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Review Article

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Safety and Efficiency of Core Muscles Training Programs for Motor Control and Injury Prevention: A Brief Review

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Abstract

The aim of this review was to investigate about what Core training programs have been developed from a scientific approach and the results thereof in connection with the correct prescription of healthy exercise. A review using online databases was performed. 77 scientific articles published between 1990 and 2014 were reviewed. 19 patients of them were selected according to the criteria defined inclusion. The analysis shows that there is agreement among authors regarding the safety and efficiency of exercises to strengthen Core muscles. However, there is considerable controversy around the load control for Core training, optimal training frequency, and volume.

Keywords: Core training; Abdominal muscle; Safe exercises; Lower back; Health

Introduction

Core: concept and benefits

Developing conditioning programs of lumbo-abdominal musculature is a widespread practice in the fitness rooms. This musculature is the central area of CORE as well as the center of gravity of the human body where most movements start [1]. There are numerous muscles that take part of this complex. The CORE is divided into the lumbar spine, the muscles of the abdominal wall, the back extensors and the lumbar square [2,3]. Some studies also include upper and lower sections of the body: shoulders, trunk, hip and thighs [4,5]. The CORE has a functional orientation, being a key factor for performance of activities of daily living due to its primordial function to stabilize and protect the spine [6]. A well trained CORE is essential for optimal performance and injury prevention [2] and prevents lower back pains [7,8]. Several studies have found an association between a decreased stability and a higher risk of causing low back or knee injuries [9,10]. CORE training is very important in health and physical performance of the individual [11].

Good abdominal muscles will stabilize the lower back and prevent hyperextension lead by the action of the hip flexors [12]. The stabilizing role of the abdominal muscles is based on its ability to decrease intradiscal pressure in the back-lumbar spine [12,13]. Health professionals advocate strengthening exercises for the abdominal muscles in order to increase the stability of this area inherently unstable. CORE stability can help in reducing the compressive forces directed toward the lumbar spine through the preservation of muscle function balanced trunk and proper body posture [14]. It has been shown that there exists an inverse relationship between the length of the voluntary reaction time and the degree of postural stability in a certain situation [15,16].

Respect to the lumbar musculature, it has been shown a relationship between lumbar weakness and lumbar pains, so training this muscles group is indicated to prevent spinal disorders [17]. Also, proper lumbar muscles training can help accelerate the recovery process proved to be extremely useful in the therapeutic field [18].

Core Evaluation and Training in accordance with the Characteristics of the Musculature

Some confusion exists about CORE musculature: how CORE strength, stability or stamina is tested, how is it trained and applied to functional performance. Therefore, we have established a classification of the musculature of the central area, from two systems (Table 1): i) local system (stabilization) and ii) global system (movement), with distinction between the CORE strength, CORE stability and functional exercises [6].

CORE MUSCULATURE		
Local muscles (stabilization system)		**Global muscles (movement system)**
Primary	**Secondary**	
Transversus abdominis	Internal oblique	Rectus abdominis
Multifidi	Medial fibers of external oblique	Lateral fibers of external oblique
	Quadratus lumborum	Psoas major
	Diaphragm	Erector spinae
	Pelvic floor muscles	Iliocostalis (thoracic portion)
	Iliocostal y longísimo (lumbar portions)	

The main muscles responsible for developing the movement and the torque of the spine are the global muscles. They have long arms and big levers of mobility and their action extend the whole column. Global system is made of type II fibers mainly, creating consequently the spine movement (mobility). The Core tends to get shortened, which should predominate fast movements and overcome higher resistances, especially the rectus abdominis [19]. They are the major muscles involved in the column movement and external forces control and adaptation occurring on the spine [3].

Core Training and Stability of the Spine

Stability is the ability of the spine to maintain its state of static equilibrium when subjected to unbalancing forces (internal or external) [20]. Appropriate muscle recruitment and timing is extremely important for providing Core stability [15]. The column will be more stable the harder it is to change its status. According to Panjabi [1] joint stability is influenced by the coordinated action of three systems:

The passive system consists of the osteoarticular structures (intervertebral discs, vertebrae, zygapophysial joint and ligaments).

The active system is formed by the trunk muscles. These muscles and tendons surrounding act on the spine, including local and global muscles.

The neural control system (central and peripheral). A primary sensory mechanism for motor control is proprioception generated by the muscles [15]

According to Faries & Greenwood [6], Core stability refers to the ability of muscles of the central zone to stabilize the spine, not the stability of the muscles themselves. Core strength is the ability of the Core muscles to produce contractile forces and intra-abdominal pressure necessary for movement. The active column stability control is achieved by regulating the strength provided by the muscles that surround it [21]. Training for improving the ability of stability and / or strength of Core is based on specificity and functionality for the day by day or sports movement to be performed [8]. Looking for a precise balance between the amount of stability and mobility, the role of sensory-motor control is much more important than the role of strength or endurance of the trunk muscles [15]. There is a combination of three levels of motor control (spinal reflex, brain stem balance, and cognitive programming) that produces appropriate muscle responses [16].

