THE EFFECTS OF CORE TRAINING ON ENDURANCE IN DIFFERENT TRUNK MOVEMENTS: A SYSTEMATIC REVIEW AND META-ANALYSIS

Ekaitz Dudagoitia Barrio[1], Raquel Hernandez-García[1], Rodrigo Ramírez-Campillo[2], and Antonio García de Alcaraz[3,4]

[1]Faculty of Sport Sciences, University of Murcia, Murcia, Spain
[2]Exercise and Rehabilitation Sciences Laboratory, School of Physical Therapy, Faculty of Rehabilitation Sciences, Universidad Andres Bello, Santiago, Chile
[3]Faculty of Educational Sciences, University of Almería, Almería, Spain
[4]SPORT Research Group (CTS-1024), CERNEP Research Center, University of Almería, Almería, Spain

Review
DOI 10.26582/k.56.1.9

Abstract:

Core muscle endurance involves the trunk muscles' capability to maintain a particular position for as much time as possible. It is essential to know how specific training aimed at this area affects endurance of different trunk movements performance and to what extent. The objective was to assess the effects of trunk training on different core muscle endurance measurements in flexion, extension, and right and left lateral flexion. A literature search was performed using different databases. The studies included: (a) cohorts of healthy people or subjects with chronic low back pain; (b) a core training intervention; (c) pre-post intervention parameters of interest; (d) a minimum of four out of 10 on the PEDro scale, and (e) randomised controlled trials. A random-effects model for meta-analyses was used. Fifteen studies were selected for the systematic review and 11 for the meta-analysis, comprising 1,213 participants. Compared to the control condition, core training induced a moderate effect on trunk flexion endurance (ES = 0.67), right-lateral trunk flexion endurance (ES = 0.77), left-lateral trunk flexion endurance (ES = 0.94), and a small effect on trunk extension endurance (ES = 0.49). To back up the results presented in this study, more research into the effects of trunk training on core muscle endurance is needed to confirm these results significantly. Core training improves core muscle endurance in four trunk movements. Core training is more effective in participants with pre-intervention poor results.

Keywords: *muscle strength, resistance training, athletic performance, exercise therapy, motor activity, physical fitness*

Introduction

The trunk zone is particularly interesting for researchers and coaches in physical activity, performance, and health (Hibbs, Thompson, French, Wrigley, & Spears 2008; Hodges, 2003). The main muscles that comprise this zone are *transversus abdominis*, internal oblique, external oblique, *rectus abdominis* and *multifidus* (Majewski-Schrage, Evans, & Ragan, 2014). The term core has been adopted by fitness centres; however, it is usually not well employed or its meaning remains unclear. The term refers to the function and capability of the central body. The main functions of the core provide force generation, generate proximal stability for distal mobility, and generate interactive movements (Kibler, Press, & Sciascia, 2006). This system is essentially designed to develop, absorb and/or transmit forces needed for human movement (Cook, 2010). Experts define core stability as "the ability to achieve and sustain control of the trunk region at rest and during precise movement" (Majewski-Schrage, et al., 2014). In this sense, core muscle endurance is understood as the trunk muscles' capability to keep a position for as much time as possible, maintaining force over time (McGill, Childs, & Liebenson, 1999). Additionally, high levels of core muscle endurance may significantly benefit musculoskeletal health (Sibson, et al., 2021).

Over the years, core exercises have been commonly prescribed for the treatment of unspecific lower back pain (LBP), or to improve athlete's performance, despite the lack of scientific evidence of solid quality about these benefits in athletes (Stuber, Bruno, Sajko, & Hayden, 2014). In adults with chronic LBP, core-based exercises seem to be one of the most effective methods to reduce pain and disability (Fernández-Rodríguez, et al., 2022). Besides, this type of training turns out to be more effective than general exercise in reducing LBP (Wang, et al., 2012). In athletes, poor core muscle endurance is likely associated with nonspecific LBP (Abdelraouf & Abdel-Aziem, 2016), but, in contrast, it is not clear that core training reduces LBP in this population (Nadler, et al., 2002). However, the core muscle endurance in trunk extension and flexion movements seems to be inversely correlated with non-specific LBP (Abdelraouf & Abdel-Aziem, 2016). Thus, it seems sensible to train these movements in this type of patients.

To put relevance of the core in context, deep core musculature is activated earlier than the anterior deltoid during arm movements (Allison & Morris, 2008) and, probably, this earlier activation is untrainable (Vasseljen, Unsgaard-Tøndel, Westad, & Mork, 2012). These results show that a strong and stable point could be necessary for the correct transfer of forces and, consequently, sports performance. In the sports performance context, a specific core training programme improves performance, increasing throwing velocity in female handball players, supporting the theory of a stable point (Saeterbakken, van den Tillar, & Seiler, 2011). Good core muscle endurance influences the ability of the subject to run intermittently, exert maximum force and power, push-up, sit and lift. In addition, individuals with higher core endurance have better quality of movement (Santos, Behm, Barbado, DeSantana, & Silva-Grigoletto, 2019). A strong and stable core provides a necessary foundation for the performance of various athletic activities, and core training seems more relevant in sports in which the core plays an important role (Reed, Ford, Myer, & Hewett, 2012).

Fitness programmes focused on the core use body weight exercises or exercises on unstable surfaces without clear justification about (Granacher, et al., 2014). Trunk training protocols usually use exercises and training variables similar to those used in core muscle endurance assessments (Hung, Chung, Yu, Lai, & Sun, 2019). For example, the front-prone plank is a common exercise used until exhaustion among athletes to assess core muscle endurance. In contrast, some sports tasks usually require trunk flexion of maximal voluntary contraction (MVC) to transfer energy from legs to arms, such as long-distance passes in rugby or a throw-in in soccer. This type of situation could be hard to replicate during usual gym core training. Thus, core endurance training could be effective in enhancing core muscle endurance but not meet the needs of the most demanding motor tasks. However, trunk training seems to be effective in improving stability (Barrio, Ramirez-Campillo, Alcaraz-Serrano, & Hernandez-García, 2022; Hsu, Oda, Shirahata, Watanabe, & Sasaki, 2018), and it could cover the demands of the specific sport. Moreover, core training promotes lumbar movement adjustments and alters the movement patterns during running (Ogaya, et al., 2021).

The most popular methods to assess core muscle endurance are field-based tests, probably due to their accessibility, easy usage and portability (Friedrich, Brakke, Akuthota, & Sullivan, 2017; Juan-Recio, López-Plaza, Barbado Murillo, García-Vaquero, & Vera-García, 2018). Different tests have been used to determine core muscle endurance, like isometric trunk flexion, isometric trunk extension and right and left side bridges (McGill, et al., 1999). In the literature, a unique test with strong reliability to assess trunk extension endurance was Biering-Sorensen isometric trunk extension (Martínez-Romero, et al., 2020). This test focused on four main movements of the trunk: flexion, extension, right flexion, and left flexion and how the trunk training may affect the capability of the trunk to maintain the position to resist over time.

Although trunk training seems effective in improving core muscle endurance (Sandrey & Mitzel, 2013), according to the pyramid-based evidence paradigm, no greater knowledge has been generated regarding trunk training and its effects on the trained population. Thus, no previous systematic review with meta-analysis (SRMA) was conducted regarding trunk training effects on core muscle endurance. In addition, the most sensible movements to train were not reported: flexion, extension and lateral flexions.

Since (i) no specific SRMA has explored the effects of trunk endurance training, (ii) the increased scientific awareness of the relevance of core training has been evidenced in the last decade (with more than 70% of all studies published in this period), and (iii) the needs to clear the relevance of core training on different trunk movements endurance, this research study aimed to conduct an SRMA to assess the effects of trunk training on different core muscle endurance measurements: flexion, extension, right and left lateral flexions. Thus, this study hypothesised that trunk training would improve all core muscle endurance measurements, especially in the most trained movements of various sports.

Methods

This systematic review was carried out according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement protocol (Moher, et al., 2009). A literature search was conducted in three of the most relevant electronic databases: PubMed, Web of Science and Scopus. The following keywords, combined with Boolean operators (AND, OR), were used: "core strength", "core muscle endurance", "core stability", and "core engagement". An example of a PubMed search is ("randomized controlled trial" [Publication Type]) OR "controlled clinical trial" [Publication Type]) AND "core" [Title/Abstract]) AND "strength" [Title/Abstract]) OR "endurance" [Title/Abstract] OR [Title/Abstract] "stability" OR [Title/Abstract] "engagement". No exclusion criteria based on the year of publication were applied. One investigator received automatically generated emails for updates regarding the search terms used. These updates were received daily (if available), and studies were eligible for inclusion until the initiation of the manuscript preparation.

