Systematic Review of Core Muscle Activity During Physical Fitness Exercises

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[1]*School of Physical Education & Exercise Science, College of Education, University of South Florida, Tampa, Florida;* [2]*School of Physical Therapy & Rehabilitation Sciences, Morsani College of Medicine, University of South Florida, Tampa, Florida; and* [3]*Shimberg Health Sciences Library, Morsani College of Medicine, University of South Florida, Tampa, Florida*

Abstract

Martuscello, JM, Nuzzo, JL, Ashley, CD, Campbell, BI, Orriola, JJ, and Mayer, JM. Systematic review of core muscle activity during physical fitness exercises. *J Strength Cond Res* 27(6): 1684–1698, 2013—A consensus has not been reached among strength and conditioning specialists regarding what physical fitness exercises are most effective to stimulate activity of the core muscles. Thus, the purpose of this article was to systematically review the literature on the electromyographic (EMG) activity of 3 core muscles (lumbar multifidus, transverse abdominis, quadratus lumborum) during physical fitness exercises in healthy adults. CINAHL, Cochrane Central Register of Controlled Trials, EMBASE, PubMed, SPORTdiscus, and Web of Science databases were searched for relevant articles using a search strategy designed by the investigators. Seventeen studies enrolling 252 participants met the review's inclusion/exclusion criteria. Physical fitness exercises were partitioned into 5 major types: traditional core, core stability, ball/device, free weight, and noncore free weight. Strength of evidence was assessed and summarized for comparisons among exercise types. The major findings of this review with moderate levels of evidence indicate that lumbar multifidus EMG activity is greater during free weight exercises compared with ball/device exercises and is similar during core stability and ball/device exercises. Transverse abdominis EMG activity is similar during core stability and ball/device exercises. No studies were uncovered for quadratus lumborum EMG activity during physical fitness exercises. The available evidence suggests that strength and conditioning specialists should focus on implementing multijoint free weight exercises, rather than core-specific exercises, to adequately train the core muscles in their athletes and clients.

Key Words electromyography, muscles, exercise, spine

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Introduction

One of the primary responsibilities of strength and conditioning specialists is to prescribe physical fitness exercises that help athletes and clients achieve specified fitness goals. Recently, a considerable amount of attention has been given to the goal of improving core strength and stability to enhance fitness performance and prevent injury in a variety of activities (14,16,27,31,36,39). Many types of physical fitness exercises have been recommended for improving core strength and stability, with a particular emphasis placed on core stability and ball/device exercises (14,16,27,31,36). Many of these recommendations have been made based on the perceived activity of the core muscles during those exercises (14,16,27,31). However, a consensus has not been reached regarding the exercises that are most effective at stimulating the activity of the core muscles. Establishing a consensus on this topic would facilitate dissemination and implementation of standardized core training approaches by strength and conditioning coaches, which could result in more effective core training across multiple settings, thereby improving performance and preventing injury in athletes and clients.

According to Behm et al. (3), the anatomical core is defined as, "the axial skeleton (which includes the pelvic girdle and shoulder girdles), and all soft tissues (i.e., articular and fibro-cartilage, ligaments, tendons, muscle, and fascia) with proximal attachment originating on the axial skeleton, regardless of whether the soft tissue terminates on the axial or appendicular skeleton (upper and lower extremities)." Some of the major muscles of the core with proximal and distal attachments in the lumbosacral region of the axial skeleton include the lumbar multifidus, erector spinae, quadratus lumborum, external oblique abdominis, internal oblique abdominis, rectus abdominis, transverse abdominis, psoas major, pelvic floor muscles, and diaphragm (14). Of the various core muscles, the lumbar multifidus, transverse abdominis, and quadratus lumborum appear to be the most meaningful muscles for fitness professionals and clinicians who prescribe exercises to improve physical performance or manage musculoskeletal disorders. Aberrant function and morphology of these 3 muscles has been associated with low back pain in the general population (15,22) and athletes (20,21,23), lower extremity injury in athletes (19), and sprint run performance in athletes (26). The lumbar multifidus is the most medial spine muscle and acts to extend, laterally flex, and rotate the spine (30). The transverse abdominis is the deepest of the abdominal muscles and acts to stabilize the spine and increase intra-abdominal pressure (30). The quadratus lumborum is the most lateral spine muscle and acts to laterally flex and stabilize the spine (30).

Muscle activity of the lumbar multifidus, transverse abdominis, and quadratus lumborum during physical fitness exercises can be determined through various methods, 1 of which is electromyography. The amplitude of the EMG signal is often reported as a raw (in millivolts) or relative value as percentage of maximum voluntary isometric contraction (%MVIC), and this value provides a general representation of the neural drive to the muscle (i.e., the number of motor unit action potentials generated over a period of time) (13). Thus, physical fitness exercises that elicit larger electromyographic (EMG) activity may represent greater challenges to the neuromuscular system, and consequently, may be most effective for improving core muscle strength and stability if included in an exercise training program.

Decisions about which core exercises to perform are often based on opinion, personal experience, and narrative review articles that may or may not be based on the existing scientific evidence. Decision making in such a manner has led to the implementation of a wide variety of core training techniques with little to no consistency among the strength and conditioning specialists about what core exercises are best in specific circumstances. Consequently, which exercises are best suited for activating the core muscles and improving core strength and stability is still being debated (27), and an evidence-based consensus has not been reached. Therefore, an evidence-based and systematic summary about core muscle activity during physical exercises is needed for the strength and conditioning specialist to make informed recommendations to their athletes and clients.

