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Electromyographic Analysis of Abdominal and Lower Back Muscle Activation During Abdominal Exercises Using an Objective Biofeedback Device

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ABSTRACT

Sell KM, Ghigiarelli J, Kitsos KM, Burke J, Yeomans SG. Electromyographic Analysis of Abdominal and Lower Back Muscle Activation During Abdominal Exercises Using an Objective Biofeedback Device. **JEPonline** 2011;14(5):54-65. Core training devices are common features within exercise facilities. However the efficacy of such devices in generating improvements in core muscle function above that of conventional modalities is debatable. The purpose of this study was to compare abdominal and low back muscle activation during common abdominal exercises using an abdominal device (the AB-Inforcer©; AB-I) and a conventional exercise mat (MT). Fifty-three adults (30 men, 23 women; 25 ± 4.7 yrs; 74.9 ± 13.3 kg; 172.7 ± 9.1 cm) volunteered to participate in this study. The mean electromyography (EMG) activity of the upper and lower regions of the rectus abdominis (URA and LRA, respectively), external oblique (EO), and paraspinal (PS) muscles was measured during three exercises on the AB-I and MT. Each participant performed five repetitions of the following exercises: (1) traditional crunch; (2) split leg scissors; and (3) bilateral heel drops. All three exercises performed using the AB-I resulted in significantly greater mean EMG activation for the right- and left-side URA, LRA, and right-side EO muscles ($P<0.001$). The split leg scissors and heel drops performed on the AB-I resulted in significantly greater EMG activation bilaterally for the EO ($P<0.001$), but was not significantly higher for the crunch ($P>0.05$). No significant differences were observed between the AB-I and MT for the PS muscles during any of the three exercises ($P>0.05$). The additional resistance and feedback provided by the AB-I may have facilitated the

increase in AB-I evoked abdominal muscle activation observed in this study. Ongoing research is necessary to further investigate the use of the AB-I as an abdominal training device that could be used by exercise and therapeutic practitioners for sport-specific or rehabilitative core training.

Key Words: Abdominal Exercise, Training Device, Muscle Activation, Electromyography

INTRODUCTION

The lumbo-pelvic hip complex or musculature of the core provide an essential foundation for purposeful movement of the entire kinetic chain (9,14). The core musculature and its function has been described in depth in previous literature (9,17,18,21). Improvements in core strength and stability may improve agility, balance, movement co-ordination, and force production (11), as well as reduce injury potential and prevalence for low back pain (3,8,15,16,21). Consequently, core training has become an integral component of conditioning and rehabilitation programs implemented by strength and conditioning coaches, athletic trainers, personal trainers, and physical therapists in recent years (2,13,21).

The core musculature is imperative for: (a) facilitating control of the trunk during dynamic movement; (b) helping to maintain postural control; (c) optimizing energy transfer through the kinetic chain; and (d) resisting unwanted movement of the trunk/body against a given force (7,15). To generate improvements in the core musculature, the target muscles must be sufficiently activated. Core activation and stabilization is demonstrated when a combination of the muscles of the pelvic floor, transversus abdominis, rectus abdominis, internal and external obliques, and lower back muscles (e.g., erector spinae, multifidus, quadratus lumborum) are activated or exhibiting co-contraction. The co-contraction of various deep abdominal muscles and the paraspinal muscles also provides an additional stabilizing effect, often prior to any limb movement, and resists excessive lumbar extension or rotation (9,17,18,21). Weaknesses in the muscles of the lumbo-pelvic and core region, including but not limited to those involved in hip adduction, abduction, and rotation, are associated with increased likelihood of injury (3,6).

Electromyography (EMG) analysis has been used extensively to provide quantifiable feedback on muscle activation and recruitment during a given exercise performance (14). In an EMG analysis of muscle activation during a crunch abdominal exercise on 4 portable exercise machines - Ab Roller Plus (Quantum North America, Glendale, CA), Torso Track II (Fitness Quest Inc., Canton, OH), AB-Doer Pro (Thane Fitness, La Quinta, CA), and Perfect Abs (Guthy-Renker, Santa Monica, CA) - versus that of a traditional abdominal crunch, only the Perfect Abs machine was able to elicit abdominal muscle activity equivalent to or greater than that of the traditional crunch in the absence of additional resistance (19). Exercises on the Abshaper (Copperart Stores, Glendenning, NSW, Australia) generated significantly higher EMG activation in the upper rectus abdominis (URA) and significantly lower activation in the sternocleidomastoid muscles compared with traditional exercises (20). In addition, no differences were observed in the lower aspect of the rectus abdominis (LRA) or external oblique (EO) muscles on either side (20). The CORE X device (Core X System LLC, corexsystem.com) was able to elicit significantly greater EMG activation in the URA and LRA and multifidi muscles compared to traditional core exercises. Consistent with previous studies, no significant difference was observed for the EO muscles (16).