Inclusion and exclusion criteria

The following inclusion criteria were applied: (a) trunk training used in intervention periods of at least two weeks of duration, defined as "exercises focusing on stimulation of one or more of the next muscles: *transversus abdominis*, internal oblique, external oblique, *rectus abdominis* and *multifidus*" (Majewski-Schrage, et al., 2014), (b) cohorts of healthy subjects or with chronic low back pain, (c) a minimum of 4 of 10 in PEDro scale, which ensures at least "moderate" quality of the study, (d) measurements of core muscle endurance that were selected based on a logically defensible rationale, and (e) randomized controlled trials with a control group. The exclusion criteria were: (a) cross-sectional, a review, or a training-related study not focused on the dynamic postural stability, (b) retrospective studies, prospective studies, studies in which trunk training was mixed with other types of training, studies for which only the abstract was available, case reports, studies with ambiguous study protocols, non-human investigations, special communications, repeated-bout effect interventions, letters to the editor, invited commentaries, errata, overtraining studies, and detraining studies (included if training period was before detraining period) and (c) non-English language studies.

Study quality assessment

The Physiotherapy Evidence Database (PEDro) (de Morton, 2009) scale was used to assess the methodological quality of the included articles. The PEDro scale is based on 11 items selected by "expert consensus". The first one requires answere "yes" or "no", and the rest ratings 0 or 1. These items show a scale where the highest value is 10 (low risk of bias) and the lowest 0 (high risk of bias). The study quality assessment was interpreted using the following 10-point scale: poor quality (≤3 points), moderate quality (4–5 points), and high quality (6–10 points) (Table 1).

Study selection

Two investigators (EDB and AGA) reviewed the studies and decided whether inclusion was appropriate. Any discrepancies were resolved via consensus with the third author (RHG). Figure 1 shows the search strategy and study selection. Out of 628 records screened, 545 were discarded due to not meeting the inclusion criteria selected by reading only the title and abstract. Out of 83 studies selected for the full text read, 68 were discarded for different reasons like not written in English, did not assess core muscle endurance, not using a control group, mixed training protocols, or high risk of bias. Four studies were removed from the systematic review (SR) to meta-analysis (MA) due to the absence of specific data or due to confusing data.

Characteristics of the studies included

For the current SRMA, the core muscle endurance measurements were selected based on a logically defensible rationale. Extracted data included the following information: type of control, type of randomisation, number of participants per group, type of test, unit of measurement for each test and the measurement of each test (flexor, extensor, right or left lateral flexor). In addition, the participants' age (years), sex, and fitness level were collected. Regarding training characteristics, the frequency of training (days per week), the duration of training (weeks), the types of exercises, with or without equipment and the sets and repetitions for each exercise were also registered.

Data extraction

The main information (authors, year, control and experimental sample, intervention duration, training frequency, total sessions, duration of each training session, type of exercises, equipment, sets, repetitions, tests, measurements and main effects) were extracted from the included studies. Two investigators verified a suitable process and discussed each item. The articles were examined and verified along with all the preliminary information collected and divided into columns in an Excel table. This way, the guideline to improved searching in PubMed (Schardt, Adams, Owens, Keitz, & Fontelo, 2007) was followed to search methodological gaps as experts recommended. To perform meta-analysis, mean pre-post, standard deviations (SD) and the number of subjects (n) were extracted and arranged on another Excel page. The Image J software (National Institutes of Health, Bethesda, MD, USA) program was used to capture the information from studies that only included results on graphics.

Data analysis

For the analysis and interpretation of results, meta-analyses were conducted if at least three studies provided baseline and follow-up data for the same parameter (García-Hermoso, Ramírez-Campillo, & Izquierdo, 2019). Further analysis was carried out (flexion, extension, left and right-lateral trunk endurance). Means and standard deviations (SD) for each measure of trunk endurance pre-post-intervention were converted to Hedges's g effect size (ES). The continuous random-effects model for meta-analysis was used because it allocates a proportional weight to trials based on the size of their individual standard errors (Deeks, et al., 2019) and facilitates analysis while accounting for heterogeneity across studies (Kontopantelis, Springate, & Reeves, 2013). In this sense, the likelihood approach with random effects was used to better account for the inaccuracy in the estimate of between-study variance (Hardy & Thompson, 1996). The ESs were presented alongside 95% confidence intervals (CIs). The calculated ES were interpreted using the conventions outlined for standardized mean difference: <0.2, trivial; 0.2–0.6, small; >0.6–1.2, moderate; >1.2–2.0, large; >2.0–4.0, very large; >4.0, extremely large (Hopkins, Marshall, Batterham, & Hanin, 2009). All analyses were conducted using the Comprehensive Meta-Analysis program (version 2; Biostat, Englewood, NJ, USA).

To gauge the degree of heterogeneity amongst the studies included, the percentage of total variation across the studies due to heterogeneity (Cochran's Q-statistic) (Higgins, Thompson, Deeks, & Altman, 2003) was used to calculate the I2 statistic. This value represents the proportion of effects due to heterogeneity compared to the chance (Moher, et al., 2009). Low, moderate and high levels of heterogeneity correspond to I2 values of <25%, 25-75%, and >75%, respectively (Higgins, et al., 2003; Higgins & Thompson, 2002). However, these thresholds are considered tentative (Higgins, et al., 2003). The Chi-square test assesses whether any observed differences in results are compatible with chance alone. A low p-value or a large Chi-square statistic relative to its degree of freedom provides evidence of heterogeneity of intervention effects beyond those attributed to chance (Deeks, et al., 2019). The risk of bias across the studies was assessed using the extended Egger's test (Egger, Smith, Schneider, & Minder, 1997).

Results

Figure 1 provides a graphical schematisation of the study selection process carried out by PRISMA. Through database searching, 790 records were initially identified. Finally, 15 studies were considered in SR (Aggarwal, Kumar, & Kumar, 2010; Chuter, de Jonge, Thompson, & Callister, 2015; Jamison, et al., 2012; Junker & Stöggl, 2019; Kuhn, Weberruß, & Horstmann, 2019; Lust, Sandrey, Bulger, & Wilder, 2009; Mayer, et al., 2014, 2016; Ozmen & Aydogmus, 2016; Sannicandro, 2017; Shamsi, Sarrafzadeh, Jamshidi, Zarabi, & Pourahmadi, 2016; Stanton, Reaburn, & Humphries, 2004a; Toprak Çelenay, & Özer Kaya, 2017; Tse, McManus, & Masters, 2005; Weston, Coleman, & Spears, 2013) and 11 for the MA (Aggarwal, et al., 2010; Jamison, et al., 2012; Junker & Stöggl, 2019; Lust, et al., 2009; Mayer, et al., 2014, 2016; Ozmen & Aydogmus, 2016; Sannicandro, 2017; Shamsi, et al., 2016; Stanton, et al., 2004a; Tse, et al., 2005), involving 16 experimental groups and 15 control groups, with 649 (412 males, 120 females, and 117 non-defined sex) and 564 (355 males, 121 females, and 88 non-defined sex) subjects, respectively.

Quality of the studies

Supplementary file 1 shows the quality of the studies included in the SRMA. Eleven out of 15 studies were considered high-quality (Aggarwal, et al., 2010; Chuter, et al., 2015; Jamison, et al., 2012; Junker & Stöggl, 2019; Kuhn, et al., 2019; Mayer, et al., 2014, 2016; Sannicandro, 2017; Shamsi, et al., 2016; Toprak Çelenay & Özer Kaya, 2017; Weston, et al., 2013) and four as moderate quality (Lust, et al., 2009; Ozmen & Aydogmus, 2016; Stanton, et al., 2004a; Tse, et al., 2005). The mode was 6 points, and the mean was 6.2 points for SRMA and 6.1 for 11 articles included in MA.