To date, numerous lay articles and narrative review articles have been published on the topic of core muscle exercises and core muscle activity, yet no systematic review article has been on this topic. Although useful in certain situations, both lay articles and narrative review articles are highly prone to bias, are often written to support the author's specific point of view, and are not systematic in their approach. Thus, the practical applications from such articles may not be substantiated from the evidence base of the scientific literature. According to Garg et al. (17), "A narrative review typically uses an implicit process to compile evidence to support the statements being made." Furthermore, according to Collins and Fauser (6), "Narrative reviews generally are comprehensive and cover a wide range of issues within a given topic, but they do not necessarily state or follow rules about the search for evidence. Also, typical narrative reviews do not reveal how the decisions were made about relevance of studies and the validity of the included studies." In contrast to narrative review articles, "A systematic review is a high-level overview of primary research on a particular research question that tries to identify, select, synthesize and appraise all high-quality research evidence relevant to that question in order to answer it. Systematic reviews seek to collate all evidence that fits pre-specified eligibility criteria in order to address a specific research question and aim to minimize bias by using explicit, systematic methods (1)." Therefore, systematic reviews offer a less biased and more systematic approach to a certain topic. However, the existing research on core muscle activity during physical fitness exercises has not been systematically reviewed. A systematic review is important for strength and conditioning specialists to help clarify the types of physical fitness exercises that may be most effective for improving core strength and stability.

The purpose of this paper was to systematically review the existing research on EMG activity of 3 core muscles (lumbar multifidus, transverse abdominis, quadratus lumborum) during physical fitness exercises. The findings of this review will help the strength and conditioning specialist determine which core exercises are most appropriate for their athletes and clients.

Methods

Experimental Approach to the Problem

Search Strategy. An electronic search was conducted using the CINAHL, Cochrane Central Register of Controlled Trials, EMBASE, PubMed, SPORTdiscus, and Web of Science databases for studies published through January 12, 2012. The search strategy was developed by the investigators and consisted of the following terms: (electromyography OR myoactivity OR electromyography OR biofeedback OR myoelectrical OR magnetic resonance imaging OR ultrasound OR neuromuscular) AND (signal OR amplitude OR magnitude) AND (exercise* OR flexion OR extension OR rotation OR lateral OR stabiliz*) AND (quadratus lumborum OR transversus abdominis OR multifid* OR lumbar) AND (paraspinal* OR extensor* OR erector spinae). References cited in articles were further reviewed to locate any additional relevant articles not retrieved within the primary search.

Study Inclusion/Exclusion Criteria

Study inclusion and exclusion criteria used for the review are shown in Table 1.

Study Selection

After retrieving the search results, 1 author screened the titles and abstracts and excluded obviously irrelevant studies. Another author verified the remaining pertinent studies according to the inclusion criteria. Full-text studies were retrieved for all citations deemed relevant or of uncertain relevance to confirm their eligibility. Studies not retrieved in the initial search but were cited in the retrieved studies were deemed eligible if they met the inclusion criteria. At this point, eligible studies were included for further analysis.

TABLE 1. Study inclusion and exclusion criteria.*

Inclusion	Exclusion
• Healthy adults	• History of spinal disorders, neurological deficits, spinal surgery, or low back pain
• Physical fitness exercises for the back and core commonly performed in a fitness environment	• Exercises not distinguished as substantially different (slight modification in postures, movements, hand/feet positions)
• EMG activity (in %MVIC or millivolts) of MU, TA, and QL	• Studies that only made comparisons of different exercises within same exercise type
• Observational studies—within-subject repeated measures of EMG activity of physical fitness exercises at 1 time point	
• Published up to and including January 12, 2012	
• Published in English	
• Published data only	
• Independent effects of intervention/exposure could be determined from data	
• Abstracts available for screening	

*EMG = electromyographic; MVIC = maximum voluntary isometric contraction; MU = multifidus muscle; TA = transverse abdominis muscle; QL = quadratus lumborum muscle.

Data Abstraction

The data were abstracted and summarized from included studies by 1 author and were verified by 2 other authors. These 3 authors then reviewed the data together until a consensus was achieved on the validity and conclusions that could be reached from these studies.

Classification of Exercise Type

The authors did not find any standard classification system for back and core exercises. Thus, for analysis purposes, each exercise in the included studies was assessed according to specific characteristics such as range of motion, contraction type, contraction speed, body weight or external resistance, and then systematically assigned to 1 of the 5 following exercise types: traditional core, core stability, ball/device, free weight, and noncore free weight (Table 2). Four of these exercise types were considered core (traditional core, core stability, free weight, and ball/device) and 1 was considered noncore (noncore free weight).

Methodological Quality Assessment

Although no standard for rating the quality of observational studies exists, all included studies were assessed for methodological quality using various aspects of the Agency for Healthcare Research and Quality (AHRQ) evidence rating tool (37) and the Effective Public Health Practice Project (EPHPP) quality assessment tool for guidance. The AHRQ tool assessed 9 domains: 7 best practice domains and 2

TABLE 2. Core exercise classification system.

Exercise classification type	Description	Example
Traditional core exercises	Dynamic, low-load, commonly performed on floor, intent to activate superficial core muscles	Back extension, sit-up
Core stability exercises	Minimal range of motion, low-load, floor-based exercises, intent to activate deep core muscles	Prone plank, side bridge
Ball/device exercises	Traditional core and core stability exercises performed with addition of a ball or device	Back extension on a ball, crunch on a ball
Free weight exercises	Dynamic, externally loaded, intent to activate lower-body and core muscles	Squat, deadlift
Noncore free weight	Dynamic, externally loaded, intent to activate the upper-body muscles distal to the core	Shoulder press, biceps curl

empirical domains. The criteria for the essential best practice domains assessed: study question, study population, exposure/intervention, outcome measure, statistical analysis, results, and discussion. The remaining 2 empirically based domains examined compatibility of subjects and funding or sponsorship. The EPHPP assessment tool examined 9 domains: selection bias, study design, confounders, blinding, data collection methods, withdrawals and dropouts, intervention integrity, and analyses.

