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The Effects of Isolated and Integrated 'Core Stability' Training on Athletic Performance Measures:

A Systematic Review

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Abstract

Background—Core stability training, operationally defined as training focused to improve trunk and hip control, is an integral part of athletic development, yet little is known about its direct relation to athletic performance.

Objective—This systematic review focuses on identification of the association between core stability and sports-related performance measures. A secondary objective was to identify difficulties encountered when trying to train core stability with the goal of improving athletic performance.

Data sources—A systematic search was employed to capture all articles related to athletic performance and core stability training that were identified using the electronic databases MEDLINE, CINAHL and SPORTDiscus™ (1982-June2011).

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Study selection—A systematic approach was used to evaluate 179 articles identified for initial review. Studies that performed an intervention targeted toward the core and measured an outcome related to athletic or sport performances were included, while studies with a participant population aged 65 years or older were excluded. Twenty-four in total met the inclusionary criteria for review.

Study appraisal and synthesis methods—Studies were evaluated using the Physical Therapy Evidence Database (PEDro) scale. The 24 articles were separated into three groups, general performance (n = 8), lower extremity (n = 10) and upper extremity (n = 6), for ease of discussion.

Results—In the majority of studies, core stability training was utilized in conjunction with more comprehensive exercise programmes. As such, many studies saw improvements in skills of general strengths such as maximum squat load and vertical leap. Surprisingly, not all studies reported measurable increases in specific core strength and stability measures following training. Additionally, investigations that targeted the core as the primary goal for improved outcome of training had mixed results.

Limitations—Core stability is rarely the sole component of an athletic development programme, making it difficult to directly isolate its affect on athletic performance. The population biases of some studies of athletic performance also confound the results.

Conclusions—Targeted core stability training provides marginal benefits to athletic performance. Conflicting findings and the lack of a standardization for measurement of outcomes and training focused to improve core strength and stability pose difficulties. Because of this, further research targeted to determine this relationship is necessary to better understand how core strength and stability affect athletic performance.

1. Introduction

Athletes are constantly striving to improve their performance. This is often accomplished through strength and conditioning programmes that invariably involve some aspect of core strengthening. The question then becomes, how does improved core strength and stability improve athletic performance? Before that issue can be examined, it must first be clear what is meant by core strength and core stability. The core encompasses both passive and active structures including bone, musculature and ligaments of the lumbar spine, pelvis and hip.[1–4] Core strength can be defined as the ability of the core muscles to generate and maintain force. Core stability, on the other hand, is a more ambiguous term. Perhaps more important than strength, core stability is the ability of passive and active stabilizers in the lumbopelvic region to maintain appropriate trunk and hip posture, balance and control during both static and dynamic movement.[2,3] Core stability can be thought of as maintaining control of the core during the application of core strength or in response to a perturbation.

The core is a popular target for athletic development training, yet little is known about the direct effects of increased core strength and stability on athletic performance. Several studies have attempted to draw correlations between the two with varying degrees of success.[4,5] Most studies that have had positive results have involved recreationally active persons,

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making it hard to generalize the results to competitive athletes. This systematic review is focused to identify the association between core stability and sports-related performance measures. Our secondary purpose is to identify the difficulties encountered when trying to train the core with the goal of improving athletic performance.

2. Methods

2. 1 Literature Search

A systematic approach was used to identify studies for this review. Electronic databases MEDLINE, CINAHL and SPORTDiscus™ were searched (1982-June 2011) for the Boolean phrase 'core strength' OR 'core stability' OR 'hip strength' OR 'hip stability' AND 'performance' and 179 articles were identified for initial review. Abstracts and unpublished studies were excluded, along with one study with no available English translation. The broad search terms were chosen to discover all of the appropriate articles, at the same time this resulted in several studies that were unrelated to athletics. Many of these articles referenced the core strength of materials such as ceramics. Articles were included if they performed an intervention targeted toward the core and measured an outcome related to athletic or sport performance. Several of the identified studies were excluded because they did not perform a targeted intervention, despite having outcome measures within the scope of athletic performance. As an example, a study that simply measured differences in core strength, balance or sports-specific measures between male and female athletes without preforming any intervention would not be included in this analysis. Twenty-nine studies with a participant population aged 65 years or older were excluded. Only one study of male golfers was excluded on the criteria of participant age alone.