Characteristics of the studies included

Table 1 synthesises studies in the SRMA (Aggarwal, et al., 2010; Chuter, et al., 2015; Jamison, et al., 2012; Junker & Stöggl, 2019; Kuhn, et al., 2019; Lust, et al., 2009; Mayer et, al., 2014, 2016; Ozmen & Aydogmus, 2016; Sannicandro, 2017; Shamsi, et al., 2016; Stanton, et al., 2004a; Toprak Çelenay & Özer Kaya, 2017; Tse, et al., 2005; Weston, et al., 2013). Nine articles included male and female athletes (Aggarwal, et al., 2010; Chuter, et al., 2015; Junker & Stöggl, 2019; Mayer, et al., 2014, 2016; Ozmen & Aydogmus, 2016; Sannicandro, 2017; Shamsi, et al., 2016; Toprak Çelenay & Özer Kaya, 2017), and five of these studies specified the participants' sex and managed data separately (Aggarwal, et al., 2010; Mayer, et al., 2014, 2016; Shamsi et al., 2016; Toprak Çelenay & Özer Kaya, 2017). Four studies included only male athletes (Jamison, et al., 2012; Stanton, et al., 2004a; Tse, et al., 2005; Weston, et al., 2013), only one comprised a female sample (Kuhn, et al., 2019), and another one did not specify the sex of the participants (Lust, et al., 2009). The participants chronological age varied from 10.8 to 66.4 years. Seven studies included athletes from different sports (American football, handball, baseball, badminton, basketball, touch

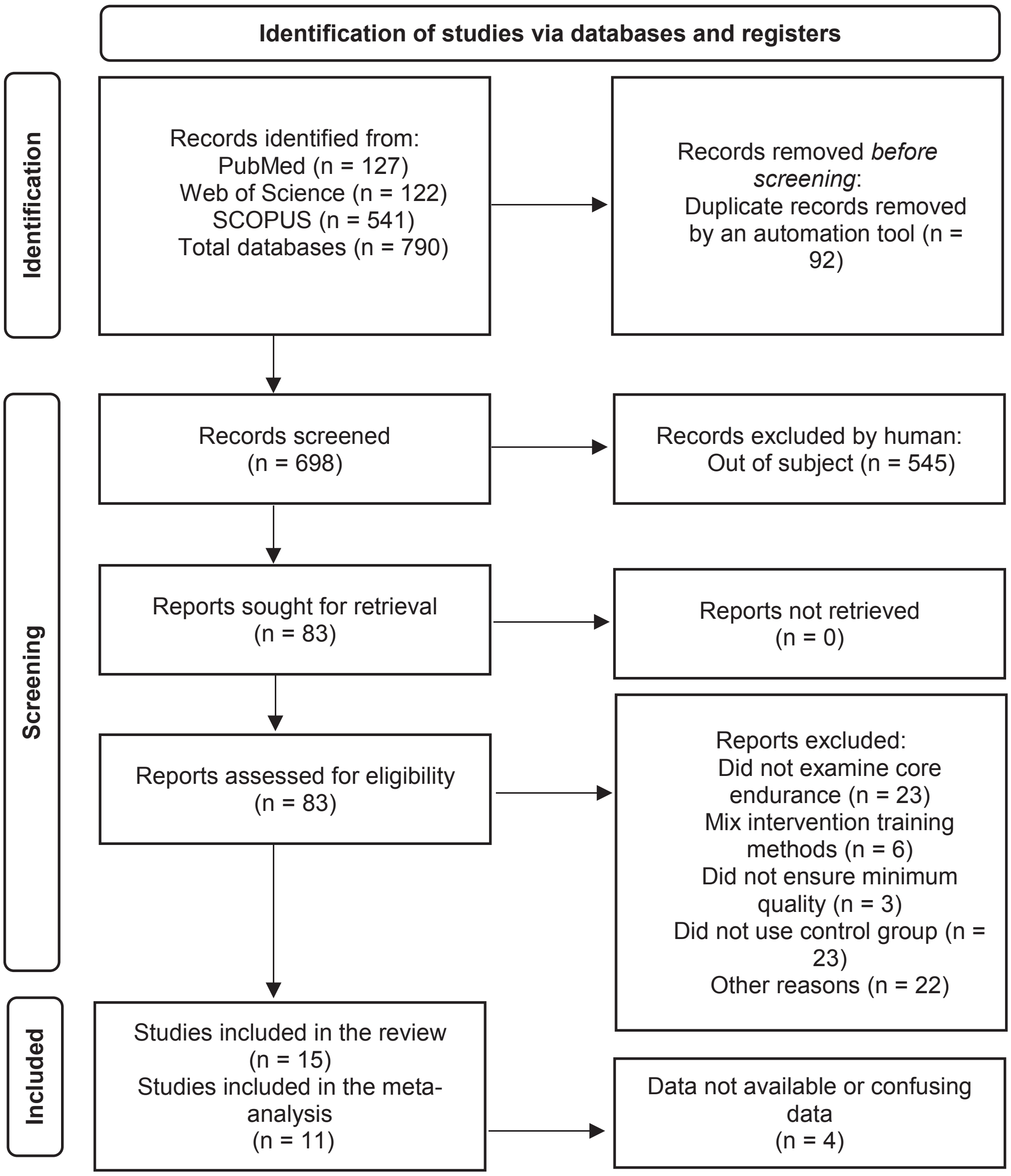

Figure 1. PRISMA flow diagram.

football, rowing, and golf) (Jamison, et al., 2012; Kuhn, et al., 2019; Lust, et al., 2009; Ozmen & Aydogmus, 2016; Stanton, et al., 2004a; Tse, et al., 2005; Weston, et al., 2013). Four articles selected active healthy people as participants (Aggarwal, et al., 2010; Junker & Stöggl, 2019; Sannicandro, 2017; Toprak Çelenay & Özer Kaya, 2017). Only one study used firefighters (Mayer, et al., 2014), and another one soldiers (Mayer, et al., 2016). Two studies comprised participants with different health problems, poor core stability (Chuter, et al., 2015) and chronic LBP (Shamsi, et al., 2016).

Six studies used only bodyweight exercises to carry out specific trunk training (Junker & Stöggl, 2019; Mayer, et al., 2014; Sannicandro, 2017; Shamsi, et al., 2016; Tse, et al., 2005; Weston, et al., 2013). The most utilised equipment was the Swiss ball, used in seven out of 15 articles included in this SRMA (Aggarwal, et al., 2010; Chuter, et al., 2015; Kuhn, et al., 2019; Lust, et al., 2009; Ozmen & Aydogmus, 2016; Stanton, et al., 2004a; Toprak Çelenay & Özer Kaya, 2017). One of these seven studies used only a Swiss ball to perform all exercises (Stanton, et al., 2004a). Medball, resistance bands and other unstable surfaces were the equipment selected in the rest of the training methodologies (Aggarwal, et al., 2010; Chuter, et al., 2015; Jamison, et al., 2012; Kuhn, et al., 2019; Mayer, et al., 2016; Ozmen & Aydogmus, 2016; Toprak Çelenay & Özer Kaya, 2017). Duration of training varied between five to 24 weeks, one to three sessions per week, 11 to 48 total sessions, 1 to 4 sets and 5 to 20 repetitions, or 6 to 105 seconds. Regarding the exercises, a great variation was found between training methodologies. Different sides planks were the most selected exercises in training programmes. The two

