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ORIGINAL RESEARCH

SWISS BALL ABDOMINAL CRUNCH WITH ADDED ELASTIC RESISTANCE IS AN EFFECTIVE ALTERNATIVE TO TRAINING MACHINES

Emil Sundstrup, MSc[1]
Markus D. Jakobsen, MSc[1]
Christoffer H. Andersen, PhD[1]
Kenneth Jay, MSc[1]
Lars L. Andersen, PhD[1]

ABSTRACT

Background: Swiss ball training is recommended as a low intensity modality to improve joint position, posture, balance, and neural feedback. However, proper training intensity is difficult to obtain during Swiss ball exercises whereas strengthening exercises on machines usually are performed to induce high level of muscle activation.

Purpose: To 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 when normalized for training intensity.

Methods: 42 untrained individuals (18 men and 24 women) aged 28-67 years participated in the study. EMG activity was measured in 13 muscles during 3 repetitions with a 10 RM load during both abdominal crunches on training ball with elastic resistance and in the same movement utilizing a training machine (seated crunch, Technogym, Cesena, Italy). The order of performance of the exercises was randomized, and EMG amplitude was normalized to maximum voluntary isometric contraction (MVIC) EMG.

Results: When comparing between muscles, normalized EMG was highest in the rectus abdominis ($P < 0.01$) and the external obliques ($P < 0.01$). However, crunches on Swiss ball with elastic resistance showed higher activity of the rectus abdominis than crunches performed on the machine (104 ± 3.8 vs 84 ± 3.8% nEMG respectively, $P < 0.0001$). By contrast, crunches performed on Swiss ball induced lower activity of the rectus femoris than crunches in training machine (27 ± 3.7 vs 65 ± 3.8% nEMG respectively, $P < 0.0001$) Further, gender, age and musculoskeletal pain did not significantly influence the findings.

Conclusion: 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. In opposition, the lower rectus abdominis activity and higher rectus femoris activity observed in machine warrant caution for individuals with lumbar pain. Importantly, both men and women, younger and elderly, and individuals with and without pain benefitted equally from the exercises.

Key Words: abdominal crunch, elastic resistance, electromyographic activity, exercise ball

[1] National Research Centre for the Working Environment, Copenhagen, Denmark

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CORRESPONDING AUTHOR
Emil Sundstrup (+45 26 22 30 45)
National Research Centre for the Working Environment
Lersø Parkalle 105, DK-2100 Copenhagen, Denmark
emilsundstrup@gmail.com

INTRODUCTION

Core muscles must produce sufficient and well coordinated muscle contraction to both support and stabilize the lumbar spine during a variety human movement tasks.[1,2] Stability in this inherently unstable area is obtained through the integration of the passive spinal column restraints, active spinal muscular control, and neurological control.[3] Core stability refers to the ability of core muscles to stabilize the spine whereas core strength denotes the ability of the core musculature to then produce the needed contractile force and intra-abdominal pressure for movement.[4] The theory of local and global muscles has been used to classify the muscles contributing to core stability.[5] Local muscles, such as the transversus abdominis and mulifidi, are primarily responsible for force generation that provides inter-segmental stability due to their attachment to the lumbar vertebra, whereas the global muscles, such as rectus abdominis and erector spinae, are primarily involved in spinal movement and control of external forces that are placed upon the spine.[5,6]

The precise cooperation of motor control and contractile strength of the abdominal musculature provides support of the spine[7] whereas inadequate abdominal muscle strength negatively influences both the stability and controlled mobility of the trunk and spine and have been associated with clinical implications such as low back pain.[8] Jeng et al[9] described that strengthening the back, legs and abdominal muscles may decrease the occurrence of LBP possibly through subsequent stabilization of the spine. Thus, health professionals advocate strengthening exercises for the abdominal muscles in order to increase stability of this inherently unstable area. Stability may be able to assist in reducing anteriorly directed shear forces on the lumbar spine through the preservation of balanced trunk muscle function and proper body posture.[7]

One common abdominal exercise, the crunch, is frequently performed on an exercise machine. This exercise is designed to specifically isolate and strengthen the abdominal muscles with the possibility to adjust for intensity by increasing or decreasing load on the weight stack. According to Bergmarks[5] description of local and global muscles, this exercise is focused on increasing the capacity of the global muscles. This is done by producing movement of the spine, which emphasizes the use of the global musculature. It should be noted that both the local and global systems theoretically work synergistically, which means, that isolation of the global system is improbable. The physical dimensions and the price of such abdominal training machines limit its use to gyms or hospital settings. Thus, easy to use alternatives to strengthen the global abdominal muscles are needed.