Assessment of Evidence Summary–Strength of Evidence

The strength of evidence was assessed exclusively for comparisons among exercise types and was not summarized for different exercises within the same exercise type. The criteria used to assess strength of evidence were adapted from criteria that were developed for use with randomized controlled trials (2,4). The evidence was graded as either strong, moderate, limited, or no evidence as follows:

- Strong evidence: generally consistent findings observed among 3 or more high-quality studies.
- Moderate evidence: generally consistent findings observed among 3 or more low-quality studies.
- Limited evidence: 1 study (either of low or high quality) or inconsistent findings observed among at least 4 studies.
- No evidence: no available studies.

Results

Search Results

The original search resulted in 2,992 citations and after removing duplicates yielded 1,388 studies examining the lumbar multifidus, 271 studies examining the transverse abdominis, and 22 examining the quadratus lumborum. The subsequent screening of titles and abstracts found 141 studies deemed potentially relevant. After screening full-text articles, 17 studies were deemed eligible and were included for further analysis (5,7–12,18,24,25,28,29,33–35,40,41). Of the 124 ineligible studies, reasons for exclusion were made comparisons between slight variations of the same exercise ($n = 37$), assessed exercises that are not typically performed in fitness setting ($n = 31$), not original research ($n = 16$), outcome measures not of interest in particular study ($n = 13$), comparisons made only within 1 exercise type ($n = 9$), no muscle of interest ($n = 6$), muscle activity assessed by magnetic resonance imaging or ultrasound ($n = 5$), intervention design ($n = 4$), not written in English ($n = 2$), and subjects reported back pain ($n = 1$).

Characteristics of Included Studies

The 17 included studies enrolled 252 subjects and examined EMG activity during 97 different exercises that were classified as the following types: 13 traditional core exercises, 13 core stability exercises, 45 ball/device exercises, 20 free weight exercises, and 6 noncore free weight exercises (Table 1). Of the 17 included studies, 11 studies assessed traditional core exercises, 10 studies assessed core stability exercises, 12 studies assessed ball/device exercises, 6 studies assessed free weight exercises, and 2 studies assessed noncore free weight exercises. Study descriptive characteristics and EMG outcomes are shown in Tables 2 and 3, respectively.

Lumbar Multifidus

All 17 included studies reported on lumbar multifidus EMG activity during physical fitness exercises (Tables 4 and 5). Traditional core exercises were compared with core stability exercises in 5 studies (9,25,34,35,40), with ball/device exercises in 6 studies (5,8,10–12,24,40), and with free weight exercises in 1 study (5). Core stability exercises were also compared with ball/device exercises in 6 studies (7,8,24,28,29,40), with free weight exercises in 2 studies (7,9), and with noncore free weight exercises in 1 study (7). Ball/device exercises were also compared with free weight exercises in 4 studies (5,7,18,33) and with noncore free weight exercises in 1 study (7). Free weight exercises were also compared with noncore free weight exercises in 2 studies (7,41).

Transverse Abdominis

Ten studies that enrolled 122 subjects reported on transverse abdominis EMG activity during physical fitness exercises (8,10–12,24,28,29,34,40,41). Traditional core exercises were compared with core stability exercises in 2 studies (34,40) and with ball/device exercises in 6 studies (8,10–12,24,40). Core stability exercises were also compared with ball/device exercises in 5 studies (8,24,28,29,40). Free weight exercises were compared with noncore free weight exercises in 1 study (41).

Quadratus Lumborum

No studies were uncovered that reported on quadratus lumborum EMG activity during physical fitness exercises.

Methodological Quality

The methodical quality was deemed to be low in 7 studies (7–9,24,25,28,35) and moderate in 10 studies (5,10–12,18,29,33,34,40,41). Given the observational design of the included studies, no studies were considered to be of high quality. Some of the common reasons that reduced study quality were failure to blind of the outcome assessors, describe appropriate power calculations for sample size, and determine the reliability of outcome measures.

Safety

One study (41) speculated on the safety of the exercises but did not specifically mention if any side effects, injuries, or other adverse events occurred in the subjects. The safety of the exercises was not reported in the other 16 included studies.

Evidence Summary—Strength of Evidence.

Lumbar Multifidus

Moderate Evidence.

- Lumbar multifidus EMG activity is greater during free weight exercises compared with ball/device exercises. Three moderate-quality studies (5,18,33) found that

TABLE 3. Physical fitness exercises assessed in the included studies categorized by exercise type.*