Table 1. Studies included in the systematic review and meta-analysis

Author/s (year)	EXPERIMENTAL group	CONTROL group	CORE training	Training material	Duration	Tests / Outcome	Effect
Aggarwal, Kumar and Kumar (2010)	Active male (n=10) and female (n=10) 24.62 y.o.	Active male (n=10) and female (n=10) 23.85 y.o.	Abdominal muscle contractions (different positions), bird -dog, superman, multi direction lunges, twists, front planks, oblique pulleys, different crunches and back bridges	Medball, Swiss ball and BW	6 weeks, 3 days/ week, 18 total sessions, 40-50 min, 1-3 sets, 10-20 reps	TF (sec) TE (sec) RP (sec) LP (sec) PP (sec)	↑ ↑ ↑ ↑ ↑
Celenay and Kaya (2017) *	Active male (n=13) and female (n=15) 21 y.o.	Active male (n=13) and female (n=12) 20.36 y.o.	Thoracic bracing (supine, prone, side lying, quadrupedal, and bipedal) with upper and lower movements	BW, resistance band and Swiss ball	8 weeks, 45 min, 3 sets, 10-15 reps	TF (sec) TE (sec) RP (sec) LP (sec)	↑ ↑ ↑ ↑
Chuter et al., (2015) *	Male and female with poor core stability (n=26) 26.31 y.o. Male and female with poor core stability (n=26) 25.22 y.o. (home CORE)	Male and female with poor core stability (n=26) 27.01 y.o.	Cat/camel, abdominal contraction, side bridge, dead bug, bird dog, hip abduction, swiss ball abdominal isometric, lunges and different trunk twists with band resistance and swiss ball	BW, resistance band and Swiss ball	8 weeks, 2 days/ week, 16 total sessions, 2-3 sets, 10-15 reps or 15-105 secs	TF (sec) TE (sec) Lateral bridge (sec)	↑ ↑ ↑
Jamison et al. (2012)	Male American football players (n=10) 20.5 y.o.	Male American football players (n=11) (RT) 20.3 y.o.	Prone planks, side planks, front, back and side lunges, sagittal and diagonal abdominal curls, hip abduction, quadruped exercises and supine exercises	BW and dumbbells	6 weeks, 60 min, 3 days/week, 18 total sessions	TF (sec) TE (sec) Side bridge (sec)	↑ ↑ ↑
Junker and Stoggl (2019)	Male and female recreationally active (n=11) 28.2 y.o.	Male and female recreationally active (n=12) 29.1 y.o.	Plank, side plank, back bridge, quadruped, back extension.	BW	8 weeks, 2 days/ week, 16 total sessions, 3 sets of 15-50 sec	Dynamic PP (sec) TE movement (sec) Dynamic side bridge (sec)	↔ ↑ ↑
Kuhn, Weberrub and Horstmann (2019) *	Female handball recreational players (n=10) 24.1 y.o.	Female handball recreational players (n=10) 23.7 y.o.	Plank push-up, sit-up, side plank prone plank and quadruped stance variations, prone plank, shoulder bridge, back extension	Swiss ball and unstable surface	6 weeks, 2 days/ week, 12 total sessions, 2 sets of 45 sec, 1 min rest	TF movement (sec) TE movement (sec) RP movement (sec) LP movement (sec)	↔ ↔ ↑ ↑
Lust et al. (2009)	Baseball players average (n=11) 20 y.o.	Baseball players average (n=8) 20 y.o.	Dead bug, partial sit-ups, bridging, prone exercises, quadruped exercises, wall slides, and ball exercises	BW and Swiss ball	6 weeks, 18 total sessions, 3 days/ week, 2 sets, 30-105 secs	TF (sec) TE (sec) RP (sec) LP (sec)	↔ ↔ ↔ ↔
Mayer et al. (2014)	Male (n=52) and female (n=2) firefighters 37.6 y.o.	Male (n=35) and female (n=7) firefighters 31.3 y.o.	Cat-camel, birddog, curl-up, side bridge and Roman chair back extension	BW	24 weeks, 2 days/ week, 48 total sessions, 1 set/ exercise, 5 reps	TE (sec) PP (sec)	↑ ↑
Mayer et al. (2016)	Male (n=266) and female (n=68) Texas soldiers 21.5 y.o.	Male (n=231) and female (n=67) Texas soldiers (n= 298) 21.8 y.o. (lumbar extension high intensity training)	Abdominal drawing-in crunch maneuver, horizontal side support, supine shoulder bridge, quadruped alternating arm and leg, and woodchopper	BW and resistance band	11 weeks, 1 day/ week, 11 total sessions, 1 set / exercise, 6 reps	Lumbar extension (reps) PP (sec)	↓ ↔

Table 1. Studies included in the systematic review and meta-analysis

Author/s (year)	EXPERIMENTAL group	CONTROL group	CORE training	Training material	Duration	Tests / Outcome	Effect
Ozmen and Aydogmus (2016)	Male and female badminton players (n=10) 10.9 y.o.	Male and female badminton players (n=10) 10.8 y.o.	Abdominal bracing, hollowing, prone, supine and side bridge, quadruped alternate-arm leg raises, seated marching, crossover crunch, dead-bug, superman and twist	BW, Swiss ball and Medball	6 weeks, 2 days/ week, 12 total sessions, 10-20 reps, 4 exercises each session	TF (sec)	↑
						TE (sec)	↑
						Lateral bridge (sec)	↑
Sannicandro (2017)	Active male and female (n=33) 66.4 y.o.	Active male and female (n=32) 66.2 y.o. (aerobic)	Plank, side plank, climber, prone plank, supine bridge and quadruped leg raises	BW	8 weeks, 3 days/ week, 24 total session, 3-4 sets, 6-8 reps or 6 secs	TF (sec)	↑
						TE (sec)	↑
						RP (sec)	↔
						LP (sec)	↑
Shamsi et al. (2016)	Male (n=7) and female (n=15) with chronic LBP 39.2 y.o.	Male (n=6) and female (n=15) with chronic LBP 47.9 y.o (general body exercises)	4 sessions → cognition of local muscle contraction sessions; 6 sessions → low contractions, isometric and minimal loaded position sessions and last 6 sessions → functional tasks with heavier loads sessions	BW	5-6 weeks, 20 min, 16 sessions 3 days per week	TF (sec)	↔
						TE (sec)	↔
						RP (sec)	↔
						LP (sec)	↔
Stanton, Reaburn and Humphries (2004)	Basketball and touch football male (n=11)15.6 y.o.	Basketball and touch football male (n=11)15.5 y.o.	Lunge, supine lateral roll, alternating superman, forward roll on knees, supine 2 leg bridge and supine Russian twist	Swiss ball	6 weeks, 2 days/ week, 12 total sessions, 2-3 sets, 10 reps, ↑volume each 2 week	Swiss ball prone stability test (sec)	↑
Tse et al. (2005)	Male rowers (n=25) 21 y.o.	Male rowers (n=20) 20.01 y.o.	Stability exercise → Static/dynamic → Controlled mobility	BW	8 weeks, 2 days/ week, 16 total sessions, 10-40 min	TF (sec)	↔
						TE (sec)	↔
						RP (sec)	↑
						LP (sec)	↑
Weston, Coleman and Spears (2013) *	Club male golfers (n=18) 47 y.o.	Club male golfers (n=18) 47 y.o.	Double-leg squat, bent-leg curl up, superman, supine bridge, prone bridge, quadruped, lunge, and side bridge	BW	8 weeks, 3 days/ week, 24 total sessions	TF (sec)	↑

Notes. y.o.= years old; sec= seconds; LBP= low back pain; REP = repetitions; ↑ : significantly improved EXPERIMENTAL; ↔ : not significantly improved; ↓ significantly improved CONTROL; BW: body weight; *: articles not included in the meta-analysis; TF: trunk flexion; TE: trunk extension; PP: prone plank; RP: right plank; LP: left plank.

studies that included the medball in the training programme improved all core muscle endurance measured in their investigation, trunk flexion, extension and both lateral (Aggarwal, et al., 2010; Ozmen & Aydogmus, 2016). In addition, methodologies that included resistance bands or dumbbells improved all measures of core muscle endurance (Chuter, et al., 2015; Jamison, et al., 2012; Toprak Çelenay & Özer Kaya, 2017). Only one study performed with soldiers, which included resistance bands in their training, did not show improvements in the prone plank test (Mayer, et al., 2016). Five weeks of training seemed ineffective in improving core muscle endurance in LBP patients (Shamsi, et al., 2016). However, six weeks of treatment showed improvements in most studies that used different types of healthy samples (Aggarwal, et al., 2010; Jamison, et al., 2012; Ozmen & Aydogmus, 2016; Stanton, et al., 2004b). Regarding total sessions in programmes, the three studies that used 24 total sessions or more showed improvements in all of their core muscle endurance measures except in trunk extension in Sannicandro study (Mayer, et al., 2014; Sannicandro, 2017; Weston, et al., 2013).

To measure the anterior muscles of core muscle endurance, predominantly rectus and transversus abdominis, the most selected test was the flexion endurance test in ten studies (Aggarwal, et al., 2010; Chuter, et al., 2015; Jamison, et al., 2012; Lust, et al., 2009; Ozmen & Aydogmus, 2016; Sannicandro, 2017; Shamsi, et al., 2016; Toprak Çelenay & Özer Kaya, 2017; Tse, et al., 2005; Weston, et al., 2013), and the prone plank test in three studies (Aggarwal, et al., 2010; Mayer, et al., 2014, 2016). In addition, one study used dynamic prone plank (with movement) (Junker & Stöggl, 2019), another analysed the dynamic trunk flexion (with movement) (Kuhn, et al., 2019), and the last one used prone plank on an instability platform (Swiss ball) (Stanton, et al., 2004a). To assess the posterior values of core muscle endurance, predominantly *multifidus* and *transversus abdominis*, the most selected test was the trunk extension endurance test in ten studies (Aggarwal, et al., 2010; Chuter, et al., 2015; Jamison, et al., 2012; Lust, et al., 2009; Mayer, et al., 2014; Ozmen & Aydogmus, 2016; Sannicandro, 2017; Shamsi, et al., 2016; Toprak Çelenay & Özer Kaya, 2017; Tse, et al., 2005). Two studies used dynamic trunk extension (with movement) (Junker & Stöggl, 2019; Kuhn, et al., 2019), and another one used a lumbar dynamometer machine to quantify repetitions of trunk extensions (Mayer, et al., 2016). To quantify lateral sides of core muscle endurance, mainly internal and external obliques and *transversus abdominis*, the most selected test was right and left plank endurance tests in six studies (Aggarwal, et al., 2010; Lust, et al., 2009; Sannicandro, 2017; Shamsi, et al., 2016; Toprak Çelenay & Özer Kaya, 2017; Tse, et al., 2005). Three studies did not separate the right and left sides and only measured one side (Chuter, et al., 2015; Jamison, et al., 2012; Ozmen & Aydogmus, 2016), and two articles used dynamic side endurance tests (with movement) (Junker & Stöggl, 2019; Kuhn, et al., 2019).