Abdominal exercises performed on a Swiss ball (exercise ball) have been widely used in both rehabilitation and clinical settings. The unstable surface of the Swiss ball may ease the stress around the hip and low back region and alter proprioceptive demands thereby enhance motor control of the local core muscles important for balance and stability.[10-13] Further, the comfort provided by the cushioning of the ball may promote exercise compliance[12] making it a simple and affordable alternative to traditional abdominal training machines present in the gym. In line with this, Behm at al[14] suggested that Swiss ball exercises are useful for stability enhancement, balance assessment, inducing proprioceptive alterations, but not for increasing muscle strength. Swiss ball training is therefore only recommended as a low threshold modality to improve joint position, posture, balance, and neural feedback.[15,16]

Training intensity is a paramount variable when designing resistance training programs. Numerous studies have used electromyography (EMG) to evaluate muscle recruitment during rehabilitation and strength training exercises based on observations of a positive and linear relationship between EMG amplitude and isometric force output.[17-20] EMG activity of at least 60% of maximal voluntary isometric contraction (MVIC) is required to obtain the desired physiological adaptations in terms of efficient strength gain, neural adaptations, and muscle fiber hypertrophy.[21,22] Rectus abdominis activity ranging from 30-60% has been reported in the literature for abdominal exercises on the Swiss ball.[10,23] Thus, with proper regulation of intensity during crunches on a Swiss ball this exercise may function as more than a low threshold rehabilitation tool and be appropriate for inducing a training response capable of inducing strength gains. Elastic resistance may provide adequate additional loading that would make crunches on a Swiss ball an effective global muscle strengthening exercise.

Table 1. *Demographics and pain intensity (worst pain in the low back) of the men and women of this study. Pain cases were defined as those having pain intensity of at least 4 in the low back and controls as those having a pain intensity of 3 or less. Mean (SD).*

	Men		Women	
	Control	Pain	Control	Pain
N	11	7	19	5
Age, yrs	37 (12)	45 (15)	44 (9)	45 (9)
Height, cm	179 (7)	177 (7)	165 (7)	167 (3)
Weight, kg	79 (9)	76 (7)	66 (12)	59 (5)
BMI	25 (2)	24 (2)	24 (5)	22 (2)
Pain intensity (0-10)	0.91 (1.2)	5.67 (1.9)	1.42 (1.3)	5.0 (1.2)

The purpose of this study was to compare muscle activation of global core and thigh muscles during abdominal crunches performed on a Swiss ball with added elastic resistance and on an isotonic abdominal training machine. It was hypothesized that no statistically significant difference would exist in nEMG during the ab-crunch on the Swiss ball with elastic resistance and the sitting crunch performed on an isotonic abdominal training machine when normalised for training intensity.

METHODS

Participants

A group of 42 untrained adults (24 women and 18 men) were recruited from a large workplace with various job tasks. Exclusion criteria were blood pressure above 160/100, spinal disc herniation, rheumatoid arthritis, or other serious musculoskeletal disorders. The participants rated their musculoskeletal pain in the low back during the last 3 months on a 10 point Visual Analog Scale (VAS 0-10) where 0 is "no pain" and 10 is "worst pain imaginable". Table 1 shows demographics and prevalence of musculoskeletal pain symptoms among subjects. All subjects performed testing using both elastic resistance on Swiss ball and the isotonic abdominal training machine.

All subjects were informed about the purpose and content of the project and gave written informed consent to participate in the study which conformed to The Declaration of Helsinki, and was approved by the Local Ethical Committee (H-3-2010-062).