Core				
Traditional core	Core stability	Ball/Device	Free weight	Noncore free weight
Back extension	Press-up: bottom	Ab Circle: levels 1, 2, 3	Deadlift: 50%, 70%, 75%, 80%, 90% 1RM, 70% MVIC, body weight	Biceps curl: barbell 50%, 75% 1RM
Back extension: kneeling	Press-up: top	Ab Doer: body bob, body boogie, good morning	Lateral step up (20 cm) body weight	Shoulder press (bilateral shoulder press, overhead press, military press): barbell 50%, 75% 1RM, 40 kg
Crunch (abdominal curl-up, crunch, curl-up, straight curl-up)	Prone plank (bridging, elbow toe, prone bridge)	Ab Revolutionizer: double crunch, oblique crunch, reverse crunch, reverse crunch with weights	Lunge 70% MVIC, body weight	
Crunch: hyperextended (hyperextended curl-up)	Prone plank with arm/leg lift	Reverse crunch, reverse crunch with weights	Squat: front 40 kg	
Flying squirrel	Quadruped arm/leg lift (contralateral extension, diagonal hip/shoulder extension, 4-point kneeling arm/leg extension, hand-knee, hand-knee arm/leg lift, leg extension with contralateral arm lift, contralateral extension, quadruped)	Ab Rocker: crunch, oblique crunch	Squat (squat: back, squat: free weight) 50%, 70%, 75%, 80%, 90%, 100% 1RM, 40 kg, body weight	
Hip extension	Quadruped single: leg lift (4-point kneeling with leg extension, single-leg extension, single-leg lift)	Ab Roller: crunch, oblique crunch		
Lateral flexion	Roll-out	Ab Slide: curved, straight		
Oblique crunch (cross curl-up)	Side bridge (lateral hip lift)	Ab Twister: crunch, oblique crunch		
Reverse crunch	Side bridge with leg lift	Back extension: ball		
Reverse crunch: inclined	Single-leg hold	Crunch: BOSU (curl-up)		
Side-lying hip abduction	Supine bridge (abdominal bridge, back bridge, bridging, bridge)	Hanging knee-up-straps		

Sit-up (bent-knee sit-up)	Supine bridge with leg lift (single-leg abdominal bridge, supine bridge with leg extension, unilateral bridge)	Hip extension: ball
Superman	Vertical hip lift	Knee-up: ball
Trunk extension (lumbar back extension)		Pike: ball
		Power Wheel: pike, knee-up, roll-out
		Press-up: ball, bottom (decline push-up), top; Prone plank: ball, elbows on ball (parallel hold, prone bridge, prone hold, elbow-toe), feet on ball (parallel hold), hands on ball
		Quadruped arm/leg lift: ball (alternating arm/leg extension, contralateral extension, quadruped); BOSU (hand-knee)
		Quadruped single-leg extension: ball (single-leg extension)
		Roll-out: ball
		SAM
		Side bridge: ball, BOSU
		Single-leg hold: ball
		Skier: ball
		Superman: ball
		Supine bridge: ball (bridge, pelvic thrust)
		Supine bridge: BOSU (back bridge)
		Torso Track

*1RM = 1 repetition maximum; MVIC = maximum voluntary isometric contraction. Parentheses indicate the various exercise names used across studies to refer to a given exercise (e.g., the abdominal curl-up, crunch, curl-up, and straight curl-up were the names used across studies to refer to the crunch exercise).

TABLE 4. Descriptive characteristics of included studies.*

Author, Country	Inclusion criteria	Exclusion criteria	n; sex; age mean (y); subject characteristics; training level†	Muscles	EMG technique; electrode placement	Exercise type
Colado et al. (5), Spain	Resistance training experience; familiar with instability training	Musculoskeletal pain, neuromuscular disorders, joint or bone disease, performance medication	*n* = 25; sex (NR); age = 24; university students; trained	Multifidus	Surface; MU: 3 cm L L5; side: NR	Ball/device; free weight; traditional
Comfort et al. (7), United Kingdom	NR	NR	*n* = 10; male (*n* = 10); age = 22; NR; trained	Multifidus	Surface; MU: 3 cm L L3 right side	Ball/device; core stability; free weight; noncore free weight
Drake et al. (8), Canada	Familiar with exercise ball	Back pain (1 year)	*n* = 8; male (*n* = 8); age = 23; university population; trained	Multifidus; transverse abdominis	Surface; MU: 3 cm L L5; TA: below EO/ superior to inguinal ligament bilateral, averaged	Ball/Device; Core stability; Traditional
Ekstrom et al. (9), United States	Good health	Low back or lower extremity pain/recent surgery	*n* = 30; male (*n* = 19) and female (*n* = 11); age = 27; healthy; NR	Multifidus	Surface; MU: 2 cm L lumbosacral junction; unilateral, side NR	Core stability; free weight; traditional
Escamilla et al. (10), United States	Normal or below normal body fat for age group	Abdominal/back pain; unable to perform exercises pain free	*n* = 21; male (*n* = 10) and female (*n* = 11); age male = 30 and female = 26; healthy; NR	Multifidus; transverse abdominis	Surface; MU: 3 cm L L3/L4; TA: 3 cm inferomedial to ASIS; right side (MU), left side (TA)	Ball/device; traditional
Escamilla et al. (11), United States	Normal or below normal body fat for age group	Abdominal/back pain; unable to perform exercises pain free	*n* = 18; male (*n* = 9) and female (*n* = 9); age male = 30 and female = 28; healthy; NR	Multifidus; transverse abdominis	Surface; MU: 3 cm L L3/L4; TA: 3 cm inferomedial to ASIS; right side (MU), left side (TA)	Ball/device; traditional
Escamilla et al. (12), United States	Normal or below normal body fat for age group	Abdominal/back pain; unable to perform exercises pain free	*n* = 14; male (*n* = 7) and female (*n* = 7); age male = 24 and female = 24; healthy; NR	Multifidus; transverse abdominis	Surface; MU: 3 cm L L3/L4; TA: 3 cm inferomedial to ASIS; right side (MU), left side (TA)	Ball/device; traditional
Hamlyn et al. (18), Canada	Weight training experience	Acute/chronic back pain	*n* = 16; male (*n* = 8) and female (*n* = 8); age = 24; university population; NR	Multifidus	Surface; MU: 2 cm L L5/S1; side: NR	Ball/device; free weight