Numerous commercial abdominal training devices are currently available to exercise practitioners and the general public (1), many are widely advertised to optimize improvements in function (and aesthetics) of the core musculature. Given the accessibility of the devices, the popularity of core training programs, and the disparity in research findings, studies examining the effectiveness of these devices to generate the proposed muscular improvements are needed in order to provide exercise practitioners, therapists, and strength and conditioning personnel with useful information.

Core training exercises or exercise device should help improve muscular function and not predispose or increase the likelihood of injury. A new abdominal exercise device, the AB-Inforcer® (AB-I; AB-Vanced Neu-Spine®, Los Angeles, CA) (Figure 1) provides biofeedback to the user to increase his or her awareness of body alignment, promote a neutral posture, and optimize the activation of core muscles while completing a core training exercise. This immediate feedback is given visually (lights), physically (vibration), and through sound. The device has a supportive cushion for the lumbar and cervical regions, which promotes the neutral position of the spine during exercises. It is also designed to minimize any unwanted head or neck movement. A “neutral” posture suggests that in the supine position there is a small gap between the lumbar spine and the floor (i.e., the back should not be flat on the floor or excessively arched) (13).

Figure 1. The AB-Inforcer® device (AB-I; AB-Vanced Neu-Spine®, Los Angeles, CA). During an exercise, the head is placed on the large red sensor (far right), and the lower back positioned on the two small circular red sensors.

No studies have compared activation of the core musculature during core training exercises on the AB-I relative to conventional training modalities. The AB-I may help minimize unwanted movement of the trunk and facilitate a “neutral” posture throughout a given exercise, which in turn may help optimize muscle recruitment and activation of the core musculature. Therefore, the purpose of this study was to compare the abdominal and low back muscle activation generated during a variety of abdominal exercises using the AB-I, compared to the traditional mat-based approach. It was hypothesized that the muscle activation would be greater during each exercise while on the AB-I compared to the same exercise on a standard exercise mat.

METHODS

Subjects

Fifty-seven healthy volunteers were recruited for this study. Recruitment occurred through a snowball approach initiated in physical activity and exercise science classes at a university in the north east region of the United States. The following exclusion criteria were used for this study: (a) low back pain that exceeded one week in duration within the past six months; (b) prior lower back or abdominal

surgery or tumor, infection, cauda equine, or fracture; (c) undergoing current treatment for lower back pain; (d) presence of significant congenital abnormalities of the spine; (e) presence of health-related contraindications to physical activity; and (f) prior use of the AB-I device. Participation was also limited to just individuals with sufficiently low subcutaneous adipose tissue to increase the accuracy of the muscle activity measure. If subcutaneous adipose tissue was too high, surface electrode measures of muscle activity would be inhibited.

Prior to participation and after receiving an explanation of the study protocol, each participant completed a university-approved informed consent form and a medical health history questionnaire. Approval from the university Institutional Review Board for the inclusion of human subjects was obtained prior to study initiation.

Exercise Devices and Exercise Selection

Two exercise conditions were tested for each exercise. These exercise conditions included the AB-I (AB-Vanced Neu-Spine®, Los Angeles, CA) and an exercise mat (5/8 inch thick; MT). The AB-I is a device with a supportive cushion for the lumbar and cervical regions of the back, which promotes the neutral position of the spine during exercises, and is designed to minimize any unwanted head or neck movement. The AB-I is designed to turn sensors on or off for the neck, the upper back, and the lumbar/abdominal regions depending on need during a given AB-I based exercise. For each of the AB-I exercises, the participant assumed the correct position on the device prior to any test or exercise (e.g., tailbone on the red tailbone registration triangle, belly button in line with the registration nubs on the side of the device). All exercises on the AB-I took place while the AB-I was in the “exercise” (as opposed to “stretch/relax”) mode. A neutral spine position on the AB-I is assumed when the sensors are activated.