Maximal voluntary isometric contraction (MVIC)

Prior to the dynamic exercises described below, isometric MVIC ramp contractions (3 second duration) were performed according to standardized procedures during 1) static trunk flexion and extension (in standing posture and pelvis fixated while the trunk was flexed/extended against a rigid band) to induce a maximal EMG response in the tested muscles, 2) static hip adduction (laying flat on the back and pressing the knees against a solid ball), 3) static hip abduction (laying flat on the back and pressing the knees outwards against a rigid band) and 4) static hip extension (laying flat on the stomach with the knee flexed (90°) and pressing the foot upwards against the instructors hands), 5) static knee extension and flexion maneuvers (positioned in a Biodex dynamometer: knee angle: 70° and hip angle: 110°).[24] Two isometric MVICs were performed for each muscle and the trial with the highest EMG was used for normalization of the peak EMGs recorded during the resistance exercises. Subjects were instructed to gradually increase muscle contraction force towards maximum over a period of two seconds, sustain the MVIC for three seconds, and then slowly release the force. Strong and standardized verbal encouragement was given during all trials.

Exercise equipment

Three different types of training equipment were utilized during the study: 1) elastic tubing (Thera-Band, The Hygenic Corporation, Akron, Ohio, USA),

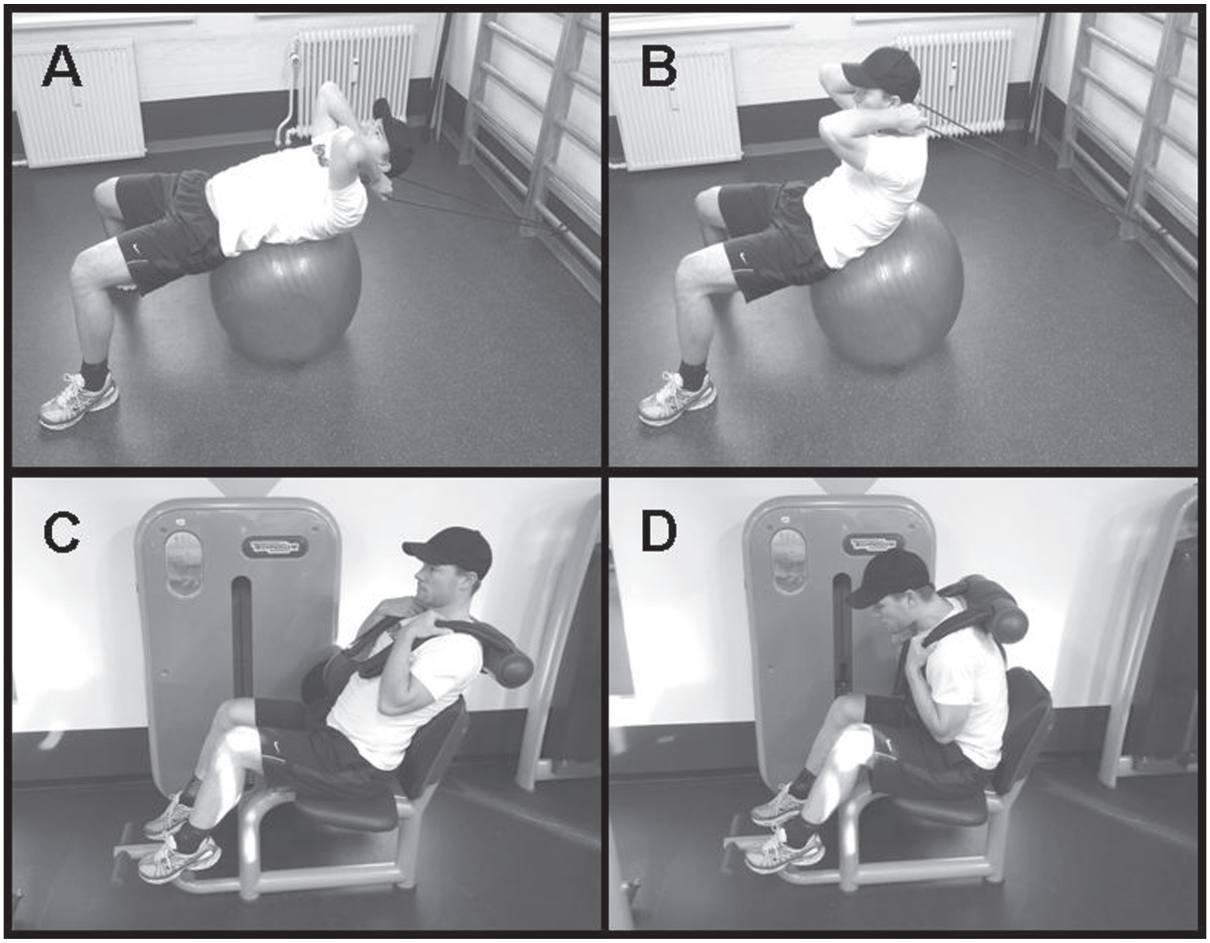

Figure 1. *Abdominal crunch using Swiss ball and elastic resistance, A = start position, B = end position. Abdominal crunch using isotonic abdominal machine, C = start position, D = end position. (Horizontal seated ab-crunch, Technogym, Cesena, Italy).*

2) inflatable Swiss ball (TheraBand, The Hygenic Corporation, Akron, Ohio, USA) 55 cm diameter was used for individuals with a height of 150-170 and 65 cm diameter was used for those with a height greater than 170 cm, and 3) an isotonic abdominal machine with loads ranging from 10 to 200 kg (Horizontal seated ab-crunch, Technogym, Cesena, Italy).

Exercise description