Imai et al. (24), Japan	No previous stabilization training experience	History lumbar spine disorder, neurological disorder, spine surgery	$n = 9$; male ($n = 9$); age = 24; healthy; untrained	Multifidus; transverse abdominis	Intramuscular; MU: 3 cm L L3; TA: between rib cage and iliac crest; bilateral, averaged	Ball/device; core stability; traditional
Konrad et al. (25), Germany	Familiar with strength training not currently training	NR	$n = 10$; male ($n = 7$); female ($n = 3$); age 27.8; healthy; untrained	Multifidus	Surface; MU: L3; right side	Core stability; traditional
Lehman et al. (28), Canada	>6 mo weight training experience	Back pain/upper limb injuries	$n = 11$; male ($n = 11$); age = 28; university students; trained	Multifidus; transverse abdominis	Surface; MU: L3; TA: NR; right side	Ball/device; core stability
Marshall and Murphy (29), New Zealand	NR	Pain during testing; low back pain (last 5 y)	$n = 8$; male ($n = 4$); female ($n = 4$); age = 24; healthy university population; NR	Multifidus; transverse abdominis	Surface; MU: 3 cm L L4/L5; TA: 3 cm inferior/medial to ASIS; right side	Ball/device; core stability
Nuzzo et al. (33), United States	NR	NR	$n = 9$; male ($n = 9$); age = 24; healthy; trained	Multifidus	Surface; MU: L5 bilateral	Ball/device; free weight
Okubo et al. (34), Japan	Experience performing back/abdominal exercises (not stabilization exercises)	Lumbar spine disorder, neurological disorder, spinal surgery	$n = 9$; male ($n = 9$); age = 24; healthy former athletes; untrained	Multifidus; transverse abdominis	Intramuscular; MU: 2 cm L L5; TA: midway between rib cage and iliac crest bilateral, averaged	Core stability; traditional
Oliver et al. (35), United States	Consistent participation in conditioning program	NR	$n = 30$; sex NR; age = 23; healthy university students; NR	Multifidus	Surface; MU: NR; bilateral, averaged	Core stability; traditional
Willardson et al. (40), United States	Physical conditioning program for previous year	NR	$n = 12$; male ($n = 6$) and female ($n = 6$); age male = 23 and female = 27; healthy; trained	Multifidus; transverse abdominis	Surface; MU: 3 cm L L5 (height of iliac crest); TA: inguinal space 3 cm medial to iliac crest; right side	Ball/device; core stability; traditional
Willardson et al. (41), United States	>4 y weight training experience; healthy (PAR-Q); consistently perform lifts in study	Low back, knee, ankle injuries during previous year	$n = 12$; male ($n = 12$); age = 22; healthy; trained	Multifidus; transverse abdominis	Surface; MU: 3 cm L L4/L5; TA: 3 cm inferior and medial to ASIS; right side	Free weight; noncore free weight

*EMG = electromyographic; NR = not reported; MU = multifidus; L = lateral; TA = transverse abdominis; EO = external oblique; ASIS = anterior superior iliac spine.
†Current physical fitness training level–based on author's description of general physical activity level, general physical training regimen, or physical training regimen for the core.

TABLE 5. Lumbar multifidus and transverse abdominis EMG activity during physical fitness exercises from the included studies.

Author	Exercise	Lumbar multifidus EMG*	Transverse abdominis EMG*
Colado et al. (5)	Back extension	56	
	Deadlift: 70% MVIC	97	
	Lunge: 70% MVIC	60	
	Supine bridge: BOSU	41	
Comfort et al. (7)	Prone plank	70 mV	
	Shoulder press: barbell: 40 kg	140 mV	
	Superman: ball	950 mV	
	Squat: 40 kg	750 mV	
	Squat: front: 40 kg	1,100 mV	
Drake et al. (8)	Back extension	44	14
	Back extension: ball	34	14
	Quadruped arm/leg lift RA/LL	23	21
	Quadruped arm/leg lift: ball RA/LL	25	17
	Quadruped single-leg lift R	20	21
	Quadruped single-leg lift: ball R	20	18
Ekstrom et al. (9)	Lateral step up (20 cm): body weight L	28	
	Lunge: body weight	25	
	Prone plank	5	
	Quadruped arm/leg lift RA/LL	46	
	Side bridge L	42	
	Side-lying hip abduction R	20	
	Supine bridge	39	
	Supine bridge with leg lift R	44	
Escamilla et al. (10)	Ab Revolutionizer: double crunch	4	51
	Ab Revolutionizer: oblique crunch	4	48
	Ab Revolutionizer: reverse crunch	4	33
	Ab Revolutionizer: reverse crunch with weights	6	51
	Crunch	3	42
	Hanging knee-up-straps	7	85
	Power Wheel: knee-up	8	72
	Power Wheel: pike	8	83
	Power Wheel: roll-out	5	66
	Reverse crunch	6	52
	Reverse crunch: inclined 30°	8	86
	Sit-up	6	49
Escamilla et al. (11)	Crunch	5	33
	Hip extension: ball L	6	45
	Hip extension: ball R	7	40
	Knee-up: ball	6	41
	Pike: ball	8	56
	Press-up: ball: bottom	6	33
	Roll-out: ball	6	46
	Sit-up	6	31
	Skier: ball	6	47
Escamilla et al. (12)	Ab Doer: body bob	8	37
	Ab Doer: body boogie	13	31
	Ab Doer: good morning	15	22
	Ab Rocker: crunch	4	24
	Ab Rocker: oblique crunch	3	23
	Ab Roller: crunch	3	38
	Ab Roller: oblique crunch	3	25
	Ab Slide: curved	2	51
	Ab Slide: straight	3	53
	Ab Twister: crunch	4	22
	Ab Twister: oblique crunch	5	28