Main analysis

Eleven studies provided data for core flexion endurance (pooled n = 822). Compared to the control condition, there was a moderate effect of intervention on core flexion endurance (ES = 0.67; 95% CI = 0.19 to 1.16; p=.006; I^2 = 87.2%; Egger's test p=.056; Figure 2). The relative weight of each study in the analysis ranged from 6.9% to 11.3%.

Nine studies provided data for core extension endurance (pooled n = 746). Compared to the control condition, there was a small effect of intervention on core extension endurance (ES = 0.49; 95% CI = -0.08 to 1.06; p=.094; I^2 = 90.0%; Egger's test p=.110; Figure 3). The relative weight of each study in the analysis ranged from 9.6% to 13.1%.

Study name	Statistics for each study						
	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Aggarwal. Kumar and Kumar (2010)	3.496	0.499	0.249	2.518	4.474	7.008	0.000
Jamison et al. (2012)	0.058	0.420	0.176	-0.764	0.881	0.139	0.890
Lust et al. (2009)	-0.107	0.444	0.197	-0.978	0.763	-0.241	0.809
Mayer et al. (2014)	0.500	0.219	0.048	0.071	0.928	2.286	0.022
Mayer et al. (2016)	-0.032	0.094	0.009	-0.216	0.152	-0.341	0.733
Ozmen and Aydogmus (2016)	2.552	0.588	0.346	1.398	3.705	4.337	0.000
Sannicandro (2017)	1.005	0.260	0.068	0.494	1.515	3.857	0.000
Shamsi et al.. (2016)	0.274	0.301	0.091	-0.316	0.864	0.910	0.363
Tse et al. (2005)	-0.053	0.347	0.121	-0.734	0.628	-0.152	0.879
Stanton. Reaburn and Humphries (2004)	0.338	0.413	0.171	-0.472	1.148	0.818	0.413
Junker and Stoggl (2019)	0.286	0.405	0.164	-0.507	1.079	0.707	0.479
	0.672	0.247	0.061	0.189	1.155	2.725	0.006

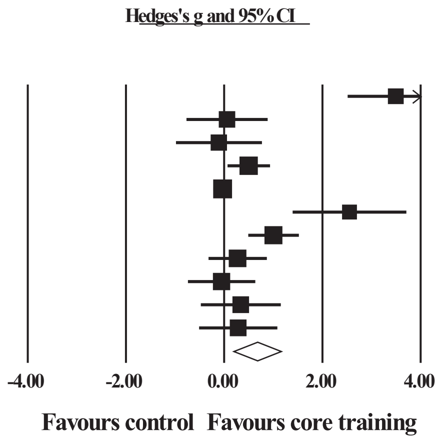

Figure 2. Forest plot of changes in core flexion endurance after the core training compared to the control condition. Values shown are effect sizes with 95% confidence intervals (CI). Black boxes: individual study groups. White diamond: overall result. The relative weight of each study in the analysis is indicated by the size of the plotted box in the figure.

Study name	Statistics for each study						
	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Aggarwal. Kumar and Kumar (2010)	3.256	0.478	0.229	2.319	4.193	6.810	0.000
Junker and Stoggl (2019)	0.547	0.410	0.168	-0.257	1.351	1.333	0.182
Lust et al. (2009)	-0.816	0.463	0.215	-1.724	0.092	-1.762	0.078
Mayer et al. (2014)	0.526	0.219	0.048	0.097	0.955	2.404	0.016
Mayer et al. (2016)	-0.252	0.098	0.010	-0.444	-0.060	-2.569	0.010
Ozmen and Aydogmus (2016)	1.505	0.490	0.240	0.545	2.466	3.072	0.002
Sannicandro (2017)	0.481	0.249	0.062	-0.006	0.969	1.934	0.053
Shamsi et al.. (2016)	0.249	0.301	0.090	-0.340	0.838	0.829	0.407
Tse et al. (2005)	-0.646	0.357	0.127	-1.345	0.053	-1.810	0.070
	0.487	0.291	0.085	-0.083	1.057	1.675	0.094

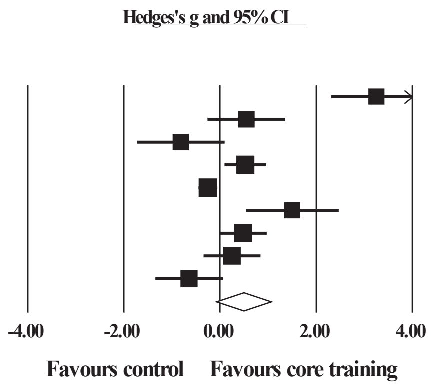

Figure 3. Forest plot of changes in core extension endurance after the core training compared to the control condition. Values shown are effect sizes with 95% confidence intervals (CI). Black boxes: individual study groups. White diamond: overall result. The relative weight of each study in the analysis is indicated by the size of the plotted box in the figure.

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Aggarwal. Kumar and Kumar (2010)	1.575	0.356	0.127	0.876	2.274	4.418	0.000
Lust et al. (2009)	-0.094	0.444	0.197	-0.964	0.777	-0.211	0.833
Sannicandro (2017)	1.590	0.282	0.080	1.037	2.143	5.638	0.000
Shamsi et al.. (2016)	-0.171	0.300	0.090	-0.760	0.417	-0.571	0.568
Tse et al. (2005)	0.857	0.364	0.132	0.145	1.570	2.358	0.018
	0.767	0.398	0.158	-0.013	1.547	1.926	0.054

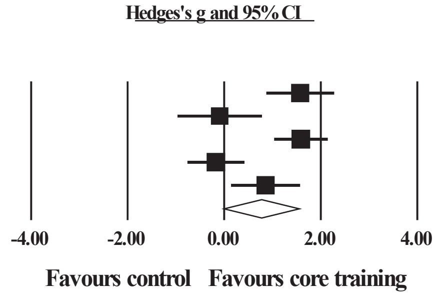

Figure 4. Forest plot of changes in core right-lateral endurance after the core training compared to the control condition. Values shown are effect sizes with 95% confidence intervals (CI). Black boxes: individual study groups. White diamond: overall result. The relative weight of each study in the analysis is indicated by the size of the plotted box in the figure.

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Aggarwal. Kumar and Kumar (2010)	2.814	0.442	0.195	1.948	3.679	6.371	0.000
Lust et al. (2009)	-0.888	0.467	0.218	-1.803	0.026	-1.904	0.057
Sannicandro (2017)	1.907	0.297	0.088	1.325	2.489	6.426	0.000
Shamsi et al.. (2016)	-0.129	0.300	0.090	-0.717	0.458	-0.432	0.666
Tse et al. (2005)	0.972	0.368	0.135	0.251	1.694	2.642	0.008
	0.939	0.611	0.373	-0.258	2.135	1.537	0.124

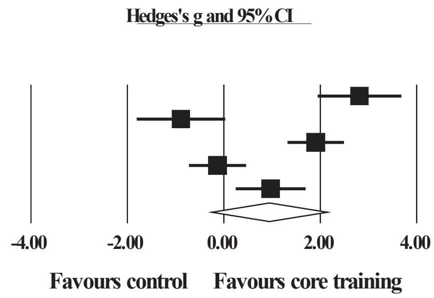

Figure 5. Forest plot of changes in core left-lateral endurance after the core training compared to the control condition. Values shown are effect sizes with 95% confidence intervals (CI). Black boxes: individual study groups. White diamond: overall result. The relative weight of each study in the analysis is indicated by the size of the plotted box in the figure.