A week prior to testing, the participants performed a 10 repetition maximum test (10 RM) for all exercises. The individual 10 RM loading was found using one or a combination of several elastic tubes with resistances ranging from light to very heavy (red, green, blue, black, gray colors) to ensure that the 10 RM measurement was comparable with that obtained in the machine. On the day of EMG measurements participants warmed up with submaximal loads (2×10 repetitions with 50% of the 10 RM load) and then performed three consecutive repetitions with the 10 RM load after a 2-minute break. All exercises were performed in a slow and controlled manner, i.e. concentrically (~1½ sec) and eccentrically (~1½ sec) without sudden jerky movements or acceleration. The rest period between exercise conditions was approximately five minutes. The order of exercises was randomized for each subject by drawing a piece of paper from an opaque bag. Randomization was not stratified by pain level. The exercises are described below and shown in Figure 1.

Ab-crunch on Swiss ball with elastic resistance (Fig. 1a and 1b): The participant was asked to lie on the Swiss ball and then walk the feet away while simultaneously going down into a lying position, allowing the ball to stop at the lumbar spine area of the lower back. The feet were placed approximately 2 feet apart while the knees were bent at a 90 degree angle for increased base of support and adequate stability and balance. The hands were placed at shoulder level grasping the elastic resistance handles – the elastic tubing was stretched to double resting length at this point (Fig. 1). The participant was asked to curl the head, neck and shoulders up and towards the pelvis region. Following this concentric phase, the participant slowly returned to the starting position (eccentric phase).

Ab-crunch in machine (Fig. 1c and 1d): The participant was seated in the isotonic abdominal machine with the feet behind the ankle rollers and the hands holding the handles at shoulder level. The participant then curled the upper-body forward and downwards as guided by the rotation of the machine until maximal flexion was reached. The participant then initiated the eccentric phase by allowing the weight to pull the upper body into starting position.