Electromyographic Analysis and Processing

All electromyographic (EMG) data were collected using an electrode configuration for use with pre-amplified bipolar, grounded, surface electrodes (Mega Electronics Ltd., MESPEC 4000 system amplifiers, Finland). Muscles were targeted bilaterally on the URA (2.5 cm above the umbilicus), LRA (2.5 cm below the umbilicus), EO (1.0 cm medial to the anterior superior iliac spine, 0.5 cm superior to the inguinal ligament) and lumbar paraspinal (PS) muscles using 10 mm bipolar, surface silver-silver chloride electrodes (1700 CLEARTRACE™, Conmed Corporation, Utica, NY). The electrodes were oriented parallel to the muscle fibers with an inter-electrode distance of approximately 40 mm. At each electrode site, the surface silver-silver chloride ground electrode was 10 mm in diameter. Prior to the application of the self-adhesive electrodes, the skin over each muscle was shaved with a disposable razor and cleansed with alcohol prep pads (70% Isopropyl Alcohol) to reduce impedance at the skin electrode interface. Surface electrodes were chosen as they are noninvasive and reliable for detecting surface muscle activity (i.e., given correct placement and protocol) (10,12,20). A certified Athletic Trainer performed manual muscle tests according to established methodology (9) to assure correct electrode placement for each muscle during a series of maximum isometric voluntary contractions (MIVCs). Consistent with previous research (16), manual muscle tests were performed to provide maximum amplitude of the linear envelope for each muscle response during each exercise. For each MVIC task, the maximum amplitude of the linear envelope for the target muscle was recorded as maximum EMG amplitude. The EMG amplitude of each muscle response during each exercise was expressed as a percentage of the maximum EMG amplitude for that muscle. The primary dependent variables were consequently the relative EMG amplitudes (%MVIC) of each muscle response during each exercise.

Pre-amplified EMG (gain =1000) cables were connected to electrodes at each muscle site and interfaced to the MESPEC 4000 system amplifiers (20 – 500 Hz (- 3dB)). EMG signals were recorded

using an analog-to-digital converter (12 bit resolution) interfaced to a computer, with a sampling rate of 1000 Hz per channel. LabView® software (National Instruments Corp., Austin, TX) was used for data acquisition and data processing. EMG signals were full wave rectified, and a moving average smoothing algorithm (75 ms window) was used to generate a linear envelope for each muscle response during the MVIC tasks and for the three different exercises. For the MVIC tasks, raw EMG signals were partitioned into a 5-sec window of maximum activity prior to applying the rectifying and smoothing algorithms. For the exercises, raw EMG signals were aligned and averaged for 5 consecutive repetitions within each set of 8 repetitions prior to applying the rectifying and smoothing algorithms.

Procedures

The protocol for this study was based upon previously published protocols for research of this nature (19). Following a consultation to complete the informed consent and medical health history questionnaire, participants underwent an initial familiarization session (during which time no study data was collected). During this initial meeting, participants were instructed on correct technique, demonstrated the appropriate technique for each exercise in the study, and were familiarized with the study protocol.

During the second meeting, participants were asked to perform 1 set of 8 repetitions for 3 exercises on the AB-I and MT. Each participant performed a traditional crunch, bilateral heel drops from a table top position, and a split leg scissor exercise on the AB-I and MT. The EMG activity for each given muscle was assessed for the consecutive exercises in each set, with adequate rest time allowed between sets to avoid fatigue. The testing order for both the exercises and the exercise condition was randomized. The exercises were conducted as follows:

Split Leg Scissor Exercise

Each participant began with both legs fully extended, while keeping the head still (i.e., “quiet”), parallel to the ceiling, and on the head sensor. Participants held on to the hand grips on the AB-I either side of the head. While keeping the core muscles braced (co-contracted) (“lights on, head quiet” with lumbar sensors closed) and the legs straight, participants lifted both legs off the floor and raised the dominant leg so the sole of the foot faced the ceiling, while maintaining the non-dominant leg approximately 10 inches off the ground. Participants then switched legs in a ‘scissor-like action’. A repetition consisted of one rotation with each leg in the raised position. For each repetition, the movement was conducted through the range of motion until lumbo-pelvic stability was lost (i.e., lights go off and/or buzzers sound). Once the prescribed set of repetitions for the non-dominant leg was completed, the exercise was repeated with the dominant leg. All movements were conducted in a slow, controlled manner. Correct posture and form were maintained throughout each exercise repetition. This exercise was also conducted over a 3-sec pace (1 sec up, 1 sec down, 1 sec pause).