Five studies provided data for core right-lateral endurance (pooled n = 199). Compared to the control condition, there was a small effect of intervention on core right-lateral endurance (ES = 0.77; 95% CI = -0.01 to 1.55; p=.054; I^2 = 85.2%; Egger's test p=.651; Figure 4). The relative weight of each study in the analysis ranged from 18.3% to 21.2%.

Five studies provided data for core left-lateral endurance (pooled n = 199). Compared to the control condition, there was a moderate effect of intervention on core left-lateral endurance (ES = 0.94; 95% CI = -0.26 to 2.14; p=.124; I^2 = 92.3%; Egger's test p=.966; Figure 5). The relative weight of each study in the analysis ranged from 19.2% to 20.6%.

Discussion and conclusions

The purpose of this SRMA was to assess the effects of trunk training on different core muscle endurance measurements (flexion, extension, right and left lateral flexion). Quantitative results showed a significant effect of trunk training on flexion core muscle endurance with a moderate effect (ES = 0.67), including eleven studies with 822 participants. However, extension core muscle endurance showed a small effect after trunk training intervention (ES = 0.49) with 746 participants in nine studies. In addition, right-lateral endurance and left-lateral endurance displayed moderate effects (ES = 0.77 and ES = 0.94, respectively) after core programmes analysed in five studies with 199 subjects.

Core flexion endurance

The data showed that the trunk training group moderately improved flexion endurance compared to the control group/condition. The most favourable results in favour of the experimental group could be seen in the studies conducted by Aggarwal et al. (2010) and Ozmen and Aydogmus (2016). These studies used similar training methodologies, with six weeks of intervention with 2-3 days per week and 12 or 18 total sessions. In addition, exercise selection in each programme had some similarities; the experimental group started their training programme with isolated exercises like abdominal contractions in different positions (Aggarwal, et al., 2010; Ozmen & Aydogmus, 2016). Additionally, equipment registered in these two studies were the same—med ball, Swiss ball and body weight exercises. In each week the progression towards more difficult exercises was applied until finalised with instability tasks. However, other training methodologies with not-so-good results, like the Stanton et al. (2004) study programme, used instability exercises performed with a Swiss ball from the first session for all tasks performed. Besides good training programmes, there may be the other reason to explain the better results of these two studies—it could be the participants fitness level. Ozmen and Aydogmus (2016) study used teenagers, and Aggarwal et al. (2010) used active people not being highly trained subjects. This could be the main reason to explain the better results of these studies; young people are more sensitive to a new stimulus. Also, the untrained subjects' improvements are usually seen after the application of almost any type of training. The third best result of MA in flexion endurance also supports this reason—the Sannicandro sample also used an active male and female sample (Sannicandro, 2017). In contrast, Jamison et al. (2012), Lust et al. (2009), Mayer et al. (2016), and Tse et al. (2005) have not shown much improvement in their control groups in flexion core muscle endurance. Neither of these four studies has an untrained sample; the participants were American football players, baseball players, soldiers, and rowers. Core muscle endurance flexion is probably an essential movement during their activities despite not being specifically trained. This sentence could be supported by the Weston, Coleman, and Spears (2013) study where male golfers performed mainly isometric trunk training for eight weeks, three days per week and showed improvements in trunk flexion endurance in the experimental group. The authors of this study discuss the transfer of this type of training to golf performance because trunk flexion is not mainly a movement in their sport. This makes them having a previous better core flexion endurance, and the effect of the training may not be as clear as in other subjects.

Core extension endurance

The results of this paper exposed that the trunk training group improved with a small effect concerning the control group/condition in extension endurance. Despite the improvement shown, three studies did not obtain improvements in this parameter with respect to the control group, which got a bit worse (Lust, et al., 2009; Mayer, et al., 2016; Tse, et al., 2005). The Lust et al. (2009) training methodology used open and closed kinetic chain exercises in the experimental and control group but added specific core exercises to the experimental group. Baseball players' fitness level in the Lust et al. (2009) study was higher than the level of the sample in Aggarwal et al. (2010) that showed the best improvement in core extension endurance parameter. The same argument could be applied to the Mayer et al. (2016) and Tse et al. (2005) participants, soldiers and rowers, respectively, that did not show improvement in this task. In addition, in the Tse et al. (2005) study methodology, participants in the control group/condition included some basic training rower exercises that involved traditional trunk extensions on apparatus. In the same way, Mayer et al. (2016) control group/condition performed lumbar extensor high-intensity progressive resistance exercise. These two specific methodologies could be the main reason for the improvement in this parameter in favour of the control group for these two studies. Probably would, after excluding these two studies, the effect of trunk training on extension endurance increase from small to moderate. Equally, participants in a trunk training programme started at a level of difficulty that was consistent with their current fitness level to get the most out of the trunk extension endurance exercises.

Core lateral endurance

The data showed that the trunk training group improved moderately with respect to the control group/condition in core-right lateral endurance. The two studies in which this parameter was most improved concerning the control group/condition were Aggarwal et al. (2010) and Sannicandro (2017) and were the unique two studies that did not include a highly trained population but active male and female participants that did not practice any specific sport. These two samples probably had a lower initial fitness level than baseball players (Lust, et al., 2009). Furthermore, male rowers (Tse, et al., 2005) showed high improvements in this parameter compared to flexion or extension core muscle endurance. The authors argue that the main reason for these results was that flexion and extension movements are used quite often in the rowing movement, primarily in the sagittal plane. In contrast, lateral flexion movements are not specifically carried out in the normal rowing stroke. The same argument could explain the similar results shown in female handball players whose core trunk flexion, extension, and right and left flexion endurance were measured with distal movements until exhaustion tests and only showed improvements in right and left flexions with respect to the control group/condition (Kuhn, et al., 2019).

The data showed that the trunk training group improved moderately compared to the control group/condition in left-lateral movement muscular endurance. In the same way, as in the right-lateral movement muscular endurance, Aggarwal et al. (2010) and Sannicandro (2017) studies showed the best improvement in this parameter and Lust et al. (2009) and Shamsi et al. (2016) methodologies did not enhance with respect to the control group/condition. Baseball players often use rotational trunk movements that involve flexion of core muscles, mainly on their dominant side (Lust, et al., 2009). That could be why this sample did not improve in these parameters; in addition, right core muscle endurance flexion showed less improvement than the left side, and it could be that most of the players were probably right-handed. Regarding Shamsi et al. (2016), which involved LBP patients, the control group/condition performed general exercises. It showed some left and right flexion core muscle endurance improvement concerning the experimental condition. That could be because, in the LBP patients, trunk training targets were too aggressive, and they did not have the fitness level to perform it correctly.

This SRMA analysed four types of trunk movements regarding core muscle endurance—flexion, extension, and right and left flexion. The exciting finding was that the trunk training improved the four core muscle endurance measures—flexion, right flexion and left flexion moderately and in extension there was a small improvement. The slightest improvement in extension movement could result from some training methodologies or samples analysed. Due to the core muscles function being hubs in the biological motor chain, which create a fulcrum for the four limbs' strength and establish a channel for the cohesion, transmission, and integration of the upper and lower limbs, core training should be included in training sessions to improve athletic performance. However, according to Dong, Yu, and Chun (2023), it is necessary to adequately design core training programmes to improve sport-specific athletic performance. For example, rotational trunk movements are essential to improve performance in sports like boxing, thus, this type of movement analysis could be a limitation in this SRMA.

To the authors' knowledge, this is the first SRMA to assess the effects of trunk training on core muscle endurance in a healthy population. In the current SRMA, 649 experimental and 564 control participants were involved. This could reduce the problem of underpowered sample studies. There are currently a limited number of randomised controlled trials investigating the effects of core training on core muscle endurance not assessed with the trunk extension, flexion, right or left flexion isometric tests proposed by McGill et al. (1999). Despite the advantages of these tests, the present study results could be skewed by their advantages and disadvantages. Therefore, the results of this study should not be generalised to all populations; only one study with LBP patients was included in this SRMA (Shamsi, et al., 2016). Due to the physiological differences between the sexes, future studies should analyse the differences between men and women in core muscle endurance. Despite these limitations, the current SRMA makes an original contribution to the literature and presents for consideration the influence of core training on core muscle endurance.