EMG signal sampling and analysis

EMG signals were recorded from 13 muscles of the trunk: rectus abdominis, left and right external obliques, left and right erector spinae, and unilaterally on the dominant side (kicking leg) of gluteus maximus, gluteus medius, rectus femoris, vastus medialis and lateralis, adductor magnus, biceps femoris and semitendinosus. A bipolar surface EMG configuration (Blue Sensor N-00-S, Ambu A/S, Ballerup, Denmark) and an inter-electrode distance of 2 cm was used. Before affixing the electrodes, the skin of the respective area was prepared with scrubbing gel (Acqua gel, Meditec, Parma, Italy) to effectively lower the impedance to less than 10 kΩ.[26] Electrode placement followed the SENIAM recommendations.[25]

The EMG electrodes were connected directly to wireless probes that pre-amplified the signal (gain 400) and transmitted data in real-time to a nearby 16-channel PC-interface receiver (TeleMyo DTS Telemetry, Noraxon, Arizona, USA). The dimension of the wireless probes was 3.4 cm × 2.4 cm × 3.5 cm. The sampling rate was set to 1500 Hz with a bandwidth of 10-500 Hz to avoid aliasing. The resolution of the signals was 16 bits. The common mode rejection ratio was better than 100 dB.

During later analysis all raw EMG signals obtained during MVICs as well as during the exercises were digitally filtered using 1) high-pass filtering at 10 Hz, and 2) a moving root-mean-square (RMS) filter of 500 ms. For each individual muscle, peak RMS EMG of the 3 repetitions performed was determined, and the average value of these 3 repetitions was then normalized to the maximal RMS EMG obtained during MVIC.[26] Each muscle contractions start- (START) and end-time (END) point was located by the following routine; 1) locate the EMG peaks (MAX) separated by 1000 ms, 2) locate the minimum EMG (MIN) before and between each MAX. START is now located as the first index (searching from MIN_i) $> 5\% * (MAX_i - MIN_i) + MIN_i$ and END as the first index (searching from MAX_i) $< 5\% * (MAX_i - MIN_{i+1}) + MIN_{i+1}$. Based on this, contraction time (i.e. time under tension) was calculated for both exercises during all repetitions.

Covariates

Subjects included both males and females, younger and elderly, and individuals with and without musculoskeletal pain. Age was dichotomized to below and above 50 years of age. Musculoskeletal pain intensity was assessed on a 0-10 visual analog scale for the low back, where 0 is 'no pain' and 10 is 'worst imaginable pain'. The authors subsequently dichotomized the musculoskeletal pain question by defining 'pain' as a score of 4-10 in the low back and 'no or minor pain' as 0-3. This cut-point was based on a previous study showing more clinically relevant findings at pain intensities of 4 or above.[27]

Statistics

A two-way (2 × 13) repeated analysis of variance (Proc Mixed, SAS version 9, SAS Institute, Cary, NC) was used to investigate whether differences existed between exercise conditions and muscles. Factors included in the model were *Exercise* (Swiss ball with elastic resistance and machine) and *Muscle* (the 13 muscles), as well as *Exercise* by *Muscle* interaction. We used gender, age and musculoskeletal pain as dichotomous multi-adjusted covariates in this analysis. Normalized EMG was the dependent variable. When a significant main effect was found relevant post hoc comparisons were utilized to locate what type of differences existed. Values are reported as least square means (SE) unless otherwise stated. P-values < 0.05 were determined to be significant.

A priori power analysis showed that 16 participants in this paired design were sufficient to obtain a statistical power of 80% at a minimal relevant difference of 10% and a type I error probability of 1%, assuming a

Table 2. *Between-exercise difference in nEMG (% of MVIC) of 13 selected muscles. Values are presented as mean ± SE and significant between-exercise differences are marked with **

	Crunch (elastic)	Crunch (machine)
Rectus Abdominis	104 (3.8) *	84 (3.8)
External Obl. (left)	86 (3.7)	79 (3.8)
External Obl. (right)	79 (3.8)	71 (3.8)
Erector spin. (left)	12 (4.8)	20 (4.8)
Erector spin. (right)	11 (4.5)	14 (4.7)
Gluteus Med	19 (3.7)	15 (3.8)
Gluteus Max	10 (3.8)	5 (3.8)
Rectus Femoris	27 (3.7)	65 (3.8) *
Vastus Medialis	22 (3.7)	25 (3.8)
Vastus Lateralis	16 (3.7)	23 (3.8)
Biceps Femoris	10 (3.7)	5 (3.8)
Semitendinosus	11 (3.7)	4 (3.8)
Adductor	19 (3.8)	14 (3.8)

standard deviation of 10% based on previous research in the authors laboratory.[17]

RESULTS

Exercise evaluation

There was a significant *muscle by exercise* interaction ($P < 0.0001$), i.e. muscle activity of the 13 investigated muscles varied differently across exercises.

