS: Club Head Speed; FHV: Forehand velocity ↑ indicates increase in mean score, ↓ indicates decrease in mean score * denotes statistical significance between pre and post test $p \leq 0.05$. D&B - Downs and Black quality assessment tool score. Items 8, 9, 13, 24, 27 omitted as not applicable.

the included studies ranged from 6–12 weeks. Five studies found a significant increase in hitting performance variables: CHS, serve speed and ball speed ranging from 3% to 15%[18,19,23,46,47] following the ballistic interventions (Table 3). The remaining ballistic training interventions showed no significant changes in hitting performance variables after intervention period, despite similar intervention lengths of 6–12 weeks and similar exercise selection in the same variables.

Studies investigating the effectiveness of specific training ranged from 6–12-week interventions (Table 4). All three studies established significant improvements in hitting speed ranging from 8% to 13% in bat velocity in baseball and 7% in forehand velocity in tennis.[22,23,49]

Quality assessment

A modified Downs and Black checklist was used to assess the quality of included articles as per previous systematic reviews and meta-analyses[29–31] the results can be seen across Tables 2, 3 and 4. Included studies ranged between 14 (61%) and 17 (74%) out of a possible 23 points; the mean score was 16.0 ± 1.92. Two studies achieved a fair rating with the

Table 4. Overview of studies reporting changes in hitting performance following specific training.

Study	Participants	Training Intervention	Relevant Findings	D&B Grade
Sergo et al. 1993	24 male college Baseball players Physical training history not stated	6 weeks, 3 sessions per week; EXP groups swung a combination of heavier and lighter bats; CON group swung normal bat weight	BV: CON 8.8% ↑ *EXP1 8% ↑ *EXP2 8.2% ↑*	GOOD 15/23
DeRenne et al. 1995	60 male college baseball players Physical training history not stated	12 weeks, 4 sessions per week; EXP groups dry swung and hit live pitched with combination of heavier and lighter bats; CON group dry swung normal bat weight	BV: CON 2% ↑ *EXP1 12.5% ↑ *. EXP2 13% ↑ *	GOOD 16/23
Genevois et al. 2013	44 male amateur tennis players Physical training history not stated	6 weeks, 2 sessions per week; EXP group used an overweighted racket to complete parts of tennis training. CON group followed their normal tennis regime	FHV: CON 4.5% ↓ EXP 7% ↑*	GOOD 16/23

EXP: Experimental; CON: Control; CHS: Club Head Spead; BS: Ball Speed; BV: Bat Velocity; FHV: Forehand velocity ↑ indicates increase in mean score, ↓ indicates decrease in mean score * denotes statistical significance between pre and post test $p \leq 0.05$. D&B - Downs and Black quality assessment tool score. Items 8, 9, 13, 24, 27 omitted as not applicable.

remaining studies all achieving a good rating. A full scoring breakdown can be seen in Supplementary Table 1.

Discussion

This review examined the effectiveness of various physical training interventions on hitting performance. Nineteen studies met the inclusion criteria, all of which concentrated on three hitting sports: golf, tennis, and baseball. Although previous studies have reported a positive relationship between measures of maximal strength and hitting performance metrics,[13,15,35] the findings from this review suggest whole-body resistance training interventions often showed improvements in physical capacities that did not consistently transfer to better hitting performance. Although this review focuses on transfer to hitting metrics, resistance training remains fundamental for developing tissue capacity, load tolerance, movement efficiency, and general athletic qualities such as force production and rate of force development.[50] Another key finding from this review was that studies investigating sport-specific training interventions seem to significantly enhance hitting performance in less than 12 weeks. Therefore, the results of this review suggest that coaches should strongly consider the principle of specificity when prescribing exercises to improve hitting performance, with exercises that match or surpass the mechanical demands of the hitting task potentially offering the greatest transfer over modest time periods (e.g., 6–12 weeks). Nonetheless, there is a lack of evidence that provides a direct comparison between interventions that seek to improve hitting performance.