Practical applications

Strength and conditioning coaches should be aware that core training improves core muscle endurance performance. However, the athletes' previous fitness level and their previous training of the specific movements is determinant in the core muscle endurance improvement. Both, athletes and healthy people should integrate this type of training into their programmes. Athletes may try to improve performance and reduce the risk of injury, while healthy people try to reduce the risk of falls and pursue to move better in their daily life tasks. Concerning the core training, it should be supervised to ensure the correct execution of exercises; a programme should be based on proper progression and suitable exercise selection that involve four basic core movements (flexion, extension, right flexion and left flexion). To show better performance after core training, athletes need to train their specific trunk weak movements to reduce compensations caused by their specific sports. Progression programmes with exercises and equipment variations seem to be more effective.

The results of this SRMA support the notion that trunk training improves core muscle endurance in four principal movements (trunk flexion and extension and right and left flexion). However, to back up the results presented in this study, more research into the effects of trunk training on core muscle endurance is needed. The higher benefits are found in trunk flexion and right and left flexion measurements. The trunk extension endurance improves with a small effect. This SRMA hypothesised that most trained movements during training methodologies would improve more. In addition, in movements with poor results in pre-intervention, core training could be more effective. Adding training equipment like medballs, resistance bands or dumbbells to increase difficulty could be a good choice. Thus, athletes with poor previous fitness level benefited more from this type of training than high-trained athletes.

References

Abdelraouf, O.R., & Abdel-Aziem, A.A. (2016). The relationship between core endurance and back dysfunction in collegiate male athletes with and without nonspecific low back pain. *International Journal of Sports Physical Therapy*, *11*(3), 337-344.

Aggarwal, A., Kumar, S., & Kumar, D. (2010). Effect of core stabilization training on the lower back endurance in recreationally active individuals. *Journal of Musculoskeletal Research*, *13*(4), 167-176. https://doi.org/10.1142/S0218957710002600

Allison, G.T., & Morris, S.L. (2008). Transversus abdominis and core stability: Has the pendulum swung? *British Journal of Sports Medicine*, *42*(11), 630-631. https://doi.org/10.1136/bjsm.2008.048637

Barrio, E.D., Ramirez-Campillo, R., Garcia de Alcaraz Serrano, A., & Hernandez-García, R. (2022). Effects of core training on dynamic balance stability: A systematic review and meta-analysis. *Journal of Sports Sciences*, *40*(16), 1815-1823. https://doi.org/10.1080/02640414.2022.2110203

Chuter, V.H., de Jonge, X.A.K.J., Thompson, B.M., & Callister, R. (2015). The efficacy of a supervised and a home-based core strengthening programme in adults with poor core stability: A three-arm randomised controlled trial. *British Journal of Sports Medicine*, *49*(6), 395-399. https://doi.org/10.1136/bjsports-2013-093262

Cook, G. (2010). *Movement.* Santa Cruz, CA: On Target Publications.

de Morton, N.A. (2009). The PEDro scale is a valid measure of the methodological quality of clinical trials: A demographic study. *Australian Journal of Physiotherapy*, *55*(2), 129-133. https://doi.org/10.1016/S0004-9514(09)70043-1

Deeks, J.J., Higgins, J.P., Altman, D.G., & Cochrane Statistical Methods Group. (2019). Analysing data and undertaking meta-analyses. In J.P.T. Higgins, J. Thomas, J. Chandler, M. Cumpston, T. Li, M.J. Page, & V.A. Welch (Eds.), *Cochrane handbook for systematic reviews of interventions* (2nd ed.; pp. 241-284). Wiley.

Dong, K., Yu, T., & Chun, B. (2023). Effects of core training on sport-specific performance of athletes: A Meta-analysis of randomized controlled trials. *Behavioral Sciences*, *13*(2), 148. https://doi.org/10.3390/bs13020148

Egger, M., Davey Smith, G., Schneider, M., & Minder, C. (1997). Bias in meta-analysis detected by a simple, graphical test. *BMJ (Clinical Research Ed.)*, *315*(7109), 629-634. https://doi.org/10.1136/bmj.315.7109.629

Fernández-Rodríguez, R., Álvarez-Bueno, C., Cavero-Redondo, I., Torres-Costoso, A., Pozuelo-Carrascosa, D.P., Reina-Gutiérrez, S., Pascual-Morena, C., & Martínez-Vizcaíno, V. (2022). Best exercise options for reducing pain and disability in adults with chronic low back pain: Pilates, strength, core-based, and mind-body. A network meta-analysis. *Journal of Orthopaedic and Sports Physical Therapy*, *52*(8), 505-521. https://www.jospt.org/doi/10.2519/jospt.2022.10671

Friedrich, J., Brakke, R., Akuthota, V., & Sullivan, W. (2017). Reliability and practicality of the core score: Four dynamic core stability tests performed in a physician office setting. *Clinical Journal of Sport Medicine*, *27*(4), 409-414. https://doi.org/10.1097/JSM.0000000000000366

García-Hermoso, A., Ramírez-Campillo, R., & Izquierdo, M. (2019). Is muscular fitness associated with future health benefits in children and adolescents? A systematic review and meta-analysis of longitudinal studies. *Sports Medicine (Auckland, N.Z.)*, *49*(7), 1079-1094. https://doi.org/10.1007/s40279-019-01098-6

Granacher, U., Schellbach, J., Klein, K., Prieske, O., Baeyens, J.-P., & Muehlbauer, T. (2014). Effects of core strength training using stable versus unstable surfaces on physical fitness in adolescents: A randomized controlled trial. *BMC Sports Science, Medicine and Rehabilitation*, *6*(1), 40. https://doi.org/10.1186/2052-1847-6-40

Hardy, R.J., & Thompson, S.G. (1996). A likelihood approach to meta-analysis with random effects. *Statistics in Medicine*, *15*(6), 619-629.

Hibbs, A.E., Thompson, K.G., French, D., Wrigley, A., & Spears, I. (2008). Optimizing performance by improving core stability and core strength. *Sports Medicine (Auckland, N.Z.)*, *38*(12), 995-1008. https://doi.org/10.2165/00007256-200838120-00004

Higgins, J.P.T., & Thompson, S.G. (2002). Quantifying heterogeneity in a meta-analysis. *Statistics in Medicine*, *21*(11), 1539-1558. https://doi.org/10.1002/sim.1186

Higgins, J.P.T., Thompson, S.G., Deeks, J.J., & Altman, D.G. (2003). Measuring inconsistency in meta-analyses. *BMJ (Clinical Research Ed.)*, *327*(7414), 557-560. https://doi.org/10.1136/bmj.327.7414.557

Hodges, P.W. (2003). Core stability exercise in chronic low back pain. *Orthopedic Clinics*, *34*(2), 245-254. https://doi.org/10.1016/S0030-5898(03)00003-8

Hopkins, W., Marshall, S., Batterham, A., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise.*, *41*(1), 3. doi: 10.1249/MSS.0b013e31818cb278

Hsu, S.-L., Oda, H., Shirahata, S., Watanabe, M., & Sasaki, M. (2018). Effects of core strength training on core stability. *Journal of Physical Therapy Science*, *30*(8), 1014-1018. https://doi.org/10.1589/jpts.30.1014

Hung, K.-C., Chung, H.-W., Yu, C.C.-W., Lai, H.-C., & Sun, F.-H. (2019). Effects of 8-week core training on core endurance and running economy. *PloS One*, *14*(3), e0213158. https://doi.org/10.1371/journal.pone.0213158

Jamison, S.T., McNeilan, R.J., Young, G.S., Givens, D.L., Best, T.M., & Chaudhari, A.M.W. (2012). Randomized controlled trial of the effects of a trunk stabilization program on trunk control and knee loading. *Medicine and Science in Sports and Exercise*, *44*(10), 1924-1934. https://doi.org/10.1249/MSS.0b013e31825a2f61

Juan-Recio, C., López-Plaza, D., Barbado Murillo, D., García-Vaquero, M.P., & Vera-García, F.J. (2018). Reliability assessment and correlation analysis of 3 protocols to measure trunk muscle strength and endurance. *Journal of Sports Sciences*, *36*(4), 357-364. https://doi.org/10.1080/02640414.2017.1307439

Junker, D., & Stöggl, T. (2019). The training effects of foam rolling on core strength endurance, balance, muscle performance and range of motion: A randomized controlled trial. *Journal of Sports Science and Medicine*, *18*(2), 229-238.