Biomechanically, selecting the most appropriate stabilization exercises for each training program is mainly based on efficacy and safety criteria [22]. An exercise is efficient when during its execution the muscles are activated with a level of sufficient intensity to produce adaptations [23]. Safety is assessed by studies of the mechanical load in tissues, considering no safe exercises those in which spinal structures are subjected to high loads [12]. The absence of the first criterion would be the lack of effectiveness, while the failure of the second and / or third criterion the lack of security.

Choosing exercises for strengthening the Core, the functionality of the exercises has to be considered, regarding to healthy populations, protocols should be oriented to activities of daily life and work, and in the case of athletes, the sport specific movements [16].

Current Subject Status and Objective

In the area of training the Core, we know those exercises that are safe and effective, their complexity and the level of activation. However, there are some unknown questions left to be answered and more researches are needed for clarifying some variables related to the Core training. For example, there is not a validated instrument to make an initial assessment as a way of knowing the level of the subject. Minimal training volume (number of reps, sets and rest) is not known to produce adaptations. There are also no references about the time that should a side bridge or bird dog last. This problem is in terms of controlling the load. In addition, there is some controversy around the realization of hypopressive abdominals (brazing and hollowing) as healthy means of strengthening the Core. The literature has not solved this problem and it is a source of unawareness in this type of research. However, these are some of the possible lines of future research.

Given these premises, the objective of this study has been i) the realization of a review of those publications related to healthy Core training in order to show the state of the art on the subject of study and ii) provide researchers a basis on which to base futures research lines around the Core training programs.

Methodology

Procedure

A literature search was conducted through the scientific databases with web access, scanning reference lists of articles and consultation with experts in the field of physical activity, sport sciences and health. This search was applied to ACSM, ELSEVIER, ISI Web of Knowledge, ProQuest, PubMed, Science Citation Index Expanded and ScienceDirect, and SPORTDiscus. Articles were selected to 1990 at 2014. A committee of three experts with university degrees and experience in Core training selected search terms. The search strategy used the terms Core training, rectus abdominis, lumbar musculature, electromyography (EMG), muscle activity, exercises and health. References cited in the articles were used to locate more additional relevant articles.

Electronic Search and Selection Criteria

The criteria for inclusion and exclusion of articles are presented in Table 2. After locating all studies on the Core conditioning were categorized into 3 different criteria:

Those documents that perform an experimental analysis to show the cause and effect of different Core strengthening exercises.

Articles that analyze descriptively the Core musculature.

Those articles that performed an analysis of the variables influencing the control of the Core training load (volume, intensity, density, frequency and methods).

Regarding the first two criteria, studies were classified into two different sub-groups [24-27]: i) those studies that support the Core training with traditional character exercises and ii) those articles that based its review in alternative character devices. As for the third criterion, those investigations which were taken over control of the Core training.

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INCLUSIONARY	EXCLUSIONARY
Health	Performance
EMG CORE exercises (RA, IO, EO, TrA, T, SM, ST, MF, QL, ES, GM, IL, RF and SA)	Analysis of infrequent exercise fitness rooms
Compressive forces on the spine	Irrelevant articles
International databases in the area	No original research
*RA: rectus abdominis; IO: internal oblique; EO: external oblique; TrA: transverse abdominis; T: trapeze; LD: latissimus dorsi; SM: semimembranosus; ST: semitendinosus MF: multifidus; QL: quadratus lumborum; ES: erector espinae; GM: gluteus maximus; IL: hip flexor iliacus; RF: rectus femoris; SA: sartorius.	

Table 2: Inclusion and exclusion criteria.

Information was extracted from each included trial on: (1) the authors and year of publication, (2) participants, (3) procedures and (4) main results.

Results

Seventy-seven (n=77) articles were found. Of these, nineteen (n=19) were excluded for not complying any of the criteria defined inclusion. Finally 58 articles were analyzed.

In most of the articles analyzed, both men and women participated together.

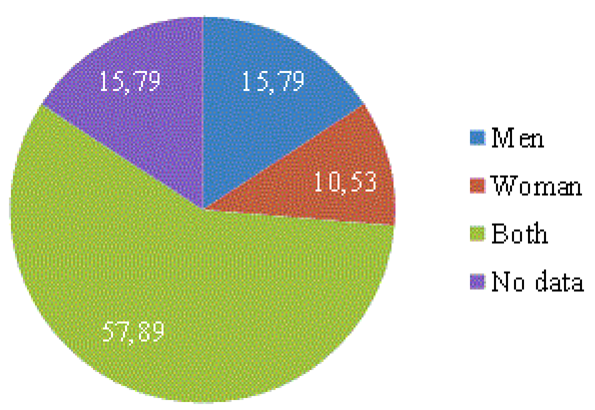

Figure 1: Participants by sex in the reviewed investigations.