2. 2 Scoring

The 24 included studies were assigned a score using the Physical Therapy Evidence Database (PEDro) scale (Centre for Evidence-Base Physiotherapy, The George Institute for Global Health, University of Sydney, NSW, Australia).[6] Scores are assigned based on the fulfilment of 11 criteria designed to assess internal and external variability of a trial. Points are awarded when a study clearly met the criteria on a literal reading of the study. A second scorer confirmed ambiguities. Scores are presented as a raw number out of a possible total of 11.

3. Results

A total of 179 studies were identified from the original Boolean search. Fifteen duplicates were removed. Studies with a participant population aged 65 years or older were excluded (n = 29). Fifty-six studies were excluded as unrelated to sport or athletic performance along with those that were solely observational (n = 53). Of the remaining 26 studies, one was only available as an abstract and one had no available English translation. For the final analysis, 24 studies met the inclusion criteria for the present review (figure 1). Ten studies with randomized groups were examined first. An additional 14 non-randomized studies were added to further elucidate the role of the core in athletic performance. The average PEDro scoring for all articles was (mean ± SD) 5.3 ± 1.3 (out of a possible 11 ± SD). The ten randomized trials had an average PEDro score of 6.4 ± 0.7, compared with the remaining 14 with an average score of 4.6 ±1.1. A summary of these articles along with their PEDro score can be found in tables I and II.

4. Discussion

Core training is a heterogeneous term. The reviewed studies represent a diverse range of populations and intervention styles, from non-active adults to collegiate athletes and from Pilates to targeted neuromuscular training. This diversity in the literature's definition and measurement of core-focused training makes comparison and synthesis of results difficult. For the purpose of this review, the studies have been divided into three categories based on the general theme of their outcome measure: general performance (n = 8), lower extremity performance (n = 10) and upper extremity performance (n = 6).

4. 1 General Performance

Measures of general performance include vertical leap, shuttle run, sprints and 1-repetition maximum (1-RM) lifts, along with balance measures, core stability testing and electromyography (EMG) measurement. Core training is rarely performed as an isolated training modality, but rather as part of a larger overall fitness routine. Therefore, it is not surprising that seven studies[9–11,18,20,26,27] reported significant improvements in maximum lift performance during post-testing. Likewise, it seems intuitive that interventions that targeted the core would show improvements in measures of core stability and endurance. However, improvements were not uniformly observed. Schiffer and colleagues showed significant improvements in the Sorensen (isometric back endurance) and 1-minute sit-up test following 10 weeks of group aerobics classes.[24] However, Oliver and Di Brezzo demonstrated improvement in the 1-minute sit-up test for athletes training with or without additional indo board work.[15] Similarly, Stanton and colleagues observed significant improvements in Sahrmann core stability testing in high-school athletes training with a Swiss ball.[16]

Others had little success in improving measures related to core stability. One study of collegiate baseball players found increased flexor endurance for groups training both with and without additional core stability routines, but saw no increases in the Sorensen or side-bridging test of either group.[13] Another by Tse and colleagues showed significant improvement in the side-bridging test of collegiate rowers, but failed to improve on the Sorensen or flexor endurance tests.[17] Lastly, a 2010 study by Donahoe-Filmore et al., showed no improvement in either abdominal strength, posture or Sorensen and flexor endurance testing after a 10-week Pilates mat programme.[12] Lust and colleagues addressed the observed range of results for core stability measures, stating that the lack of significant improvement of core stability can be explained by the large SDs in their population and those of similar studies.[13,17]

Conventional performance measures, such as a vertical leap or shuttle run have a less defined core component. Myer and colleagues examined the vertical leap performance of female high-school athletes following two distinct training programmes.[8] Participants were assigned to perform a routine consisting of either plyometric or dynamic balance exercises. Both groups significantly improved vertical leap after the 7-week training session; however,

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the balance group did so while significantly decreasing the vertical ground reaction force (VGRF) observed during a single leg hop and hold; where the plyometric group saw a significant increase in landing VGRF.[8] Similarly, Aggarwal and colleagues compared results from core stability and balance training protocols and found that both improved balance as measured by the stork balance test (a measure of static balance) and star excursion balance test (SEBT, a measure of dynamic balance), but neither improved functional balance as measured by a multiple single leg hop test.[7] In a 2010 study, Filipa and associates also used the SEBT as an outcome to measure the effects of 8 weeks of targeted neuromuscular and core stability, and found a 103% increase in composite score after finishing the programme.[14]