When comparing across muscles, nEMG was generally highest in the rectus abdominis and oblique muscles (range 62-110% nEMG, Table 2). However, crunches with elastic resistance showed higher activity of the rectus abdominis than crunches performed on the isotonic machine (range 96-110 vs 76-91% nEMG respectively, $P < 0.0001$, Table 2). By contrast, crunches in machine showed higher activity of the rectus femoris (range 57-72 vs 20-34% nEMG , $P < 0.0001$, Table 2) than crunches with elastic resistance. Further, there was no main effect on contraction time (exercise duration) between the 2 exercises (3155 ± 153 ms on Swiss ball vs. 3205 ± 154 ms in machine, $P = 0.74$).

Influence of gender, age and musculoskeletal pain

There were no significant main effects of gender, age and musculoskeletal pain on nEMG during the exercises. For women and men, respectively, nEMG averaged for all muscles was 33% (+/-1.8%) and 33% (+/-2.5%) % ($P = 0.78$). For younger and elderly individuals, respectively, nEMG averaged for all muscles was 32% (+/-1.6%) and 34% (+/-2.9%) ($P = 0.21$). For individuals without and with musculoskeletal pain, respectively, nEMG averaged for all muscles was 34% (+/-2.2%) and 32% (+/-2.1%) ($P = 0.18$).

DISCUSSION

The main finding of the present study was that crunches performed on Swiss ball with added elastic resistance elicited higher normalized rectus abdominal activity than crunches performed on an isotonic training machine when normalized for training intensity. In contrast, the flexed hip position during the seated crunch in machine resulted in higher rectus femoris activation as compared to the Swiss ball crunch.

The current data indicate that sitting crunches in an exercise machine designed to isolate the abdominal muscles does not target this muscle group to the same extent as the supine crunch on the Swiss ball although both exercises caused high activation. Biomechanically, the seated position in the machine with near 90 degree flexion of both knee and hip promotes assisted hip flexor activity from the rectus femoris while bending the torso forward. The rectus femoris muscle functions over two joints as both a knee extensor and a hip flexor, however the authors hypothesize that the static flexed position of the knee makes it a dominant hip flexor. Further, the hold and fixation of the feet by the ankle bar can contribute to additional rectus femoris activity.[28]

Previous authors have reported that increased external load in the abdominal crunch exercise does not enhance rectus abdominis activity but instead increases the activation of the hip flexors.[29,30] However, in the current study this was only the case for seated crunch in machine whereas the elastic assisted crunch on Swiss ball resulted in very high rectus abdominis nEMG with a concomitant low rectus femoris activity. The authors observed activation levels of more than 100% of nEMG for rectus abdominis during the Swiss ball crunch whereas values ranging from 30-60% of nEMG have been reported in the literature for abdominal exercises on the Swiss ball.[10,23] Thus, it seems that the added external load provided by the elastic resistance can maximize abdominal activity and limit hip flexor activation simultaneously. Importantly, the muscle recruitment during these two exercises was equally high regardless of gender, age and pain intensity.

High activity from the hip flexors, such as rectus femoris or iliopsoas, can be unsuitable for persons with low back pain or lumbar instability in general. Increased hip flexor activity will cause an anterior tilt, increased lumbar lordosis, which potentially creating anteriorly directed shear forces on the lumbar spine. This combination may contribute to the genesis of low back pain.[23,30,31] Therefore, abdominal crunches performed in an exercise machine, in a seated position may not be desirable for individuals with lumbar disk pathologies, low back pain, or weak abdominal musculature due to high rectus femoris activity. Instead, crunches with elastic resistance on Swiss ball could serve as isolated daily routine abdominal exercise for both prophylactic and rehabilitation purposes where limited hip flexor moment is desired.