Regarding the exercises analyzed through the electromyographic analysis of muscle participation, the abdominal crunches were the most analyzed (12.8%), followed by the front-bridge (7.7%). In a smaller number, exercises such as Back-bridge, Side-bridge, Bird-dog, Bent-knee sit-up, Power Wheel, Curl-ups or Trunk flexion sit-tup are analyzed, all with 5.1%. Finally, the lowest percentage of exercises analyzed in the articles reviewed with 2.6% is as follows: Isometric crunch, Crunch on a stability ball, Ball exercises, AbSlide, TRX, Fitness ball, Trunk curl-up, Hanging knee-up, Back extensions on the physioball, Trunk and hip flexion, Trunk lateral flexion, Trunk and hip extension, Hip flexion sit-up, Spontaneous sit-up, Leg lift, Torso rotation muscle strength, Isometric lumbar extension torque (Figure 2).

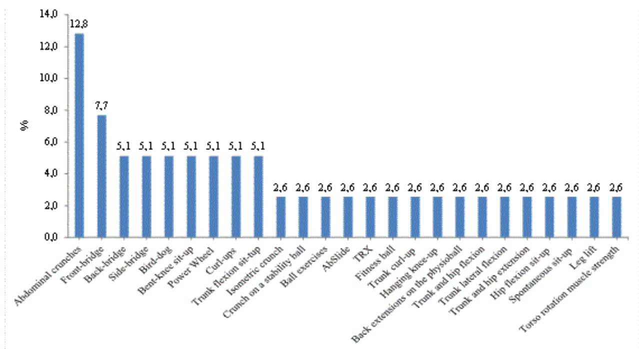

Figure 2: Exercises analyzed in the reviewed investigations.

Regarding the treatments applied in the reviewed researches, the comparison between traditional training exercises of CORE and new and alternative exercises stands out (17.4%). Works comparing the effect of different trainings on various groups (17.4%) and comparison of different training exercises of the CORE (13.0%). And in a smaller quantity, other treatments are shown reflected in Figure 3, with values of 8.7% and 4.3%.

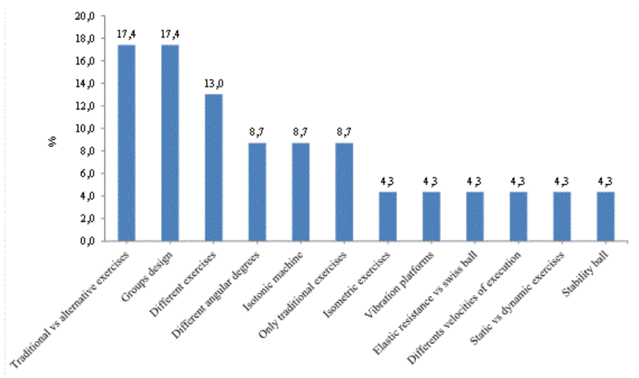

Figure 3: Treatments applied in the reviewed investigations.

The results of the research analyzed are summarized and presented in Table 3, in order to facilitate the reader's understanding. All the results are presented in Appendix.