	Crunch	2	41
	Oblique crunch	5	40
	SAM	4	36
	Sit-up	4	49
	Torso Track	2	58
Hamlyn et al. (18)	Deadlift: body weight	35	
	Deadlift: 80% 1RM	80	
	Side bridge: ball	65	
	Squat: body weight	35	
	Squat: 80% 1RM	125	
	Superman: ball	40	
Imai et al. (24)	Crunch	5	27
	Crunch: BOSU	4	15
	Prone plank	4	14
	Prone plank: ball, elbows on ball	4	28
	Quadruped arm/leg lift RA/LL	27	22
	Quadruped arm/leg lift: ball RA/LL	26	29
	Side bridge R	9	24
	Side bridge: BOSU R	8	19
	Supine bridge	38	9
	Supine bridge: BOSU	38	11
Konrad et al. (25)	Back extension: kneeling	47	
	Crunch	3	
	Crunch: hyperextended	4	
	Hip extension	32	
	Lateral flexion L	59	
	Oblique crunch	29	
	Side bridge R	3	
	Quadruped arm/leg lift RA/LL	41	
	Sit-up	5	
	Supine bridge	37	
	Trunk extension	52	
	Vertical hip lift	5	
Lehman et al. (28)	Prone plank	5	30
	Prone plank: ball, elbows on ball	5	40
	Side bridge R	28	43
	Supine bridge	25	12
	Supine bridge: ball	27	20
Marshall and Murphy (29)	Press-up: bottom		13
	Press-up: ball, bottom	14	20
	Press-up: ball, top	7	33
	Press-up: top	10	13
	Quadruped arm leg lift LA/RL	34	13
	Quadruped arm leg lift: ball LA/RL	32	15
	Quadruped arm leg lift RA/LL	22	12
	Quadruped arm leg lift: ball RA/LL	24	13
	Roll-out	12	19
	Roll-out: ball	11	22
	Single-leg hold L	12	23
	Single-leg hold: ball L	12	23
Nuzzo et al. (33)	Back extension: ball	52	
	Deadlift: 50% 1RM	124	
	Deadlift: 70% 1RM	125	
	Deadlift: 90% 1RM	143	
	Deadlift: 100% 1RM	163	
	Quadruped arm/leg lift: ball LA/RL	40	
	Squat: 50% 1RM	93	
	Squat: 70% 1RM	96	
	Squat: 90% 1RM	112	

(continued on next page)

	Squat: 100% 1RM	129	
	Supine bridge: ball	49	
Okubo et al. (34)	Crunch	7	32
	Prone plank	3	13
	Prone plank with arm/leg lift LA/RL	6	35
	Prone plank with arm/leg lift RA/LL	4	26
	Quadruped arm/leg lift LA/RL	22	24
	Quadruped arm/leg lift RA/LL	22	21
	Side bridge	10	23
	Side bridge with leg lift L	18	22
	Supine bridge	38	
	Supine bridge with leg lift L	42	15
	Supine bridge with leg lift R	53	14
Oliver et al. (35)	Flying squirrel	55	
	Superman	59	
	Supine bridge	31	
	Supine bridge with leg lift L	36	
	Supine bridge with leg lift R	36	
Willardson et al. (40)	Ab Circle: level 1	0.10 mV	0.04 mV
	Ab Circle: level 2	0.10 mV	0.04 mV
	Ab Circle: level 3	0.10 mV	0.03 mV
	Crunch	0.03 mV	0.06 mV
	Quadruped arm/leg lift	0.09 mV	0.03 mV
	Side bridge R	0.13 mV	0.04 mV
Willardson et al. (41)	Biceps curl: barbell: 50% 1RM	20	24
	Biceps curl: barbell, 75% 1RM	34	46
	Deadlift: 50% 1RM	64	11
	Deadlift: 75% 1RM	63	15
	Shoulder press: barbell, 50% 1RM	14	32
	Shoulder press: barbell, 75% 1RM	17	43
	Squat: 50% 1RM	46	10
	Squat: 75% 1RM	55	11

*Values listed as %MVIC unless noted otherwise. EMG = electromyographic; MVIC = maximal voluntary isometric contraction; RA = right arm; LL = left leg; R = right; L = left; 1RM = 1 repetition maximum; LA = left arm; RL = right leg; F = female; M = male.

lumbar multifidus EMG activity is greater during free weight exercises compared with ball/device exercises, whereas 1 low-quality study (7) reported no difference in lumbar multifidus EMG activity between free weight exercises and ball/device exercises.

- Lumbar multifidus EMG activity is similar during core stability exercise and ball/device exercises. Three low-quality studies (8,24,28) and 2 moderate-quality studies (29,40) found no difference in lumbar multifidus EMG activity between core stability exercises and ball/device exercises, whereas 1 low-quality study (7) found that lumbar multifidus EMG activity is greater during ball/devices exercises compared with core stability exercises.

Limited Evidence.