In contrast to the seated crunch, crunch on a Swiss ball provides a neutral starting hip position, which seems to minimize hip flexor activity during the exercise. During a traditional crunch the resistance is provided solely by the body mass and the lever arm is constantly decreasing from start to end of the concentric (lifting) phase. However, by adding elastic resistance the loading is more uniform during the entire range of motion due to the elongation of the elastic material and the concomitant decrease in body mass lever arm as the concentric phase advances. Thus, at starting supine position with the greatest lever arm the traction from the elastic tubing is small compared with the resistance produced at higher elongation levels during the end of the concentric phase. Besides these biomechanical differences, the labile surface of the Swiss ball might also have contributed to the contrasting activation strategies of the rectus abdominis and rectus femoris muscles. It has been speculated, that the unstable surface provided by the ball alters proprioceptive demands thereby stimulating the core muscles to a greater extent than stable services, which may be important for balance and stability.[10-13] However, in the present study no differences in oblique or erector spinae activation were observed, indicating that these muscles were not affected by exercise type. It is beyond the scope of the current study to determine the role of the local core muscles during these two exercise tasks as this would require intra-muscular EMG.

To obtain proper strength adaptations exercises that produce EMG activity of at least 60% of isometric MVC are recommended.[21,22] Thus, both exercises were able to induce sufficient EMG activity to provide a stimulus for strengthening of the rectus abdominis and the obliques and should therefore also be considered as a high threshold rehabilitation tool by health professionals. The suggestion by Behm,[14] that Swiss balls are useful for providing an exercise condition capable of increasing stability, balance and proprioception but not muscle strength may need to be re-evaluated in light of the current findings regarding the abdominal crunch performed on a Swiss ball with added elastic resistance. Future studies should address the more long term strength adaptations that may occur, along with changes in stability and proprioception in order to determine this.

Low back pain is traditionally associated with repetitive load handling and heavy manual labor. However, office work with a high degree of chair confinement (prolonged sitting) is also a frequently reported risk factor.[32] Self-reported low back pain in subjects in the current study did not affect the muscle activation during the two exercises in office workers. However, caution should be applied to this interpretation, as sensitization could have depressed muscle activation during the MVICs and thereby influenced the normalization of EMG. As strong abdominal muscles provide support for the lumbar spine during everyday movements strengthening the abdominal muscles may decrease the occurrence of low back pain.[7,9] However, controversy exists with this assertion, and some authors have suggested that if the global muscles are over trained before the local muscles are sufficiently developed, it could result in situations where the force produced by the global muscles can not be controlled by the local musculature.[4] Hence, abdominal training on the Swiss ball with added elastic resistance should be introduced thoughtfully, with gradual intensity progression in order to ensure optimal local musculature development before focusing on strengthening the global muscles.

Evaluations of abdominal exercises using nEMG comparisons has been based on identical movement velocity or cadence normalization using a metronome[13,23,33,34] rather than loading intensity. In the present study identical contraction time and intensity (3 reps of 10 RM load) were used as normalization mediators to secure valid results. Further, the participants were accustomed to the exercises and performed a 10 RM test to determine appropriate intensity a week prior to testing. This study compared relative level of muscle activity across the two exercises. Thus, the effects of crunch on Swiss ball with added elastic resistance on muscle strength cannot be directly measured and a randomized controlled trial would be necessary to draw such conclusions. Further, the study population included working aged adults only, which limits the reported lack of an age effect to this relative narrow age-range.

CONCLUSION

Both crunches performed on a Swiss ball and on an isotonic training machine caused high activation of the abdominal muscles. Specifically, crunches on a Swiss ball with added elastic resistance induces high abdominal activity accompanied by low hip flexor activity, which could be beneficial for individuals with low back pain. Conversely, the lower levels of abdominal activity and higher levels of rectus femoris activity observed in the isotonic machine exercise warrant caution for individuals with lumbar pain. Importantly, both men and women, younger and elderly, and individuals with and without pain benefitted equally from the exercises.

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