Training intervention

Across eleven studies, eight demonstrated that whole-body resistance training had a limited ability to directly impact measures of hitting performance in various sports. However, in youth golfers, Shaw[44] demonstrated that a 12 week whole body resistance training programme positively influenced both physical and hitting performance metrics of youth golfers, with increases in peak isometric mid-thigh pull peak force, countermovement jump height and peak CHS, using free weight exercise such as trap bar deadlift, back squat, romanian deadlift, split squat where volume and intensity were progressed over the intervention.[44] In youth tennis players, dynamic and static core exercises which were progressed over time led to increased serve velocity and improvement in countermovement jump and hand grip performance.[45] However, in collegiate golfers, Lamberth et al.[39] only found a significant increase in leg press and bench press performance but no change was found in club head speed using similar training modalities over a 6-week training period.[39] This finding was consistent across this review for studies investigating the effects of whole-body multi-joint resistance training on hitting performance, where no change was observed in hitting performance.[2136–38,40,41,43] Typically, exercise selection generally focused on the same compound multi joint resistance exercises which included leg press, back squat, bench press and barbell row. Nonetheless, it appears that general strength training programs performed in isolation of specific exercises may lead to negligible changes over a shorter time frame (less than 12 weeks) in hitting performance when programmed for a single mesocycle. Therefore, over a single mesocycle, practitioners should not expect significant improvements in hitting performance when the training is focused on enhancing general strength qualities.

Ballistic training methods, including both upper and lower body exercises (e.g., medicine ball throws mimicking swings and single and double leg jumps) have shown a significant increase in hitting performance.[19,23,47,48] Over 57% of ballistic training, where intervention length lasted 6–8 weeks, demonstrated an increase in hitting performance variables (CHS, ball speed and serve velocity).[18,19,46,47] For instance, Choi et al. found that rotational medicine ball (3–5 kg) training when thrown at waist and shoulder height increased CHS by 15% in amateur golfers.[47] Similar outcomes were achieved when using rotational throws with a medicine ball, mirroring a golf swing, an improvement of 3% in ball speed and CHS were observed.[19] Fernandez et al.[18,46] also reported that combined lower-limb jumps with upper body chest pass throws and medicine ball slams could result in 5–6% performance increase in serve velocity. These studies suggest that exercises that utilise low external loads (medicine balls) at high velocities could enhance CHS, serve speed and ball speed. Consequently, practitioners should prioritise exercises with high dynamic correspondence relative to the hitting activity to achieve greater performance adaptations. However, this has not been measured in any of the investigations included within this review.

Specific training investigated the impact of manipulating the weight of implement on the specific power hitting activities associated with the sport (i.e., weighted bat in baseball). Two out of the three studies included in this review found significant improvements from pre- to post-training.[22,49] DeRenne et al.[22] used an intervention where balls were struck with different weighted baseball bats, from both a tee and live pitch drills, leading to 13% improvement in bat velocity. This approach facilitates neural recruitment specific to the task and allows more practice at the necessary velocities, potentially explaining the improvement in bat velocity.[22] However, with specific approaches such as overweighted forehand swings, the length of the intervention and number of sessions appear to matter. Twelve sessions over six weeks improved tennis racket velocity,[23] whereas 48 sessions across 12 weeks produced a larger 12–13% increase in implement velocity.[22] This could be attributed to the number of sessions; however, a small sample size was used highlighting the need for further research to draw definitive conclusions regarding exercise selection, frequency of training, and length of intervention.

Due to the variety in exercise types included within this review, it is difficult to determine which style optimally transfers to hitting performance. Nevertheless, the findings suggest that practitioners should include exercises that require athletes to produce high force at high velocities,[4] with a similar kinematic coordination strategy.[51] Alvarez et al.,[38] reported an 18-week programme combining whole-body, ballistic, and sport-specific training. The first six weeks involved maximal strength work, with three sets of five repetitions at 85% of one-repetition maximum with four minutes rest between sets.[38] A six-week ballistic training programme followed this which included supersetting bench press with plyometric push up and back squats into vertical squat jumps 3 sets of 6 on strength and 3 sets of jump on ballisitic exercises respectively.[38] The final intervention was sport-specific training for six weeks; participants were instructed to hit golf drives with weighted clubs for 3 sets of 10 repetition.[38] This intervention showed a significant increase in hitting performance in mean club head speed and ball speed. Club head speed increased from 149.9 m/s (one week before the intervention) to 152 m/s (5 weeks after the 18-week intervention), while ball speed increased from 226 to 244 km/h during the same time frames.[38]