Two additional studies examined the use of instability training on general performance. In a randomized controlled trial (RCT) of 36 re-creationaily active adults, Yaggie and Campbell utihzed a 4-week programme using the both sides up (BOSU®) balance trainer to study the effects of balance training on selected performance measures.[28] The authors found improvements in the total time on the ball (time spent on the BOSU® standing on the dominant leg with eyes closed), as well as a significant improvement in shuttle run time in the treatment group. However, participants showed transient improvement in balance measures that diminished on a retention assessment 2 weeks post-cessation of training. The authors concluded that the BOSU® training may improve dynamic skills and sway parameters; however, it is unclear if those skills are transferable to performance of recreational sport or activity.[28] Marshall and Murphy employed EMG techniques to evaluate core muscle activation during four exercises on stable ground versus an unstable surface (a Swiss ball). Their findings showed an increase rectus abdominis activity with the use of the Swiss ball; however, it is unclear whether this is helpful or is a hindrance to improving core stability through activation of the other lumbopelvic stabilizers.[23]

4. 2 Lower Extremity Performance

The largest collection of studies identified focused on the lower extremity effects of core strengthening. This is likely because the core is closely associated with the lower limb attachment at the hip joint, and the crucial role it plays in the stabilization and transfer of energy from the lower limb throughout the body during movements such as squatting and running.[1,29,30] As was seen in those studies of general performance, these studies showed mixed results. Three studies[19,24,31] found positive increases in running performance following training while two others[16,32] showed no improvement.

In an RCT, Sato and Mokha subjected a cohort of adult runners to a 6-week protocol consisting of five core-related exercises performed 4 days per week.[31] Following training, those in the experimental group saw a decrease (47 seconds), in 5000 m run time.[31] The SEBT was also used an outcome measure, and while the SEBT score was found to be nonsignificant on the basis of interaction effect, the number did improve to a greater extent in the experimental group during the 6 weeks of training.[31] Similarly, Deane and associates demonstrated that an 8-week programme of targeted hip flexion resistance training could achieve significant improvements in 40-yard dash time, shuttle run time and isometric hip strength in a controlled study of 48 healthy adults.[19] They concluded that hip flexor

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strength training is valuable for relatively untrained individuals; however, it is unclear if the same effects would be seen in highly trained, elite athletes.[19] Finally, in an intriguing report by Schiffer and colleagues, it was concluded that long-term participation in an aerobic dance and fitness programme increased core muscle strength, as measured by the Sorensen test and 1-minute sit-up challenge, but also showed improvement in submaximal running performance during an incremental 400 m endurance test.[24]

Not all running studies reported positive results. Stanton and associates trained high-school athletes using a Swiss ball and found significant increases in core muscle strength, but no improvement in VO_{2max} or running economy.[16] Likewise, Steffen and colleagues developed a programme consisting of ten exercises, performed as a warm up, targeted to core stability, balance, dynamic stabilization and eccentric hamstring strength in female soccer players.[32] After the investigation period, no significant differences were found in lower extremity isokinetic or isometric strength or in isometric hip strength. Also, no significant improvements were made in jumping ability, 40 m sprint, or shooting distance, while both experimental and control groups improved their speed dribbling time with no between-group differences.[32]

The remaining lower extremity performance studies all evaluated some level of lower extremity strength following core training. Myer and associates employed 10 weeks of targeted neuromuscular training (TNMT) of the trunk and hip in a group of high-school female volleyball players. It was found after 10 weeks that TNMT increased standing hip abduction strength, and it was concluded that this may improve the abihty of female athletes to increase control of lower limb alignment and decrease motion and loads resulting from increased trunk displacement during sports activities.[18] In another study, Drinkwater and colleagues examined the effects of surface stability on muscle performance during a standard squat exercise with varying degrees of load. The use of unstable platforms decreased measures of concentric force, velocity and power, in addition to squat depth and eccentric power.[22] The authors conclude that while training on an unstable surface promotes core stability and balance, it does so at the expense of strength and power, and that the pursuit of both may require separate protocols.[22]

Another set of studies had a less defined core training component, but rather incorporated it as part of a larger strength and conditioning programme. Fowler and associates studied the effect of adding a swinging pendulum exercise to a weight training protocol.[20] Similar to the competition of balance and strength in the Drinkwater study mentioned previously, the authors found that the addition of the pendulum exercise improved dynamic measures such as vertical jump height and power; however, the weight-training-only group showed greater gains in strength parameters of hip and knee flexion and hip extension.[20] Similarly, Trzaskoma and associates saw increases in 1-RM squat and hip and knee flexor and extensor strength following a 2-week protocol that included four different combinations or traditional weight ‘training and pendulum swim exercises.[27] O’Bryant and colleagues compared a ‘periodized’ (high volume, low intensity) training programme with traditional weight training, both of which included aspects of core training.[26] Both training modalities increased maximum strength and endurance on cycle ergometer testing, while the periodized group produced superior results.[26]