Bilateral Heel Drops

Each participant began with the hips and knees flexed at 90° (90-90 hold position) with the back (upper and lower) flat on the ground. When completing the exercise on the MT, the upper arm and forearm were placed behind the head (fingers not interlocked). When completing the exercise on the AB-I, the participants held on to the hand grips on the AB-I located on either side of the head, and established the “lights on, head quiet” position. Participants then moved the heels of both feet slowly to touch the floor and then they were returned to the 90-90 position. When completing the exercise on the AB-I each participant held on to the hand grips on the AB-I located on either side of the head, and established the “lights on, head quiet” position. This position implied that the head was held still and remained on the sensors behind the head and upper back, thus keeping the sensory lights fully on.

This exercise was conducted over a 3-sec pace (1.5 sec per movement phase – 3 sec for the each repetition).

Traditional Crunch

Each participant began with the hips and knees flexed at 90° (90-90 hold position) with the back (upper and lower) flat on the ground (Figure 1a). When completing the exercise on the MT, the hands were placed behind the head (fingers not interlocked). When completing the exercise on the AB-I the participant was instructed to hold on to the hand grips on the AB-I located on either side of the head, and establish the "lights on, head quiet" position. This position indicates that the head was held still and remained firmly on the sensors behind the head and upper back, thus keeping the sensory lights fully on. Participants were asked to flex the trunk so that the head, shoulders, and scapulae were raised completely off the mat. This has been the approach used to conduct a traditional upper crunch in prior research (19).

All data for each individual participant were collected in a single session. As suggested by Sternlicht and Rugg (19), to promote "temporal consistency" (constant speed throughout each exercise phase), the participants were asked to complete each exercise through a full range of motion and to a metronome-paced cadence (1.5 sec per movement phase – 3 sec for the each repetition). Participants were instructed to use the same movement pattern for a given exercise in each exercise condition, but verbal cueing was also used to assure correct form throughout each set. If the AB-I sensors were not activated, or incorrect form or inadequate range of motion was shown on either the AB-I or MT-based exercises, the participant was asked to rest, re-set and resume the exercise set.

Statistical Analysis

Differences in the magnitude of muscle activation (%MVIC = dependent variable) for each muscle group analyzed in each of the 3 exercises on the AB-I and mat were evaluated using a two-way (exercise modality by exercise type) MANOVA (Wilks' Lambda). Tukeys post-hoc tests were used to identify the location of significant differences. Multivariate homogeneity of variance and normality assumptions were satisfied. All statistical analyses were conducted using the Statistical Package for the PASW Statistics 17 software (SPSS Inc., Chicago, IL). Unless specified otherwise, P=0.05 was used as an acceptable level of significance for all analyses.

RESULTS

Fifty-three college students (30 men, 23 women; 25 ± 4.7 yrs; 74.9 ± 13.3 kg; 172.7 ± 9.1 cm) completed the exercises. No pain was experienced by any of the participants that completed the study. Four participants were excluded during the study period for either failing to attend the laboratory meeting or excessive subcutaneous adipose tissue, which prevented adequate EMG readings. These participants were not included in the demographic data. The two-way MANOVA generated a significant multivariate main effect for exercise modality [$F(8,305) = 7.82$, $P<0.001$] and for exercise type [$F(16,610) = 3.49$, $P<0.001$], but no significant interaction effect was present [$F(16,610) = 0.31$, $P = 0.99$]. Significantly higher activation in the URA and LRA, and right-side EO muscles was observed when using in AB-I for all exercises (Figure 2). However, significantly higher activation in the left-side external oblique muscle was also observed when using the AB-I during the bilateral heel drops and split-leg scissor exercises ($P<0.05$; Figures 3 and 4), but not for the traditional crunch (Figure 5). Consistent with previous studies exploring the practicality of a core training device (16), effect sizes were also calculated to provide an overall gage of practical significance. Medium (4) effect sizes (d = 0.4-0.7; Table 1) were calculated for the URA and LRA, suggesting the results had clinical significance and that the exercises conducted with the AB-I actually generated greater

activation of muscle potentials in the rectus abdominis muscles. A small to medium (4) effect size (*d* = 0.27; Table 1) was observed for the right-side EO muscle, suggesting that the results do not strongly support the same conclusion for the EO muscles.