Authors and year of publication	Participants	Methods	Main results
Vera-García, Barbado and Moya [54]	An asymptomatic 31 year old man, with a body weight of 59.7 kg and a height of 165.1 cm. He was healthy without current back, hip or shoulder pain or past pathology in these regions. In addition, he was recreationally trained and familiar with trunk stabilization exercises.	Analyze the trunk muscular response with EMG (RA, EO, IO, ES) during different variations of some of the most popular stabilization exercises: front-bridge, back-bridge, side-bridge, and bird-dog	-The highest activation levels were found in three exercises: sagittal walkout in a front-bridge position, rolling from right side-bridge into front-bridge position, and side-bridge with single leg support on a BOSU. -Performing front- and side-bridges with elbows extended, and especially kneeling on the bench, reduces muscle activation. -Performing the back-bridge with elbows extended elicited higher muscular activation than the conventional exercise. -Single leg support and/or limb motions while performing stabilization exercises increase the activation of the trunk rotators, especially the IO.
López-Valenciano, Biviá-Roig, Lisón-Párraga and Vera-García, [(38]	20 healthy subjects: 10 men (age = 23.44 ± 2.50 years, mass = 75.67 ± 4.96 kg, height = 1.76 ± 0.08 m) and 10 women (age = 22.66 ± 2.12 years, mass = 55.49 ± 8.14 kg, height = 1.62 ± 0.06 m). Not participating in structured design of the trunk musculature programs.	EMG analysis of the activation of RA, OE, OI, ES and RF muscles during the performance of an isometric crunch in the following positions: inclined position (-10 ° and -20 °) to the horizontal position with the head at the bottom of the bank; horizontally or conventional position (0 °), tilted position (10 ° and 20 °) with the head in the top of the bank.	-Increased muscle activation with increasing negative slope inclinations (head down). -In positive inclinations, increasing the slope from +10 ° to +20 ° reduced the activation of RA, but increased the oblique muscles, especially the IO.
Vera-García, Barbado, Flores-Parodl, Alonso-Roque and Elvira [53]	16 asymptomatic women (age: 24.38 ± 4.54 years, mass: 57.74 ± 4.95 kg, height: 1.64 ± 0.04 m).	Levels of coactivation of trunk muscles was analyzed by EMG for RA, EO, IO and ES during the performance of back-bridge, front-bridge and side-bridge. An isometric repetition of 5 s duration was performed.	-The levels of muscle activation needed to stabilize the trunk during the execution of the bridges were low or moderate. -The abdominal muscles are activated mainly in the frontal- and side-bridge, and erector spinae was activated in the back-bridge. -In the side- bridges all the muscles on the side of the support arm were activated.
Lisón-Párraga et al. [37]	12 women and 19 men (n = 31) with no experience in vibration training. Mean age 25.9 ± 5.3 years, height 1.70 ± 0.10 m and a mass 69.1 ± 13.3 kg.	The level of activation of the RA muscle was analyzed during the performance of a front bridge (prone position) on a vibrating platform with different vibration frequencies.	-The percentage of RA EMG activity increased with each increase in the frequency of vibration of the platform. -Significant differences between frequencies were shown.
Sundstrup, Jakobsen, Andersen, Jav and Andersen [51]	42 untrained individuals (18 men and 24 women) aged between 28 and 67 years participated in the study.	Compare muscle activation as measured by electromyography (EMG) of global core and thigh muscles during abdominal crunches performed on Swiss ball with elastic resistance or on an isotonic training machine. EMG activity was measured in 13 muscles during 3 repetitions with a 10 RM load.	-Crunches on Swiss ball with elastic resistance showed higher activity of the rectus abdominis than crunches performed on the machine. -Crunches performed on Swiss ball induced lower activity of the rectus femoris than crunches in training machine. -Gender, age and musculoskeletal pain did not significantly influence the findings.
Escamilla et al. [20]	18 healthy subjects (9 women and 9 men). Anthropometric measurements in women 27.7 (7.7) years, 61.1 (7.8) kg, 165.0 (7.0) cm, and 18.7% body fat (3.5%), In men 29.9 (6.6) years, 73.3 (7.2) kg, 178 1 (4.3) cm, and 11.6% (3.6%).	Analysis of8 Swiss ball exercises (roll-out, pike, knee-up, skier, hip extension right, hip extension left, decline push-up, and sitting march right) and 2 traditional abdominal exercises (crunch and bent-knee sit-up) on activating core (lumbopelvic hip complex) musculature.	-EMG signals during the roll-out and pike exercises for the URA (63% and 46% MVIC, respectively), LRA (53% and 55% MVIC), EO (46% and 84% MVIC), and IO (46% and 84% and 56% MVIC) were significantly greater compared to most other exercises. -RF EMG signal was greatest with the hip extension left exercise (35% MVIC), and least with the crunch, roll-out, hip extension right, and decline push-up exercises -Lumbar paraspinal EMG signal was relative low for all exercises.
Schoffstall, Ticomb and Kilbourne [48]	21 active subjects. The characteristics of the subjects were (mean ± SD): age 20.5 ± 1.5 years, height 177.6 ± 7.5 cm, weight 75,205 ± 11,684 kg, body fat 12.4 ± 5.0% for men (n = 11) and 20.6 ± 1.2 years, height 166.5 ± 5.8 cm, weight 55,806 ± 6,787 kg, body fat 17.0 ± 4.9% for women (N = 10).	Compare SEMG activity of the URA, LRA, IO, EO, TA, and RF during varied abdominal strengthening exercises. The exercises consisted of both the traditional crunch and nontraditional abdominal exercises. The nontraditional exercises used devices including the Ab Slide, TRX (TRX), Fitness ball (FB), and Power Wheel (PW).	-There were no differences between any of the 6 exercises when measured using the EO muscle, the URA, or the LRA. In the IO muscle, there was a difference in the muscle activity for the Slide (89.73 ± 88.87mV) and the supine V-up abdominal (138.26 ± 81.01mV). -The muscle activity of the RF during the crunch was less than in any of the other 5 exercises.
Moraes et al. [43]	13 healthy subjects (8 men and 5 women). The mean age was 19.76 ± 1.53. with no history of injury	Activation of RA, OE and RF muscles was analyzed by means of EMG during crunch adding external loads representing 80, 60, 40 and 20% 1 RM. The time for executing each repetition	-The muscles analyzed were recruited in greater condition during execution of 1RM. -There was a significant reduction in the intensity of the EMG activation according the percentage of external load descended except loads of 20 and 40% which did not differ.