4. 3 Upper Extremity Performance

Six studies evaluated aspects of upper extremity performance as primary outcomes. The population of these studies included males and females competing at various levels in the sports of base-ball, handball and golf. In 2007, Szymanski et al.[9,10] implemented a 12-week medicine ball training programme for high-school baseball athletes. Forty-nine players were randomized to two groups, each performing the same training programme plus 100 bat swings a day. The second group performed additional rotational and full-body medicine ball exercises. General performance measures including squat and bench press maximums, as well as torso rotational strength, were tested at 4, 8 and 12 weeks.

Sport-specific measures included the medicine ball hitter's throw and linear bat end velocity. Both groups made significant improvements in all categories; however, the group performing the additional core training demonstrated a significantly greater rotational strength gain and higher bat end velocity over the group performing resistance training and bat swings alone.[9,10] The group who trained with additional rotational and full-body medicine ball exercises also showed significant increases in angular hip and shoulder velocities where group one showed no such improvement.[9] The authors concluded that it is possible to increase the bat swing velocity of high-school baseball players by the addition of a rotational medicine ball exercise regimen. In 2010, Szymanski and colleagues took an indepth look at the anthropometric data of the participants of this original study.[11] While the authors were able to relate many anthropometric variables to linear bat velocity, they acknowledge considerable variation within these factors, and recommend using the results to identify general relationships of the data as applied to training programmes and recruitment.[11]

Lust and associates enrolled athletes from a division III collegiate baseball team in a 6-week training programme consisting of open- and closed-kinetic chain exercises.[13] One group of participants was randomly assigned to perform additional core stability exercises. The study also enlisted a group of 15 age and activity matched controls; however, they were not part of the college's baseball programme. Three common measures of core stability were used to assess improvement of core endurance, the back extensor (Sorensen) test, the abdominal fatigue test and the right and left side-bridging test. There were no improvements in core stability measures between groups or between testing occasions, with the exception of improved abdominal fatigue times for both experimental groups compared with baseline.[13] The functional throwing-performance index (FTPI) was used to assess the throwing accuracy of the three groups. Both the training groups exhibited greater FTPI scores than control at post-testing, and trending toward significance compared with baseline without achieving it.[13] The small sample size, non-randomized control, and short 6-week training programme make it difficult to generalize the results of this study. The authors conclude that either 6-week programme is capable of improving core stability and throwing accuracy.

In a recent study by Saeterbakken and colleagues,[21] 24 female handball players were stratified by team and assigned to an experimental or control group. After a 6-week core and rotational stability programme, the experimental group demonstrated a significant 4.9% increase in maximal throwing velocity over the unchanged control group.[21] Lephart and associates had equally good results in a 2007 study of experienced golfers.[25] Fifteen healthy subjects followed an 8-week golf-specific training programme, including abdominal and hip strengthening, as well as balance exercises. Post-testing revealed significant increases in torso rotational strength, hip abduction strength and improved balance measures. Golf-specific tesfing also revealed significant increases in swing kinematics, ball velocity and club head velocity, as well as carry distance and total distance.[25]

The current results of the systematic review support the findings of Okada and colleagues[33] who employed McGill's trunk muscle endurance tests to assess core stability to determine associations with performance in the functional movement screen and sport performance measures (backward, overhead, medicine ball throw and T-run agility test). They reported moderate to weak correlations of core stability and functional movement screens and the core stability measures were not strong predictors of performance on either physical' performance test. These authors concluded that the current assessments of core stability do not appear to substantiate the importance of core stability on functional movement.[33] These results, in combination with the current systematic review, indicate that isolated training focused solely to improve core and functional movement should not be the primary emphasis of any sports performance-enhancement training programme, but may be a worthwhile component to include for injury prevention.[34]

5. Conclusion

Core training is a mainstay in many, if not all, athletic development training programmes despite little evidence to prove its direct contribution to athletic performance. There are several challenges to a comprehensive examination of the beneficial effects of core training. First, core training is almost never the sole exercise being performed but, rather, it is a subset of a larger training regimen, making it difficult to isolate the core as a mediator of performance. Second, many studies that show the greatest effect have a study population of re-creationally active students or adults and cannot be readily translated to highly trained competitive athletes. Also, when working with a group of athletes, especially teammates, performing an RCT is difficult.