- Lumbar multifidus EMG activity is greater during core stability exercises compared with traditional core exercises. Two moderate-quality studies (34,40) and 1 low-quality study (9) found that lumbar multifidus EMG activity is greater during core stability exercises compared with traditional core exercises. One low-quality study (25) found no difference in lumbar multifidus EMG activity between core stability exercises and traditional core exercises, whereas another low-quality study (35) found that lumbar multifidus EMG activity is greater during traditional core exercises compared with core stability exercises.
- Lumbar multifidus EMG activity is greater during ball/device exercises compared with noncore free weight exercises. One low-quality study (7) found that lumbar multifidus EMG activity is greater during ball/device exercises compared with noncore free weight exercises.
- Lumbar multifidus EMG activity is greater during free weight exercises compared with traditional core exercises. One moderate-quality study (5) found that lumbar multifidus EMG activity is greater during free weight exercises compared with traditional core exercises.
- Lumbar multifidus EMG activity is greater during free weight exercises compared with noncore free weight exercises. One moderate-quality study (41) and 1 low-quality study (7) found that lumbar multifidus EMG activity is greater during free weight exercises compared with noncore free weight exercises.

- Lumbar multifidus EMG activity is greater during noncore free weight exercises compared with core stability exercises. One low-quality study found that lumbar multifidus EMG activity is greater during noncore free weight exercises compared with core stability exercises (7).
- Conflicting evidence was found regarding lumbar multifidus EMG activity during traditional core exercises compared with ball/device exercises. One moderate-quality study (5) and 1 low-quality study (8) found that lumbar multifidus EMG activity is greater during traditional core exercises compared with ball/device exercises, whereas 3 moderate-quality studies (10,12,40) found that lumbar multifidus EMG activity is greater during ball/device exercises compared with traditional core exercises. One moderate-quality study (11) and 1 low-quality study (24) found no difference in lumbar multifidus EMG activity between traditional core exercises and ball/device exercises.
- Conflicting evidence was found regarding lumbar multifidus EMG activity during core stability exercises compared with free weight exercises. One low-quality study (9) found that lumbar multifidus EMG activity is greater during core stability exercises compared with free weight exercises, whereas 1 low-quality study (7) found that lumbar multifidus EMG activity is greater during free weight exercises compared with core stability exercises.

No Evidence.

- No evidence was found comparing lumbar multifidus EMG activity during traditional core exercises with noncore free weight exercises.

Transverse Abdominis

Moderate Evidence.

- Transverse abdominis EMG activity is similar during core stability exercises and ball/device exercises. One moderate-quality study (40) and 3 low-quality studies (8,24,28) found no difference in transverse abdominis EMG activity between core stability exercises and ball/device exercises, whereas 1 moderate-quality study (29) found that transverse abdominis EMG activity is greater during ball/device exercises compared with core stability exercises.

Limited Evidence.

- Transverse abdominis EMG activity is greater during noncore free weight exercises compared with free weight exercises. One moderate-quality study (41) found that transverse abdominis EMG activity is greater during noncore free weight exercises compared with free weight exercises.
- Transverse abdominis EMG activity is similar during traditional core exercises and core stability exercises. Two moderate-quality studies (34,40) found no difference in transverse abdominis EMG activity between traditional core exercises and core stability exercises.
- Conflicting evidence was found regarding transverse abdominis EMG activity during traditional core exercises compared with ball/device exercises. One low-quality study (24) found that transverse abdominis EMG activity is greater during traditional core exercises compared with ball/device exercises, whereas 2 moderate-quality studies (10,12) found that transverse abdominis EMG activity is greater during ball/device exercises compared with traditional core exercises. One low-quality study (8) and 2 moderate-quality studies (11,40) found no difference in transverse abdominis EMG activity between traditional core exercises and ball/device exercises.

No Evidence.

- No evidence was found regarding transverse abdominis EMG activity during the following comparisons: traditional core exercises with free weight exercises, traditional core exercises with noncore free weight exercises, core stability exercises with free weight exercises, core stability exercises with noncore free weight exercises, ball/device exercises with free weight exercises, and ball/device exercises with noncore free weight exercises.

Quadratus Lumborum

No Evidence.

- No evidence was found regarding quadratus lumborum EMG activity during physical fitness exercises.

Discussion

The purpose of this paper was to systematically review the existing research on EMG activity of 3 core muscles (lumbar multifidus, transverse abdominis, quadratus lumborum) during physical fitness exercises. A key finding of this systematic review is that relatively few studies were uncovered for lumbar multifidus and transverse abdominis EMG activity muscles, and no studies were uncovered for quadratus lumborum EMG activity during physical fitness exercises that met our inclusion criteria. Furthermore, the overall quality of the included studies was low to moderate, indicating a high risk for bias. Therefore, the evidence base for EMG activity of 3 major core muscles (lumbar multifidus, transverse abdominis, quadratus lumborum) during physical fitness exercises studied is not strong, despite the widespread and long-term use of core exercise in the physical fitness and rehabilitation communities. This review demonstrates the need for high-quality studies to reduce the risk of bias to make definitive conclusions about core muscle activity. Improved research in this area would provide strength and conditioning specialists with additional evidence-based knowledge when prescribing core exercises for athletes and clients.

Despite the overall lower quality of the studies that were uncovered in this review, the currently available evidence allows certain conclusions to be drawn about which physical fitness exercises are most effective to elicit EMG activity of the multifidus and transverse abdominis muscles, as discussed below. For example, the findings of this systematic review indicate that lumbar multifidus EMG activity is greatest during free weight exercises compared with other physical fitness exercises. This finding indicates that strength and conditioning specialists should promote use of multijoint free weight exercises rather than ball/device exercises for optimizing the EMG activity of the lumbar multifidus muscle. Possible explanations for greater lumbar multifidus EMG activity during free weight exercises include the use of external loading and full-body movements with free weight exercises compared with isolated exercises exclusively targeting the core.