		was 4 s (2 s for each of the concentric and eccentric phases)	
Vera-García, Flores-Parodi, Elvira and Sarti, [56]	20 trained subjects (16 women and 4 men, aged 23.7 ± 4.3 years, height 166.2 ± 6.3 cm, mass 61.0 ± 8.2 kg).	Evaluate the effects of different trunk curl-up speeds on both the intensity of muscular activation and coactivation during 4 different curl-up cadences (1 repetition per 4 s (C4), 1 repetition per 2 s (C2), 1 repetition per 1.5 s (C1.5), and 1 repetition per 1 s (C1) and maximum speed curl-ups (Cmax). EMG activation analysis RA, OI, OE, ES muscles.	-Normalized EMG amplitudes of trunk muscles increased with curl-up speed. -The RA (ranged from 23.3% of MVICs at C4 to 49.6% of MVICs at Cmax) and internal oblique (ranged from 19.2% of MVICs at C4 to 48.5% of MVICs at Cmax) were the most active analyzed muscles at each speed, contribution of the EO increased appreciably with velocity (ranged from 5.3% of MVICs at C4 to 33.3% of MVICs at Cmax). -Increasing trunk curl-up speed supposed greater trunk muscular coactivation.
Sternlicht, Rugg, Fujii, Tomomitsu and Seki [50]	41 healthy adults (23 men and 18 women) mean values for anthropometric Their age, height and body mass were 20.3 (± 1.5) years, 177.5 (± 8.9) cm and 74.0 (± 14.7) kg,	Compare the abdominal muscle activity while performing a crunch on a stability ball with the ball at the level of the inferior angles of the scapulas (SB-high) and with the ball at the level of the lower lumbar region of the back (SB-low). EMG is registered in the upper and lower parts of the RA and EO.	-A crunch performed with the stability ball placed at the level of the lower lumbar region of the back exhibited greater URA, LRA, and EO activity by 31%, 38%, and 24%, respectively, than a traditional crunch. -The crunch performed with the stability ball placed below the scapulas elicited less URA, LRA, and EO activity by 21%, 29%, and 39%, respectively, than a traditional crunch. -The abdominal muscle activity doubled when the stability ball was moved from the upper to the lower back position.
Escamilla et al. [19]	21 healthy subjects (10 men and 11 women). Mean men: 29.6 ± 5.9 years, 82.5 ± 11.5 kg, 178.0 ± 6.8 cm 12.5 ± 2.8% body fat. Mean for women: 26.0 ± 3.3 years, 58.6 ± 4.9 kg, 164.8 ± 4.1 cm, 17.7 ± 1.7% body fat.	Compare the effectiveness of traditional and nontraditional abdominal exercises in activating abdominal and extraneous musculature. Traditional exercises included the crunch and bent-knee sit-up; nontraditional exercises included 2 variations of the reverse crunch, 4 variations of exercises performed with the Ab Revolutionizer device, 3 variations of exercises performed with the Power Wheel device, and 1 hanging knee-up exercise performed with an abdominal strap device.	-Upper and lower RA, IO, and LD muscle EMG activity were highest for the Power Wheel (pike, knee-up, and roll-out), hanging knee-up with straps, and reverse crunch inclined 30 degrees. External oblique muscle EMG activity was highest for the Power Wheel (pike, knee-up, and roll-out) and hanging knee-up with straps. -RF muscle EMG activity was highest for the Power Wheel (pike and knee-up), reverse crunch inclined 30 degrees, and bent-knee sit-up while lumbar paraspinal muscle EMG activity was low and similar among exercises
Cosio-Lima, Reynolds, Winter, Paolone and Jones [15]	30 female students with no previous experience in Swiss ball exercises with (N = 15 experimental group trained with the Swiss ball, N = 15 control group coaching exercises on floor).	Compare the effects of 5 weeks of physioball core stability and balance exercises with conventional floor exercises. The experimental group performed curl-ups and back extensions on the physioball while the control group performed the same exercises on the floor.	-The experimental group resulted in significant increases in abdominal and ES muscle EMG activity and duration of static balance times on floor exercises. -The experimental group stressed the musculature and activated the neuroadaptative mechanisms that led to the early phase gains in stability and proprioceptor activity.
Konrad, Schmitz and Denner [30]	10 healthy subjects (3 women, 7 men, age 27.8 ± 2.4 years, weight 75.8 ± 15.8 kg, height 177.9 ± 10.4 cm) familiar with strength training and gymnastics exercises.	EMG activity (RA, EO, RF, T, ES, GM, ST and SM) 12 exercises of CORE musculature were analyzed, including 5 for trunk and hip flexion, 2 for trunk lateral flexion, and 5 for trunk and hip extension..	-Pure spine-flexion exercises, such as a curl-up, produced sufficient and isolated activation (greater than 50% MVIC) of the abdominal muscles. In the sit-up the peak activation was increased. -Lateral-flexion tasks targeted primarily the EO muscle, which demonstrated high activity in side-lying flexion tasks. -Back- and hip-extension exercises, such as bridging and diagonal hip and shoulder extension, produced only moderate mean activities.
Lehman and McGill [35]	11 trained subjects from a university population were recruited because of their athletic abilities and low subcutaneous fat. Eight of the subjects were varsity athletes in basketball and volleyball, and the remaining subjects had performed abdominal muscle training exercises more than 3 times per week prior to this study.	Assess the activation of the upper and lower portions of the RA muscle during a variety of abdominal muscle contractions. EMG activity of the EO muscle and upper and lower portions of RA muscle was measured during the isometric portion of curl-ups, abdominal muscle lifts, leg raises, and restricted or attempted leg raises and curl-ups.	-No differences in muscle activity were found between the upper and lower portions of the RA muscle within and between exercises. -The activity during the abdominal muscle lift and the isometric leg raise was greater when compared with the external oblique muscle activity during the curl-up and the isometric curl-up.
Callaghan, Gunning and McGill [10]	Thirteen male volunteers were recruited from a university student population (mean age=21.0 years, SD=1.0, range=19-23; mean height=176.0 cm, SD=6.2, range=165-188; mean mass=77.0	Analysis the loading of the lumbar spine and trunk muscle activity levels while subjects performed typical trunk extensor exercises through EMG RA, OI, OE, GD, ES and MF muscles.	-The exercises involving active trunk extension produced the highest joint forces and muscle activity levels. -Exercises involving leg extension with the spine held isometrically demonstrated asymmetrical activity of the trunk muscles, thereby reducing loads on the spine. When