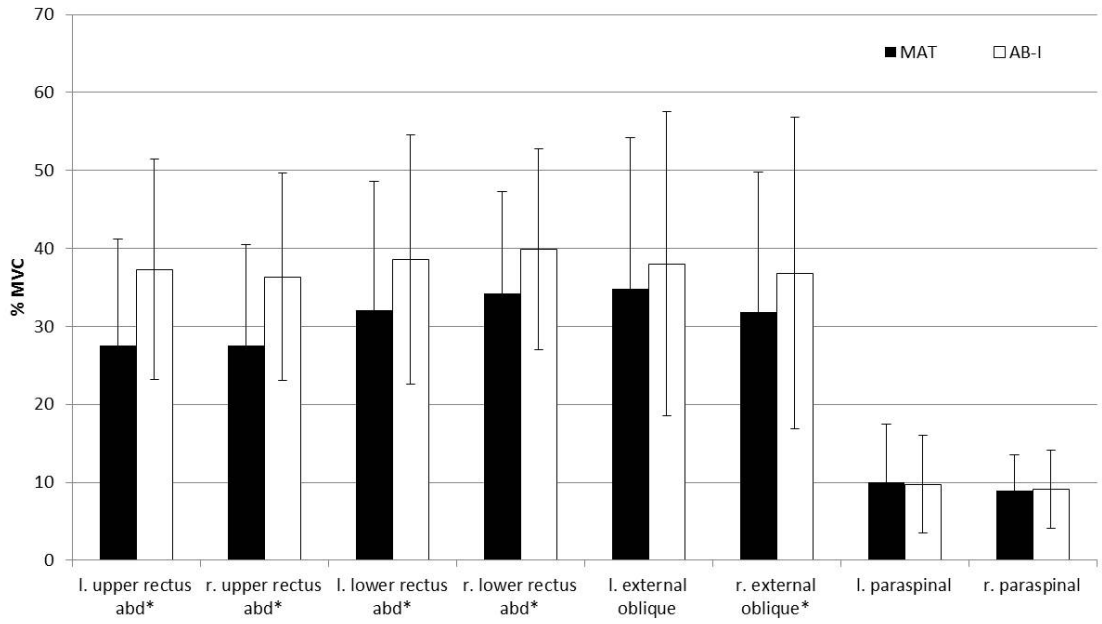

Figure 2. Means ± SD for percent maximal voluntary contraction (%MVC) for exercises on a traditional mat (MT) and on the Ab-Inforcer©(AB-I) for the right (r) and left (l) upper and lower rectus abdominis (abd), external oblique, and paraspinal muscles. Significant differences indicated * at P<0.05.