Training duration

The length of interventions within this review ranged from 6 to 36 weeks. Whole-body resistance training, where interventions lasted longer than 12 weeks, demonstrated a significant increase in hitting performance in tennis and golf of 28%[42] and 4.6%,[44] respectively. Kraemer[42] programmed multi-joint exercises such as leg press and split squat and demonstrated an improvement of 29% in serve speed over 36 weeks and Shaw[44] used the split squat, back squat and Romanian deadlift over 12 weeks and found an increase in CHS. Interestingly, these studies were the only whole-body resistance training studies which lasted longer than 12 with more than one session in the week, Coughlan et al.[36] lasted 12 weeks but there was only one training session per week. Whole-body resistance interventions lasting 12 weeks or more, with multiple sessions per week, should be used to improve the physical capacities developed through such training. Longer interventions are likely to allow these enhanced capacities to translate into more skilled movement patterns, such as improved hitting performance. The improvements in physical capacities are seen across whole body resistance interventions and are not necessarily dependant on length of intervention. Kraemer et al.[42] found a 23% increase in bench press performance after 36 weeks, and Alvarez et al.[38] participants exhibited a 6 kg increase in their one repetition maximum bench press after 18 weeks and 45 kg increase in back squat performance. However, Lamberth et al.[39] used a 6-week intervention and found a significant increase of 7 kg in one repetition maximum bench press performance and 9 kg in leg press performance, the two whole body resistance interventions with significant improvement in hitting performance had longer interventions and greater frequency of sessions compared to the rest.[42,44]

Whole-body resistance training alone has been associated with limited increases in CHS, ball speed and bat velocity. Nonetheless, this could be true in the case of an immediate, single, post-test measurements, as optimal hitting performance may take several weeks following a training intervention.[52] Whole body resistance training, lacking sport specific elements, may need longer time to transfer the enhanced physical capacities into hitting performance, considering how highly complex and coordinated the movement patterns of hitting performance are.[42] Therefore, longer whole-body strength interventions are needed to allow for strength to be continually developed alongside these high skilled movements to transfer into hitting performance.

Ballistic and specific training have shown to have significant improvements in interventions of up to 12 weeks.[18,19,22,23,46,47,49] However, participants in these studies had limited experience with this training style, so the novel element may have elicited greater improvements in neuromuscular coordination (learning effect) and strength related to hitting performance compared to athletes already familiar with this training.[53] These interventions highlight the relatively rapid improvement in hitting performance that can be expected when using ballistic intervention or overweighted implements in biomechanically similar tasks. This suggests that such interventions can benefit athletes needing to improve hitting performance over a shorter timeframe.

Training volume and intensity

Training volume and intensity must be strategically prescribed and monitored to ensure body adaptations. Three out of the nineteen studies included in this review reported the load at which the exercise was performed with a range of 65–85% of 1RM for whole body resistance training, and between 60–70% 1RM within ballistic training despite reporting training intensity had no effect on hitting performance.[37,38,48] Additionally, whole body resistance training repetitions ranged from 4–20 repetitions, across 1–4 sets, there is no general consensus as to the optimal sets and repetition range as they vary across interventions.[2136–45] For strength gains, a training structure of medium to high weekly sets for multi joint training (5 sets performed per week per exercise) were recommended as optimal in a recent meta-analysis,[54] the findings of this systematic review support these findings.

The principle of progressive overload is evident in numerous articles in this review either as percentage of one repetition maximum week to week, or time performing the exercise.[37,43,45] Researchers recorded rating of perceived exertion and if the target number of repetitions were achieved, subsequently volume or intensity were adapted to drive adaptation.[42,44] For example, Fletcher and Hartwell[21] used 3 set of 6 repetitions and when 6 were achieved the repetitions increased to 8 repetitions and once 8 repetitions were achieved 5% of the load was added to the bar, this process was repeated across the intervention. Therefore, volume and intensity and optimal weekly sets are evidenced within this review to allow for strength adaptations to occur but, do they transfer to hitting performance? Shaw et al.[44] mirrored this concept of 3–4 sets of 6–8 repetitions and as repetitions decreased, the intensity of the lift increased to maintain progressive overload resulting in an improvement in CHS as reported in Table 2.[44] The time performing the exercise can be progressed, Egesoy et al.[45] increased the time youth tennis players performed dynamic or static core exercises over 8 weeks from 20–40 s and found a 6% improvement in serve velocity. One study compared overall volume by having a single set training group and a multiple set training group which lasted 36 weeks and reported that there was a 16% improvement in single set protocol compared to a 29% improvement in serve velocity for the multiple sets protocol.[42] Therefore, it can be concluded that overall training volume is an important factor for eliciting adaptations, with greater training volume leading to superior hitting performance when compared to lower training volumes.[42]

Ballistic training exercises show that interventions with sets between 2–4 and repetitions from 10–20, performed 2–3 times per week, yielded significant improvements on hitting performance.[18,19,46,47] The improvement in hitting performance may be attributed to the high velocity movements of ballistic training (i.e., rotating medicine ball throw, countermovement jumps), replicating the limited time available to produce force during hitting movements.[4] Furthermore, the learning effect and increased exposure to the task can be seen in Choi et al.[47] the skill of power hitting was replicated with a medicine ball in the intervention which can offer a potential reason as to why improvements were seen.

