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ORIGINAL RESEARCH

Abdominal Muscle Activity During Exercise Ball, Machine, and Floor Strengthening Exercises

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ABSTRACT

Introduction: Core dynamic muscle control is important for stabilizing the spine and reducing mechanical stress on the back. This study was designed to compare abdominal muscle activation of four abdominal strengthening exercises performed with repetitions and isometric holds. Our hypothesis was that there is no significant difference in abdominal electromyographic (EMG) activity between exercises.
Methods: Twenty-one healthy subjects (mean age 37.2) concurrently involved in a cardiovascular/strength training program performed one set of 10 repetitions and one 20-second isometric hold of each of the following exercises: baseline exercise on a Cybex trunk curl machine, PhysioBall neutral crunch (BNC), PhysioBall full crunch (BFC), Abench crunch (AbM), and floor trunk curl reach (TCR). Surface EMG was used to record activation of the upper rectus abdominis (URA), lower rectus abdominis (LRA), and external oblique (EO) muscles.
Results: EMG activity for the repetition exercises demonstrated that the AbM had significantly higher activity than the BNC and TCR, whereas the BFC was significantly higher than the BNC. EMG activity for the isometric exercises demonstrated that the AbM had significantly higher activity than the BNC and TCR, whereas the BFC was significantly higher than the BNC.
Discussion: AbM and BFC crunch exercises yielded significantly higher activation of both the URA and LRA compared with the other tested exercises. No single exercise was able to significantly activate the EO.
Keywords: Abdominal muscles; Electromyography; Exercise therapy; Low back pain.

INTRODUCTION

Pain in the soft tissues of the back is common among adults. As reviewed by Andersson (1), in the United States back pain is the most common cause of activity limitation in people younger than 45 years, the second most frequent reason for visits to a physician, the fifth-ranking cause of admission to a hospital, and the third most common cause of surgical procedures. Core strengthening through flexion and extension exercises

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is many clinical workers' approach of choice because of evidence linking abdominal muscle strength and trunk stability with the prevention and rehabilitation of low back injury (2,3). Others question the efficacy of active rehabilitation and its effects on pain and functional disability indices (4,5).

Important components in reducing low back pain and preventing low back injury are abdominal muscle strength and the ability to generate sufficient intra-abdominal pressure. The alignment necessary to stabilize and generate movement of the pelvic girdle depends on adequate strength and endurance of the abdominal musculature (6); increasing intra-abdominal pressure is designed to improve the stability of the trunk through stiffening the whole segment (7). The transversus abdominis and internal obliques have been cited as the primary muscles of the anterior abdominal wall involved in stabilization of the lumbar spine (8). Exercises that can co-activate the oblique abdominal muscles may generate greater intra-abdominal pressure, and, thus, greater lumbar spine protection during functional tasks (3).

The specificity of an abdominal strengthening exercise is equally important. In a comparison of portable abdominal devices, it was found they are most effective if they not only mimic the mechanics of a traditional crunch, but also provide external resistance to increase the involvement of the abdominal musculature (9). Equally, the exercise selected should minimize hip flexor activity (9). Many devices are available to exercise the abdominal muscles. Exercises performed on an unstable surface (eg, a PhysioBall) provide greater abdominal muscle activity because of the added activity needed for balance and trunk stability (10).

The main application for this study was to assess the ability of an exercise to effectively contract the abdominal musculature and therefore be utilized as a beneficial means to strengthen the trunk and core musculature. Identifying efficacious exercises would permit use in a core strengthening program, which may help in the prevention, reduction, or rehabilitation of low back pain. Therefore, the present study was designed to compare abdominal muscle activation by four abdominal strengthening exercises, performed through both continuous repetitions and isometric contraction. Surface electromyography (EMG) was used to record activation of the upper rectus abdominis (URA), lower rectus abdominis (LRA), and external oblique (EO) muscles during trunk flexion. Two hypotheses were tested: first, there will be no significant difference in abdominal EMG activity between exercises; second, there will be no significant differences in abdominal EMG activity between repetitions and isometric holds when using an exercise ball, machine resistance, or floor exercises.