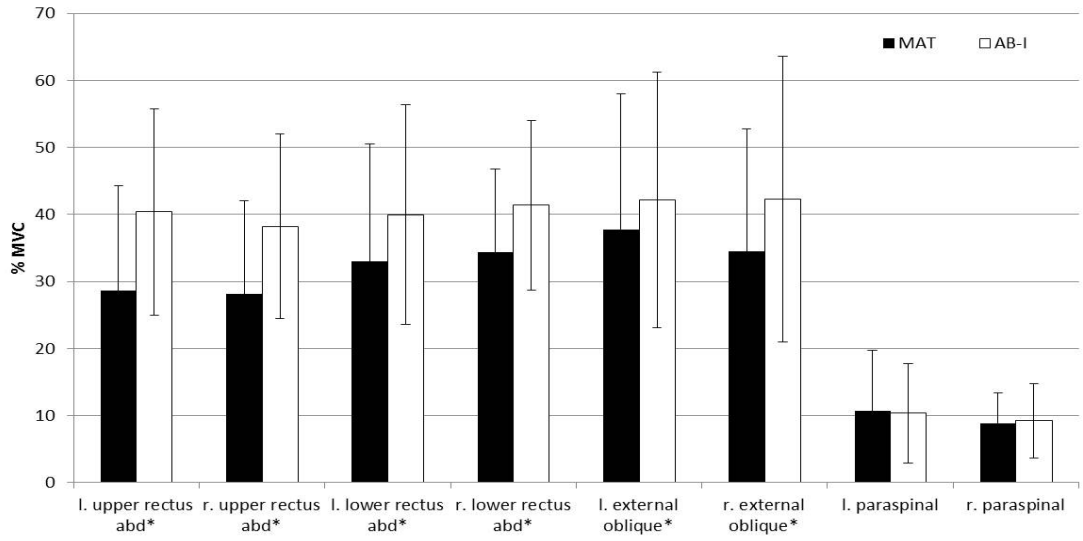

Figure 3. Means ± SD for percent maximal voluntary contraction (%MVC) for the split leg scissor exercise on a traditional mat (MT) and on the Ab-Inforcer©(AB-I) for the right (r) and left (l) upper and lower rectus abdominis (abd), external oblique, and paraspinal muscles. Significant differences indicated * at P<0.05.

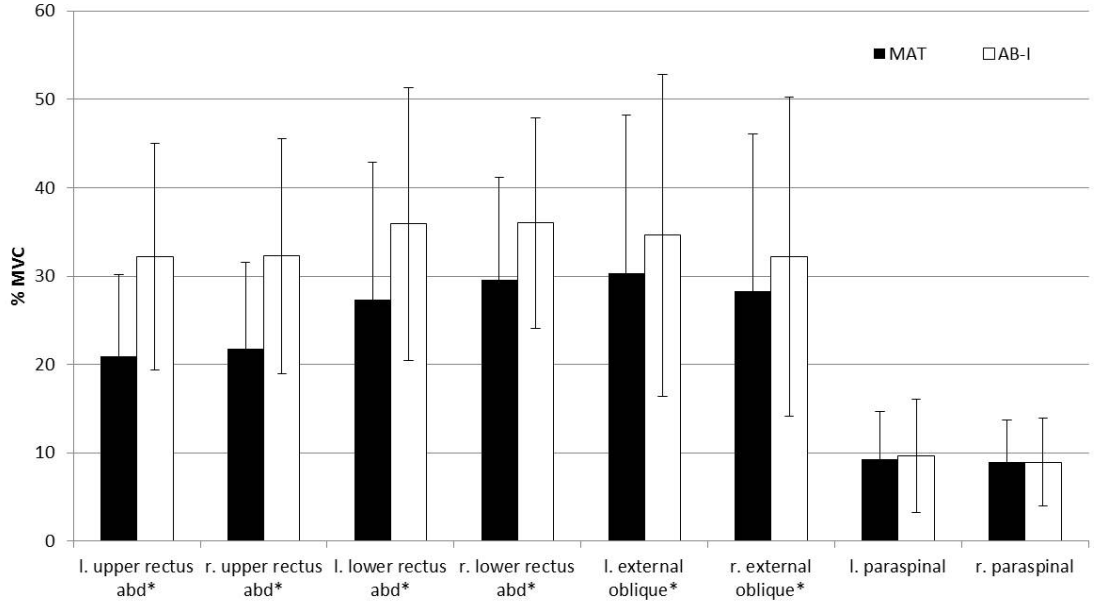

Figure 4. Means ± SD for percent maximal voluntary contraction (%MVC) for the bilateral heel drops exercise on a traditional mat (MT) and on the Ab-Inforcer©(AB-I) for the right (r) and left (l) upper and lower rectus abdominis (abd), external oblique, and paraspinal muscles. Significant differences indicated * at P<0.05.