Specific training used high volumes of practice per week compared to whole-body resistance and ballistic training. For example, the participants in De Renne et al. completed 450 swings of the bat every week for 12 weeks with a manipulated bat weight. While Sergo et al.[49] had participants swinging the bat 300 times a week across 3 sessions per week. Both studies have reported improvements in bat velocity by 8–9%[22] and 12–13%,[49] respectively. However, in the Genevois et al.[23] study, the weekly volume for overweighted racket swings was less volume of swings compared to the aforementioned baseball studies at 140 swings per week which increased to 200 by the end of the intervention and found an improvement 7% in racket velocity after the intervention. We can conclude that participants need exposure to specific interventions which contains a high volume of repetitions and manipulation of the weight of the bat or racket if the aim of the programme is to increase hitting speed.

Within this review a higher volume of repetitions during the intervention have contributed to improvements in hitting performance variables, it is important to acknowledge that all not just high-volume interventions showed improvements. The magnitude of these improvements was not assessed because of the differences in study characteristics and given the known inverse relationship between volume and intensity and considering the wider range of differences of other external factors in this review (participant age, training history, sex, playing level) it would be unsuitable to conduct this type of assessment as to which type intervention is optimal for improving hitting performance and we encourage future research in this area.

Participants

Cohorts across the included studies were not homogenous, ranging from 11 to 47 years old, including youth collegiate-level athletes and recreational level participants.[36,41] None of these participants were stated as professional athletes in their respective sports. Long term development models showed that elite athletes have more efficient skills and physical conditioning than non-professionals. That is, first, because of the years of practice[55] and second it is more feasible to base training and performance assessment on training history and playing level (stage of development).[56] Therefore, the training interventions presented in this review may not be applicable to elite athletes. Specific training might be more beneficial for elite athletes, who often have shorter training periods and limited opportunities for long term physical training interventions. In collegiate baseball athletes, specific training has shown to increase hitting performance in 66% of studies.[22,49] Interventions were kept simple as participants used overweighted, underweighted, and standard weight bats and either hit live pitched balls, dry swung or hit balls off a tee. However, there is still a gap on the effect of specific training on elite athletes hitting performance. We have generated this hypothesis based on the limited data available from this review. Furthermore, only three studies in this review were conducted on females,[42,45,48] highlighting the need for more research on female populations.

Quality of studies

Overall, the standard of the studies was '*good*' based on a modified downs and black, with all studies having clear aims and hypotheses. However, all studies within this review reported inconsistencies in the participant's physical training history. An individual's physical training history can influence the results of a training intervention, as evidence suggests that those with no physical training experience when learning a new physical exercise will experience the following physical gains at rapid rate: neuromuscular adaptations, changes in connective tissue, and increased muscle cross sectional area.[57] Some studies within the review have offered an explanation on the principles of training, specifically training intensities, to ensure appropriate progression was being made, however it appears in some instances it was reliant upon the trainer to make appropriate progression. To progress this area of research percentage of one repetition maximum should be reported within the research to allow the intervention to be repeated.

Practical applications and limitations

The findings of this study would suggest that hitting performance can be enhanced by general and specific training interventions. However, due to the inconsistencies in the quality and methodology of the above studies, practitioners should consider the types of athletes they are working with, and which training intervention may fit the profile of their athlete. Whole body resistance training, ballistic training and specific training interventions show their potential value in a programme or in a long-term athlete development strategy for athletes in hitting sports. There is a lack of consensus still about which type of intervention is best for an athlete relative to their playing standard, age and physical training history. When time is limited, highly specific ballistic movements may offer the quickest gains in hitting performance. These interventions can be prescribed at task-specific intensities, set either above or below the sport's demands. With more time, a concurrent approach is preferable, allowing physiological adaptations to develop alongside continued hitting practice. In practice, an effective coach integrates whole-body resistance training with highly specific training across the weekly microcycle and periodises the volume and intensity, as well as the overall emphasis, so that the desired adaptations occur at the optimal time within the athlete's programme and competition schedule. As a limitation, the included studies were confined to three sports, golf, baseball and tennis. Consequently, our conclusions primarily reflect these sports and should be generalised to other hitting sports with caution. Finally, our synthesis emphasises pre to post changes rather than pooled between group effects. This retains outcomes in their native units but warrants cautious interpretation given baseline imbalances and heterogeneity across studies.

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Supplemental material

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