	kg, SD= 7.0, range=63-89). None of the subjects had experienced any low back pain for a minimum year.		combined with contralateral arm extensions, the challenge and demand of the exercise were increased.
Andersson, Nilsson, Zhijia, and Thorstensson [3]	Six healthy, habitually active, male subjects participated in the study. Their average age, body mass and height were 25 (22 ± 29) years, 75 (65 ± 84) kg and 1.81 (1.76 ± 1.87) m, respectively.	Analysis EMG activity levels for three trunk muscles(RA, EO, IO) and three hip flexor muscles (IL, RF, SA) during different static and dynamic sit-up and leg lift exercises, with standardized positions, velocity and modifications for the leg: trunk flexion situp (TF), hip flexion situp (HF), spontaneous situp (SP), leg lift (LL).	-The hip flexors were highly activated only in exercises involving hip flexion, either lifting the whole upper body or the legs. Bilateral, but not unilateral, leg lifts required activation of abdominal muscles. -In TF, the abdominal muscles were activated to a moderate to high degree. Higher values in RA and IO. -The TF showed no significant difference in the EMG levels of any of the abdominal muscles depending on leg position or whether the legs were supported or not. -In HF, flexed and supported legs increased hip flexor activation, whereas such modifications did not generally alter the activation level of the abdominals.
DeMichele et al., [17]	58 untrained subjects participated in the study. 33 men (age 30 ± 11years) and 25 women (age 28 ± 10years) with no history of low back pain,	Examine training frequency's effect on torso rotation muscle strength (1 x 8-12RM) during 12 weeks: -Group 1: once a week. -Group 2: 2d/week. -Group 3: 3d/week. -Control group: no exercise	-The 1d/wk group did not increase in isometric (IM) torso rotation strength compared to the control group at any angle. -Both the 2 and 3d/ wk groups increased their IM torso rotation strength compared to the control group at all but one angle. There were no significant differences in IM torso rotation strength between the groups that trained 2 or 3d/wk -2, 3 d/s > 1 d/s.
Carpenter et al., [11]	56 men and women with an age range between 19 and 53 untrained: • Group 1 N = 10. • Group 2 N = 12 • Group 3 N = 13	Compare the effect of varied training frequencies on the development of isometric lumbar extension torque (strength) over 12- and 20-week training periods. Training program: (1 x 8-12RM) -Group 1: Once every other week. -Group 2: 1d /week. -Group 3: 2d /week. -Group 4: 3d /week. -Control group: no training.	-The control group showed no change in isometric torque. -All training groups showed significant increases in lumbar extension torque at 12 and 20 weeks of training, whereas no significant differences were found among the groups with respect to the magnitude of torque gained. -1d/2wk= 1d/w= 2d/w= 3d/w.
Graves et al. [22]	72 men (age = 31 ± 9 years) and 42 women (age = 28 ± 9 years).	Evaluate effects of training frequency and specificity of training on isolated lumbar extension strength during 12 weeks of training (1 x 8-12 RM). -Group 1: Once every other week. -Group 2: 1d/week. -Group 3: 2d week. -Group 4: 3/ week. -Group 5: trained isometrically 1d / week. -Control group: no training.	-All training groups improved their ability to generate isometric torque at each angle measured when compared with controls -There was no statistical difference in adjusted post-training isometric torques among the groups that trained. -These data indicate that a training frequency as low as 1d/ week provides an effective training stimulus for the development of lumbar extension strength. -1d/2s= 1d/s= 2d/s= 3d/s.

Table 3: Research on core strengthening exercises. Articles selected to 1990 at 2014.