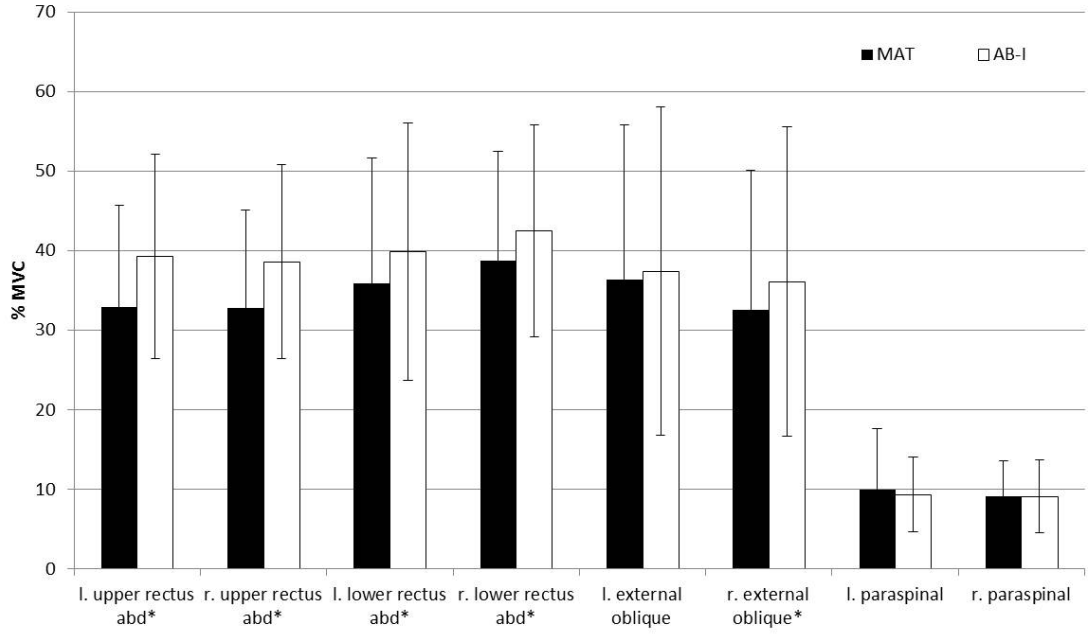

Figure 5. Means ± SD for percent maximal voluntary contraction (%MVC) for the traditional crunch exercise on a traditional mat (MT) and on the Ab-Inforcer©(AB-I) for the right (r) and left (l) upper and lower rectus abdominis (abd), external oblique, and paraspinal muscles. Significant differences indicated * at P<0.05.

Table 1. *F*-value, significance, effect size, and power statistics for the right (r) and left (l) upper and lower rectus abdominis, external oblique, and paraspinal muscles between MT and AB-I exercises.

Muscle	df	F	Sig	Effect size	Power
l. upper rectus abdominis	1	43.13	<0.001	0.72	>0.90
r. upper rectus abdominis	1	38.54	<0.001	0.67	>0.90
l. lower rectus abdominis	1	12.85	<0.001	0.40	>0.90
r. lower rectus abdominis	1	16.44	<0.001	0.44	>0.90
l. external oblique	1	2.24	0.135	n/a	0.32
r. external oblique	1	5.73	0.017	0.27	0.67
l. paraspinal	1	0.08	0.778	n/a	0.06
r. paraspinal	1	0.06	0.802	n/a	0.06

df = degrees of freedom; sig = significance; l = left; r = right; n/a = not applicable

DISCUSSION

The purpose of this study was to determine if the AB-I would elicit different magnitudes of abdominal and low back muscle activation during 3 core exercises compared to the same exercises conducted on a conventional exercise mat. Abdominal exercises using the AB-I evoked greater EMG muscle activation compared than when conducted on an exercise mat. The magnitude of difference was significantly greater for the URA and LRA muscles and for the EO muscles on two of the three exercises.

Most abdominal exercise devices are designed to promote correct form without providing additional resistance. This reasoning has been used to explain why previous studies have shown minimal differences in EMG activation during exercises conducted on abdominal devices compared to traditional approaches (19). The AB-I is an abdominal training device that provides auditory and visual feedback regarding body position as well as compensatory actions such as an excessive activation of the sternocleidomastoid muscles. While exercises on the AB-I are not conducted with any additional resistance, maintaining pressure on the AB-I sensory pads and gripping the handles of the AB-I device may demand greater muscle activation of the trunk muscles than in their absence.