Kibler, W.B., Press, J., & Sciascia, A. (2006). The role of core stability in athletic function. *Sports Medicine (Auckland, N.Z.)*, *36*(3), 189-198. https://doi.org/10.2165/00007256-200636030-00001

Kontopantelis, E., Springate, D.A., & Reeves, D. (2013). A re-analysis of the Cochrane Library data: The dangers of unobserved heterogeneity in meta-analyses. *PloS One*, *8*(7), e69930. https://doi.org/10.1371/journal.pone.0069930

Kuhn, L., Weberruß, H., & Horstmann, T. (2019). Effects of core stability training on throwing velocity and core strength in female handball players. *The Journal of Sports Medicine and Physical Fitness*, *59*(9), 1479-1486. https://doi.org/10.23736/S0022-4707.18.09295-2

Lust, K.R., Sandrey, M.A., Bulger, S.M., & Wilder, N. (2009). The effects of 6-week training programs on throwing accuracy, proprioception, and core endurance in baseball. *Journal of Sport Rehabilitation*, *18*(3), 407-426. https://doi.org/10.1123/jsr.18.3.407

Majewski-Schrage, T., Evans, T.A., & Ragan, B. (2014). Development of a core-stability model: A Delphi approach. *Journal of Sport Rehabilitation*, *23*(2), 95-106. https://doi.org/10.1123/JSR.2013-0001

Martínez-Romero, M.T., Ayala, F., De Ste Croix, M., Vera-Garcia, F.J., Sainz de Baranda, P., Santonja-Medina, F., & Sánchez-Meca, J. (2020). A meta-analysis of the reliability of four field-based trunk extension endurance tests. *International Journal of Environmental Research and Public Health*, *17*(9), 3088. doi: 10.3390/ijerph17093088

Mayer, J.M., Childs, J.D., Neilson, B.D., Chen, H., Koppenhaver, S.L., & Quillen, W.S. (2016). Effect of lumbar progressive resistance exercise on lumbar muscular strength and core muscular endurance in soldiers. *Military Medicine*, *181*(11), e1615-e1622. https://doi.org/10.7205/MILMED-D-15-00543

Mayer, J.M., Quillen, W.S., Verna, J.L., Chen, R., Lunseth, P., & Dagenais, S. (2014). Impact of a supervised worksite exercise program on back and core muscular endurance in firefighters. *American Journal of Health Promotion*, *29*(3), 165-172. https://doi.org/10.4278/ajhp.130228-QUAN-89

McGill, S.M., Childs, A., & Liebenson, C. (1999). Endurance times for low back stabilization exercises: Clinical targets for testing and training from a normal database. *Archives of Physical Medicine and Rehabilitation*, *80*(8), 941-944. https://doi.org/10.1016/S0003-9993(99)90087-4

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., & PRISMA Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Medicine*, *6*(7), e1000097. https://doi.org/10.1371/journal.pmed.1000097

Nadler, S.F., Malanga, G.A., Bartoli, L.A., Feinberg, J.H., Prybicien, M., & DePrince, M. (2002). Hip muscle imbalance and low back pain in athletes: Influence of core strengthening. *Medicine and Science in Sports and Exercise*, *34*(1), 9-16.

Ogaya, S., Suzuki, M., Yoshioka, C., Nakamura, Y., Kita, S., & Watanabe, K. (2021). The effects of trunk endurance training on running kinematics and its variability in novice female runners. *Sports Biomechanics*, 1-12. https://doi.org/10.1080/14763141.2021.1906938

Ozmen, T., & Aydogmus, M. (2016). Effect of core strength training on dynamic balance and agility in adolescent badminton players. *Journal of Bodywork and Movement Therapies*, *20*(3), 565-570. https://doi.org/10.1016/j.jbmt.2015.12.006

Reed, C.A., Ford, K.R., Myer, G.D., & Hewett, T.E. (2012). The effects of isolated and integrated 'core stability'training on athletic performance measures. *Sports Medicine*, *42*(8), 697-706. https://doi.org/10.1007/BF03262289

Saeterbakken, A.H., van den Tillaar, R., & Seiler, S. (2011). Effect of core stability training on throwing velocity in female handball players. *Journal of Strength and Conditioning Research*, *25*(3), 712-718. https://doi.org/10.1519/JSC.0b013e3181cc227e

Sandrey, M.A., & Mitzel, J.G. (2013). Improvement in dynamic balance and core endurance after a 6-week core-stability-training program in high school track and field athletes. *Journal of Sport Rehabilitation*, *22*(4), 264-271. https://doi.org/10.1123/jsr.22.4.264

Sannicandro, I. (2017). Effects of strength and core stability training versus strength and aerobic training in subjects aged over 65. [Effetti dell'allenamento di forza e core stability versus allenamento di forza e aerobico a intensità controllata in soggetti over 65.] *Medicina dello Sport*, *70*(4), 410-418. https://doi.org/10.23736/S0025-7826.17.03132-5

Santos, M.S., Behm, D.G., Barbado, D., DeSantana, J.M., & Da Silva-Grigoletto, M.E. (2019). Core endurance relationships with athletic and functional performance in inactive people. *Frontiers in Physiology*, *10*, 1490. https://doi.org/10.3389/fphys.2019.01490

Schardt, C., Adams, M.B., Owens, T., Keitz, S., & Fontelo, P. (2007). Utilization of the PICO framework to improve searching PubMed for clinical questions. *BMC Medical Informatics and Decision Making*, *7*(1), 16. https://doi.org/10.1186/1472-6947-7-16

Shamsi, M., Sarrafzadeh, J., Jamshidi, A., Zarabi, V., & Pourahmadi, M.R. (2016). The effect of core stability and general exercise on abdominal muscle thickness in non-specific chronic low back pain using ultrasound imaging. *Physiotherapy Theory and Practice*, *32*(4), 277-283. https://doi.org/10.3109/09593985.2016.1138559

Sibson, B.E., Tobolsky, V.A., Kistner, T.M., Holowka, N.B., Jemutai, J., Sigei, T.K., Ojiambo, R., Okutoyi, P., & Lieberman, D.E. (2021). Trunk muscle endurance, strength and flexibility in rural subsistence farmers and urban industrialized adults in western Kenya. *American Journal of Human Biology*, *34*(2), e23611. https://doi.org/10.1002/ajhb.23611

Stanton, R., Reaburn, P.R., & Humphries, B. (2004). The effect of short-term Swiss ball training on core stability and running economy. *Journal of Strength and Conditioning Research*, *18*(3), 522-528. https://doi.org/10.1519/1533-4287(2004)18<522:TEOSSB>2.0.CO;2

Stuber, K.J., Bruno, P., Sajko, S., & Hayden, J.A. (2014). Core stability exercises for low back pain in athletes: A systematic review of the literature. *Clinical Journal of Sport Medicine: Official Journal of the Canadian Academy of Sport Medicine*, *24*(6), 448-456. https://doi.org/10.1097/JSM.0000000000000081

Toprak Çelenay, Ş., & Özer Kaya, D. (2017). An 8-week thoracic spine stabilization exercise program improves postural back pain, spine alignment, postural sway, and core endurance in university students: A randomized controlled study. *Turkish Journal of Medical Sciences*, *47*(2), 504-513. https://doi.org/10.3906/sag-1511-155

Tse, M.A., McManus, A.M., & Masters, R.S.W. (2005). Development and validation of a core endurance intervention program: Implications for performance in college-age rowers. *Journal of Strength and Conditioning Research*, *19*(3), 547-552. https://doi.org/10.1519/15424.1

Vasseljen, O., Unsgaard-Tøndel, M., Westad, C., & Mork, P.J. (2012). Effect of core stability exercises on feed-forward activation of deep abdominal muscles in chronic low back pain: A randomized controlled trial. *Spine*, *37*(13), 1101-1108. https://doi.org/10.1097/BRS.0b013e318241377c

Wang, X.-Q., Zheng, J.-J., Yu, Z.-W., Bi, X., Lou, S.-J., Liu, J., …, & Chen, P.-J. (2012). A meta-analysis of core stability exercise versus general exercise for chronic low back pain. *PloS One*, *7*(12), e52082. https://doi.org/10.1371/journal.pone.0052082

Weston, M., Coleman, N.J., & Spears, I.R. (2013). The effect of isolated core training on selected measures of golf swing performance. *Medicine and Science in Sports and Exercise*, *45*(12), 2292-2297. https://doi.org/10.1249/MSS.0b013e31829bc7af

Submitted: September 14, 2023
Accepted: January 24, 2024
Published Online First: June 27, 2024

Correspondence to:
Ekaitz Dudagoitia Barrio, Ph.D. candidate
Faculty of Sports Sciences, University of Murcia
Murcia, Spain
E-mail: ekaitz10@icloud.com

Data availability statement

The datasets generated and/or analysed during the study are available from the corresponding author upon a reasonable request.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding
No sources of funding were used to assist in the preparation of this article.