Discussion

Traditionally in the fitness rooms, CORE training protocols have focused on strengthening the global muscles by incorporating classic trunk [6]. However, considering the results obtained, it appears that the spinal flexion position involves a significant risk to the health of the lumbar intervertebral disc and ligament damage [12,38], as well as people with osteoporosis because the increased intradiskal pressure and lumbar spine compression can trigger to vertebral fractures [25]. Sit-up produces a high activation of the hip flexors, especially the psoas [38]. According to Axler & McGill [12], this task generates a comprehensive stress ranging between 3200 and 3500 Newton. If the sit-up is carried out with rotation or a high speed, the risk of compression is greater [21]. Considering the results obtained, it can be stated that in fields related to health and fitness, it is appropriate to use exercises that activate the abdomen muscles without producing large compressive forces on the spine [39]. Thus, the crunch is recommended instead of exercises incorporating trunk because it has been shown to activate the abdominal muscles as effectively as the sit-up, but without the very high activity of hip flexors produced during the sit-up. The crunch is safe for the lumbar spine back to minimize compressive forces (2000-2500N) and shear stress and actives to a lesser extent the hip flexors than sit-up [12,33]. In performing the crunch, there are no significant differences in activation CORE musculature depending leg position or if the feet are clamped [40]. McGill [38] recommends the curl-up with the hands under the lumbar spine to preserve a neutral spine posture and one knee flexed but with the other leg straight to lock the pelvis-lumbar spine and help preserve a loss in the neutral lumbar posture, usually on beginners subjects. In tasks that involve curl-up with rotation (cross curl-up) with the aim of working widely abdominal muscles (EO, IO and TA) there are no significant differences from the curl-up in the activation of this musculature [41,42].

To improve the CORE muscles activation during the crunch, abdominal bracing and hollowing should be practiced [7]. Thus, the spine is stabilized providing greater stability to it when subjected to external loads in various situations in daily life and sport. Abdominal bracing increases the stability of the spine to a greater extent than the abdominal hollowing [36]. The first strategy produces an increase in the abdominal muscle activation, what contributes to the maintenance of the upright posture. Recent researches have questioned its application and many scientists suggest that the most appropriate method for the spine stabilization may be the abdominal bracing [6].

Biomechanical studies have shown that during crunches performance in the negative inclinations (upside down) increases the intensity of the task, increasing the activation levels of abdominal wall muscles, while positive inclinations (head up) extensor moment is reduced, and consequently the bending moment and the activation of the rectus abdominis is reduced too[22].

Continuing the analysis of the studies reviewed, several studies have analyzed the involvement of different trunk muscles and hip flexors as well as lumbar load level during a set of commonly used in fitness, rehabilitation and sport exercises [40,43]. Their results indicate that the exercises involving bilateral leg lifts produce a high activation of the hip flexor muscles and large compressive loads on the lower back [40]. The exercises involving active trunk extension produced the highest joint forces and muscle activity levels (around 6000 Newton). In the health area, tasks involving a lower load are recommended as single-leg extension or extension of the contralateral arm combined with leg extension. [43]. Bridging is presented as a suitable exercise for strengthening the lumbar musculature [41]. However, performing the back-bridge with elbows extended elicited higher muscular activation than the conventional exercise (bridging) [44].

The lumbar musculature has an hypotonic character. Its electromyographic activation in standing is around 2-4% of the maximum voluntary contraction [32]. According to McGill [38], the spine can reach a range of 20 degrees in proned position. If the task is performed, ballistic motion can be dangerous to the vertebral structures by lack of muscle control. For its work is recommended to perform exercises by slower speeds with isometric stops, with a ratio with respect to the work of abdominal muscles, tending to a 1:1 ratio [45].

Several investigations have focused their work on the analysis of the CORE muscle activation with Swiss ball [24,27,29,46]. It has been shown that an unstable surface (eg a Swiss ball) leads to increased demands on trunk muscles, thereby improving Core stability and balance [15] and higher profits of neuronal activity and proprioceptive mechanisms than an stable surface [29, 47]. Crunch muscle activity with the ball at the level of the lower lumbar region of the back is significantly greater than the ball at the level of the inferior angles of the scapula position. According to the physical condition of the subject, the ball can progressively be positioned lower on their back to increase the training load and, therefore, increase their abdominal muscle activity. [27]. Crunches on a Swiss ball with added elastic resistance induces high rectus abdominis activity accompanied by low hip flexor activity which could be beneficial for individuals with low back pain. However, using an isotonic training machine produces low activation of the rectus abdominis and high activity of hip flexors warrant caution for individuals with lumbar pain [46].

Although the exercises performed on unstable surfaces usually enhanced the muscle activation, performing the exercises on the BOSUTM balance trainer did not always increase the trunk muscle activity. Overall, this information may be useful to guide fitness instructors and clinicians when establishing stabilization exercise progressions for the trunk musculature [44].

Pike, rol-out and skier are exercises that produce a high activation of CORE musculature compared to the crunch and bent-knee sit-up exercises. These exercises are a good alternative to traditional abdominal exercises for CORE muscle contraction, in addition to seeking greater energy expenditure. These exercises may be beneficial for individuals with limited workout time and whose goal is to perform exercises that not only provide an abdominal workout but also an upper and lower extremity workout [24].

In view of the results obtained it is appreciated that in recent years there has been an inclusion of devices and alternative materials in the fitness rooms to strengthen the abdominal muscles, like the Power Wheel roll-out, which is the most effective recruiting the abdominal and latissimus dorsi musculature minimizing rectus femoris and lumbar paraspinal muscle [25]. However, according to Schoffstall et al. [26] the training benefits of the abdominal musculature in an isometric fashion using commercial equipment could be called into question because when performing traditional isometric abdominal exercises, the activation of abdominal muscles is similar to equipment-based exercises.