While this systematic review shows mixed results for the role of core training in improving athletic performance, many studies show promise that a strong and stable core provides a necessary foundation for performance of a variety of athletic movements. Thirteen of the 24 studies included in this analysis tested a population of athletes. These studies used a variety of interventions ranging from a general 8-week core endurance protocol[17] to an 8-week golf-specific training protocol.[25] The general trend of these studies suggests that training tailored to the athlete's sport is more successful in significantly improving sport-specific measures. All six studies that utilized targeted training techniques were able to report at least one significant improvement in sport-specific function.[9–11,14,18,25] On the other hand, of the nine of these studies that also reported general measures, such as 1-RM or 40 m sprint, only four reported a significant improvement.[8,15–17]

Where athletes respond to targeted training with little improvement in general measures, the opposite holds true for the adult nonathletic population. Only two studies of this population involved a targeted intervention[7,22] and seven of the 11 studies reported a significant improvement in a general performance measure.[19,20,24,26–28,31] While beyond the scope of this review, core stability has also been implicated in prevention of athletic injury,[3–5,30] a concept that is tightly intertwined with performance. Further target studies are necessary to fully define the connection of core strength and stability to athletic performance.

- There is little evidence tying core stability to athletic performance.
- Core training is an integral part of many athletic development training programmes.
- Improvements in general performance are not directly attributable to core training alone.
- Movements and sports with strong core components such as golf, swinging a bat or running show the greatest improvements from core training.

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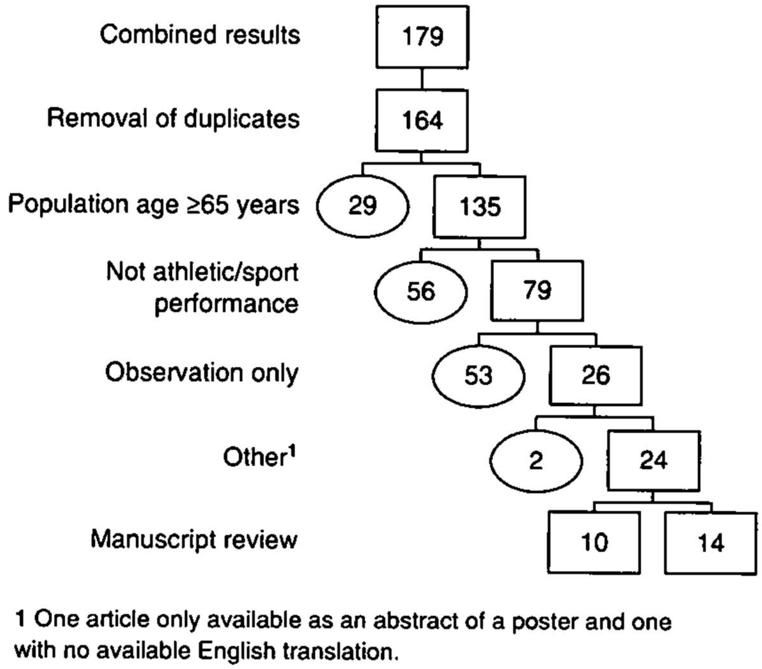

Fig. 1.

Results of systematic literature survey. A search of three electronic databases returned 179 results. Studies were evaluated by title and abstract for inclusion. Twenty-four articles met the predetermined criteria, with a subset of ten studies utilizing randomized trial populations. The numbers in ovals represent the quantity of studies excluded at each stage.