It is not surprising that the URA and LRA generated similar patterns of muscle activation. The rectus abdominis muscles are innervated by a group of thoracic nerves that are united by a common set of nerves stemming from the ventral rami, supporting the notion that activation levels would be similar. The lack of significance for the left EO muscle during the crunch is an unexpected finding, especially given the significantly greater EMG activation using the AB-I for the right *and* left EO muscles during the other two exercises. The argument that this difference may be the result of biomechanical differences in the execution of the crunch compared to the heel drops and split-leg scissor exercises, is somewhat muted by the disparity in statistical significance between the right and left EO muscles and the fact that such disparity was not noted for the other two exercises. A possible explanation for the difference in EMG activity detected within the EO muscles during the crunch exercise could be methodological error or an inability to stabilize effectively on a less familiar piece of apparatus. During the crunch exercise, participants were asked to complete a partial crunch while maintaining contact with the AB-I device by gripping the sides of the AB-I or by placing the hands behind the head when

using the MT (while the hips and knees were flexed 90°). This movement pattern requires trunk flexors to raise the upper torso (9), but does not allow for arm fixation to assist with rotational control as with the other two exercises. This may potentially elicit greater input from the EO muscles in maintaining side-to-side stability. The left EO muscles will tend to be the stronger trunk rotator compared to the right EO muscles in a right-handed individual. The lack of statistical difference in the left EO muscle during the crunch exercise might be partially explained given the movement pattern and the relative potential strength of the left side.

The low level of EMG activation and lack of difference between AB-I and MT readings in the PS may be explained by the sagittal plane in which each of the exercises was conducted and the predominant concentric and eccentric actions of the trunk and hip flexors in controlling each movement pattern. A different choice of exercise may have elicited significant differences in the EO muscles on both sides and in the PS muscle groups.

The results of this study partially agree with previous research. Similar to the CORE X device (16), the Abshaper (20), and the Perfect Abs device (19), the AB-I was able to facilitate greater EMG muscle activation in the rectus abdominis during comparable conventional exercises. However, the Perfect Abs and Torso Track devices did generate significantly greater EMG readings in the EO muscles during a crunch exercise compared to the same exercise on a mat (19). In the current study, the EMG activation of the EO muscles generated on the AB-I was significantly higher on the left side only. Significantly higher EMG activation of the right and left EO muscles was observed during the heel drops and scissor exercises on the AB-I. Few studies have compared EMG muscle activation on different modalities for exercises other than a traditional crunch, which limits the comparability of the findings for the heel drops and scissor exercises in the current study.

As with previous research using abdominal exercise devices (20), convenience sampling was used to recruit subjects. Competency using the AB-I was controlled (i.e., subjects were excluded if they had previously used the AB-I), as was the case with abdominal exercise habits (within study limitations), but variations in subjects' body composition, gender, and abdominal muscle integrity (e.g., strength, stability) may have impacted patterns of muscle innervations and study findings. However, adequate rest time was allowed between sets of exercise to minimize fatigue, and the testing order for both the exercises and the exercise condition (AB-I vs MT) was randomized. These attributes should have minimized the influence of any differences in physical fitness and abdominal strength or endurance throughout the sample. Surface electrodes were used to measure EMG activation, which limits accessibility to the deep core musculature. For example, the transversus abdominis muscles play an important role in core stabilization.

The present study represents the first quantitative study of EMG muscle activation during exercises on an AB-I, a commercially available abdominal training device. Future research needs to examine the utility for using the AB-I in individuals of different ages and clinical populations, especially those with diminished proprioception and abdominal strength or integrity. The utility of the AB-I to generate the improvements observed within the limitations of this study may differ in other populations, such as individuals with orthopedic limitations or low back complaints. Undoubtedly, this requires further investigation. Future research should explore the utility of exercises on the AB-I to generate significant activation of the paraspinal muscles given the relationship between poor paraspinal muscle group strength and low back pain or disorder (5,6).

CONCLUSIONS

Training of the core musculature has become a fundamental component of exercise programs for athletic performance or rehabilitation over recent years. Identification of appropriate and efficient training tools for core muscle activation, adaptation, and strength development is consequently useful information for therapists and strength and conditioning professionals. In the current study, exercises conducted on the AB-I generated significantly greater activation in several regions of the core musculature, relative to the same exercises conducted on a standard exercise mat. The AB-I is a portable, adjustable, and easy to use device, which may further augment its potential utility as a tool for core training. However, further research is needed to fully evaluate its efficacy in wellness, clinical, rehabilitative, and athletic settings.

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