Isometric bridges are exercises used to develop patterns of muscle co-activation of low or moderate intensity that facilitate postural control of the trunk and spine stability [45,48]. These are tasks that activate the trunk muscles without causing compressive forces that damage the structures of the lumbar spine [33]. Bridge exercises with double leg support produced the highest activation levels in those muscles that counteracted gravity, single leg support while bridging increased the activation of the trunk rotators, especially internal oblique [44]. According to McGill, [38], given the evidence for quadratus lumborum as a spine stabilizer, the optimal technique to maximize activation but minimize the spine load appears to be the side bridge. Compared to the conventional form of the front- and side-bridge, performing these exercises kneeling on a bench or with elbows extended reduced the muscular challenge [44].

Whole body vibration has recently become popular as a mean for improving the musculoskeletal system in different populations. However, current knowledge about the possible effects of physical exercise on vibrating platform is still limited. Most commonly, bipedestation exercises have been studied. [30]. In the area of CORE training, studies that apply vibration as a method for conditioning trunk muscles are scarce [37]. More researching is necessary to progress in this field as a mean for improving the strength, resilience and active stabilization of the spine.

It appears that the safest and mechanically most justifiable approach to enhancing lumbar stability through exercise entails a philosophical approach consistent with endurance, not strength; that ensures a neutral spine posture when under load [38]. The results of studies that have measured the mechanical stability of the spine indicate that it is not necessary to generate high levels of activation to stabilize the spine to the forces to which it is subjected in many of the actions that are performed daily [28,49] (5% of maximal voluntary contraction for activities of daily living and 10% of maximal voluntary contraction for rigorous activity [50]. Thus, maintaining sufficient stability when performing tasks, particularly the tasks of daily living, is not compromised by insufficient muscle strength [43].

Although in populations with objectives related to improving health can be more appropriate to strengthen the muscles of the trunk from an endurance approach, some studies as Moraes et al. [31] analyzed the implementation of a crunch adding external loads, for the CORE strength training. Stephenson and Swank [3] suggested that once the bodyweight exercises are not challenging enough, the subjects must use additional weights. Training Core strength and endurance simultaneously would be a very interesting option. Further research is required to develop CORE training programs of this type.

Assessment of CORE musculature has some limitations (validity and reliability factors) as it is very difficult to assess the ability of CORE stabilization with one single test because a single exercise is not able to activate all the muscles of trunk (active and passive system). It may be advisable to test the CORE stability through a battery of tests. Some tools that have been proposed in the literature are: Biering-Sorensen test [35], test FRT [51] side bridge test [56] and front abdominal power test [52].

According to Vera-García et al. [23] speed increase during curl-up required higher levels of muscular activation. However, the curl-up performance is a closed movement, if carried out a more global task at high speed you may cause forces on the lumbar region that may compromise the stability of the spine. Around the training frequency of the CORE there is some controversy [34, 53,54]. It seems that increase or decrease the frequency of training is not relevant. Faced with this, it seems that it is important the speed in the execution of the extension exercises, demonstrated this variable positive effects effects for the strengthening of CORE. In studies examining the extensor muscles of the trunk [53,54] there was no difference in the training frequency used, that is to say, train 1, 2 or 3 days a week not supposed significant differences in muscle gains between groups. In rotator muscles [34], 2 days of training a week is the recommended frequency.

Finally, we stress that it is necessary to carry out research with adults and older people, who require exercises adapted to their state of health. In the articles reviewed, the age of the participants is between 19 and 31 years, and they are physically healthy subjects. Accordingly these data, it is necessary to increase the knowledge about the effects of CORE training on adult and older populations with special needs.

Conclusion

A program to strengthen CORE muscles must be based on the individual characteristics of the subject, according to their personal needs and interests as well as their health status. Exercise prescription must have a functional orientation, relative to job performance and activities of daily life that make the individual. Therefore, the program must be completely individualized and meet the criteria of safety, efficacy and functionality.

Crunch is a safe and effective exercise to activate the abdominal muscles. Sit-up produces great coxofemoralis activation, secondarily involving the participation of the abdominal muscles. Recent research suggests the abdominal bracing as an effective maneuver for stabilizing the spine. The exercises involving active trunk extension and bilateral leg lifts don't meet the safety criteria. Single-leg extension and bird-dog are preferable.

The Swiss ball is an effective surface for the CORE muscles training, because it provides proprioceptive adaptations and higher values of muscle activation compared to stable surfaces. Isometric bridges are effective and safe exercises that generate muscle coactivation patterns of low or moderate intensity. Research must continue to improve the field of vibration platforms training as a means to improve strength, endurance and active stabilization of the spine.

The conditioning of the trunk muscles to improve CORE stability should be oriented to endurance training. There is no consensus regarding the minimum dose to produce adaptations (volume, intensity and density) for CORE training. Further research is required to develop training programs and evaluation methods for CORE training.

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