Table I

Randomized controlled studies. Average PEDro score (mean ± SD): 6.4 ± 0.7

Study (year)	Demographic	No. of subjects	Intervention	Performance measures	PEDro (n/11)
Aggarwal et al.[7] (2010)	Adults, recreationally active	30	Core stability or balance training	Multiple single leg hop stabilization test	7
Myer et al.[8] (2006)	Athletes, high-school females	19	Plyometrics or dynamic balance	Single leg hop and balance, vertical leap, 1-RM squat, bench and hang clean	6
Sato and Mokha[7] (2009)	Adults, runners	28	5 core-related exercises	5000 m run	5
Steffen et al.[7] (2008)	Athletes, youth female soccer	31	10 exercises focusing on core stability and balance	Jumping ability, 40 m sprint, speed dribbling, shooting distance	7
Yaggie and Campbell[7] (2006)	Adults, recreationally active	36	Balance training with BOSU®	Time on ball, vertical leap, shuttle run	6
Szymanski et al.[9] (2007)	Athletes, high-school baseball	49	Resistance exercise programme, 100 swings/day, with or without additional medicine ball exercises	Angular velocities of the hips and shoulders, linear velocities of the bat end and hands, 1-RM squat, 1-RM bench press	7
Szymanski et al.[10] (2007)	Athletes, high-school baseball	49	Resistance exercise programme, 100 swings/day, with or without additional medicine ball exercises	1-RM squat and bench press	7
Szymanski et al.[11] (2010)	Athletes, high-school baseball	49	Resistance exercise programme, 100 swings/day, with or without additional medicine ball exercises	Angular velocities of the hips and shoulders, linear velocities of the bat end and hands, 1-RM squat, 1-RM bench press	7
Donahoe-Fillmore et al.,[12] (2007)	Adults, healthy females	11	Pilates mat exercise programme and received general postural education	Abdominal strength, posture, Sorensen, flexor endurance	6
Lust et al.[13] (2009)	Athletes, collegiate baseball	19	Open kinetic chain, closed kinetic chain, with or without core-stability exercises	FTPI timed throwing-accuracy test, closed kinetic chain upper extremity stability test	6

BOSU® = both sides up balance trainer; **FTPI** = functional throwing performance index; **PEDro** = Physical Therapy Evidence Database; **RM** = repetition maximum.

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Table II

Studies that did not follow a randomized control protocol. Average PEDro score (mean ± SD): 4.6 ± 1

Study (year)	Demographic	No. of subjects	Intervention	Performance measures	PEDro (n/11)
Filipa et al.[14] 2010	Athletes, female soccer	20	NMTP focused on core stability and lower extremity strength	Star excursion balance test	4
Oliver and Di Brezzo[15] (2009)	Athletes, collegiate females	26	10 min of indo board training 4 days a wk	1 min sit-up test, single leg squat	5
Stanton et al.[16] (2004)	Athletes, high-school males	18	Swiss ball training	$\dot{V}O_{2max}$, running economy	2
Tse et al.[17] (2005)	Athletes, collegiate rowers	45	8 wk core endurance protocol	Vertical leap, standing broad jump, shuttle run, 40 m sprint, medicine ball throw, 2000 m row ergometer	4
Myer et al.[18] (2008)	Athletes, high-school females	21	Trunk and hip focused neuromuscular training	Isokinetic hip abduction, knee flexion/extension strength	4
Deane et al.[19] (2005)	Adults, healthy	48	Hip flexion resistance training	40 yard dash, shuttle run, vertical leap, isometric hip strength	5
Fowler et al.[20] (1995)	Adults, healthy males	9	Weight training only or combined pendulum and weight training	Isometric knee and hip extension flexion, 1-RM squat, vertical leap, countermovement jump	6
Saeterbakken et al.[21] (2011)	Athletes, female handball	24	Progressive core stability-training programme	Maximum throwing velocity	6
Drinkwater et al.[22] (2007)	Adults, recreationally active	14	3 repetitions squat with 10-RM resistance, 40% of 10-RM resistance, and 20.45 kg (45 lbs) on surfaces of various stability	Peak concentric power, peak concentric force, peak concentric velocity, squat depth, peak eccentric power	4
Marshall and Murphy[23] (2005)	Adults, healthy	8	4 exercises on and off a Swiss ball	EMG (rectus abdominis, external oblique, transversus abdominis, internal oblique, and erector spinae)	4
Schiffer et al.,[24] (2009)	Adults, healthy	20	Aerobic dance and fitness programme	Vertical leap velocity, 1 min dip test, submaximal running performance	5
Lephart et al.,[25] (2007)	Athletes, trained golfers	15	8 wk golf-specific conditioning programme	Swing kinematics, ball velocity, launch angle, backspin rate, club head velocity, carry distance, total distance	4
O'Bryant et al.[26] (1988)	Adults, healthy collegiate males	90	11 wk, 2 groups, group 1: 'periodized' approach high volume, low intensity to low volume, high intensity; group 2: 3×6-RM	1-RM parallel squat, power capacity on cycle ergometer	5
Trzaskoma et al.[27] (2010)	Adults, recreationally active	38	4 groups of strength and power training	1-RM in full squat and squat jump with the barbell, maximal force measured during countermovement jump, and hip and knee flexion/extension isometric strength	6

EMG = electromyography; **NMTP** = neuromuscular training programme; **PEDro** = Physical Therapy Evidence Database; **RM** = repetition maximum; $\dot{V}O_{2max}$ = maximal aerobic power.