Although performing core stability or traditional core exercise with a ball/device has commonly been considered useful to increase activity of the core muscles, the role of ball exercises in training programs has recently been debated (27). Evidence uncovered in this systematic review suggests that the lumbar multifidus EMG activity is similar during ball/device exercises and core stability exercises without a ball, and no conclusions can be drawn about lumbar multifidus EMG activity when comparing ball/device and traditional core exercises. Considering that there is potentially a higher risk of harm during ball exercises compared with their non-ball counterparts, along with the lack of increased multifidus muscle activity during ball exercises as noted in this systematic review, the use of ball exercise is not advised.

In this systematic review, no specific type of exercise was deemed to be clearly more effective than another exercise type for eliciting transverse abdominis EMG activity. Comparisons between exercise types demonstrated either no differences or conflicting findings, with the exception of limited evidence demonstrating greater transverse abdominis EMG activity during noncore free weight exercises compared with free weight exercises. Also, many of the potential comparisons between exercise types appear to be unstudied. For example, no studies were found comparing transverse abdominis EMG activity during core stability exercises with free weight exercises. Thus, any claim or recommendation made about 1 type of physical fitness exercise being most effective at eliciting transverse abdominis EMG activity is not supported by the current literature. Given the lack of relative effectiveness, decisions regarding specific exercise type to be prescribed by the strength and conditioning specialist for the transverse abdominis muscle may be simply based on the preference of the athlete, client, and strength and conditioning specialist, along with the available equipment and resources.

This systematic review did not uncover any articles on quadratus lumborum EMG activity during fitness exercises that fit the systematic review's inclusion and exclusion criteria. Therefore, strength and conditioning specialists cannot rely on the scientific evidence to inform decisions about which exercises are optimal for quadratus lumborum activity to prescribe for their athletes and clients. Furthermore, claims made about the effect of certain physical fitness exercises on quadratus lumborum EMG activity are likely made based on factors other than comparative analysis of core EMG activity during various exercise types.

The studies included in this systematic review displayed certain design features that limited the ability to summarize the findings in a quantitative manner. Numerous studies were found to be of low quality because of various factors such as the exercise interventions were not fully described, no exercise familiarization was provided, small sample sizes were enrolled, inadequate information about the study sample was provided, and the safety of the exercises was not discussed. In addition, the diversity of exercise and EMG techniques among the studies made pooling and summarizing data problematic. For example, different studies referred to the same exercise with different names, different exercises were sometimes referred to with the same name, and exercises were performed differently in terms of cadence and range of motion. Furthermore, how EMG activity was recorded, processed, and reported differed among the studies. For example, electrode placement for a certain muscles was not consistent, and some studies reported EMG activity in %MVIC, whereas others reported absolute EMG activity in millivolts. This systematic review's finding of low quality and methodological diversity of published studies on core exercises and EMG activity was also reported in a recent review of abdominal exercise (32). Given the limitations of the available scientific literature on this topic, the strength and conditioning specialist should review individual research studies with caution when interpreting findings for practical applications.

This article's systematic review, analysis, and reporting strategies have certain limitations, which should be considered when interpreting the results. First, this systematic review assessed core EMG activity in healthy populations, not those with low back pain or other disorders. Therefore, the findings of this systematic review are not directly generalizable for clinical rehabilitation. Moreover, exercises in the reviewed studies were arbitrarily assigned to specific exercise types, and no comparisons were made among exercises within 1 exercise type. Furthermore, patterns of activity within a muscle (e.g., right vs. left) or among muscles (e.g., multifidus vs. transverse abdominis) were not assessed. Finally, no attempts were made to characterize changes in core muscle EMG activity after exercise training programs. Future research, including systematic reviews and prospective experimental studies, is needed to fully characterize core muscle EMG activity in various populations, conditions, and exercise strategies.

Practical Applications

The findings of this systematic review have practical applications for strength and conditioning specialists who prescribe common fitness exercises to athletes and clients to improve core muscle endurance, strength, and stability. The findings of this review indicate that free weight exercises, such as the squat and deadlift, are optimal to produce activity of the lumbar multifidus muscle, and no specific type of exercise appears to be more effective than others at producing activity of the transverse abdominis muscle. Adding isolated core exercises to supplement a comprehensive fitness routine involving multijoint free weight exercises is probably unnecessary to activate these core muscle groups. Therefore, strength and conditioning specialists should focus on prescribing multijoint free weight exercises, rather than core-specific exercises, for athletes and clients to train the core muscles.

Typically, free weight exercises are dynamic multijoint movements that use external loading. When performed in such a manner along with application of progressive resistance, free weight exercises have multiple health and fitness benefits (38), such as improving body composition, muscular strength, bone density, and cardiovascular health. None of these benefits have been associated with core-specific floor (core stability or traditional core) or ball/device exercises. Furthermore, in contrast to core-specific floor or ball/device exercises, free weight exercises simultaneously activate multiple major muscle groups and act upon multiple joint systems. Thus, the strength and conditioning specialist may find that prescribing multijoint free weight exercises, which are associated with various health benefits, is more time efficient than prescribing numerous core-specific floor or ball/device exercises. Additionally, the resistive load of free weight exercises can be continually progressed as the muscles adapt and become stronger over the course of a training program, whereas core-specific floor or ball/device exercises are typically limited to the resistance of the body mass.

The findings of this systematic review also indicate that adding a ball/device to floor-based core-specific exercises does not increase lumbar multifidus or transverse abdominis muscle activity relative to performing that exercise without a ball/device. Therefore, given the simplicity of performing floor exercises, adding balls/devices appears to be unnecessary and is not recommended.

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