MATERIALS & METHODS

Subjects

Eleven men (mean age 36.4 years; mean height 180.4 cm; mean weight 79.5 kg) and 10 women (mean age 37.9 years; mean height 165.1 cm; mean weight 61.4 kg) participated in the study. Written informed consent was obtained from each subject. Subjects were healthy adults currently involved in cardiovascular/strength training approximately three times per week. All subjects were given visual and auditory encouragement to complete the range of motion with each repetition.

Study Design

Electrode Placement

Surface EMG values were recorded from three abdominal sites each on the left and right sides of the body. For accurate positioning, a measuring tape was used to place pairs of EMG surface electrodes over the belly of the following muscles: URA (approximately 2 cm lateral and 5 cm superior to the umbilicus), LRA (approximately 2 cm lateral and 5 cm inferior to the umbilicus), and EO (approximately 15 cm lateral to the umbilicus at 45 degrees to the horizontal), as seen in Figure 1.

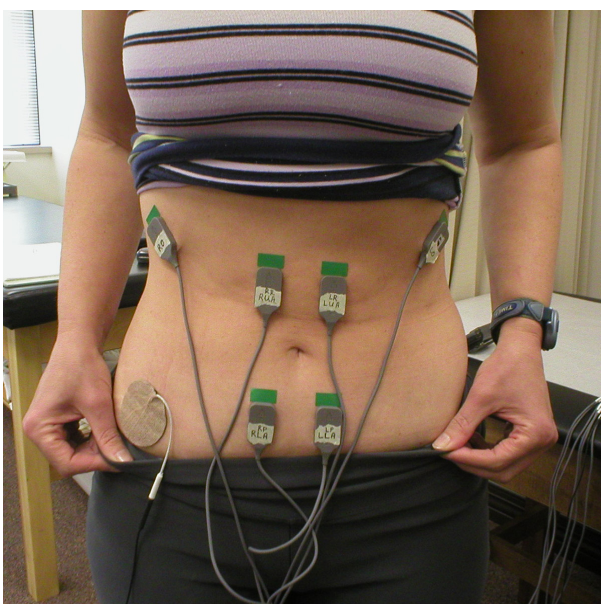

Figure 1. Positioning of EMG surface electrodes over the bellies of the URA, LRA, and EO muscles.

Data Acquisition

A Myo-Monitor portable EMG (DelSys, Inc, Boston, MA) data acquisition system with an HP Jornada 720 series hand-held computer (HP, Ltd, Singapore) was used to record muscle activity. Electrodes were positioned by the same investigator so that the contact bars lay perpendicular to the muscle fibers to obtain maximal signal detection.

Exercises

Twenty-one subjects were used to obtain data about abdominal activation with the chosen exercises. Each subject performed four types of exercises, varied as one set of 10 repetitions and one 20-second isometric hold, for a total of eight exercises. All exercises were recorded in one testing session; a rest period of 30 seconds to approximately two minutes was allowed between exercises to avoid fatigue. Before the exercise sequence was begun, a baseline value for normalizing the 10-repetition EMG data was established for each subject by performing 10 repetitions on the seated Cybex trunk curl machine (Cybex, International, Inc., Medway, MA) against 40 lb (18 kg) of resistance (Figure 2). The Cybex trunk curl

Figure 2. The baseline exercise on Cybex trunk curl machine. The isometric hold portion was measured at the full curl position.

machine was used as the baseline in order to standardize against a single known amount of resistance to collect the baseline EMG data for each subject. In contrast, using the subject as the baseline by recording the EMG activity, for instance, during a "traditional crunch," would have an unknown or unquantifiable amount of body weight resistance that would produce the EMG activity. Recording of the data from the isometric hold was performed at the fully contracted/terminal position of each exercise.

Surface EMG activity was recorded while each variation of the following exercises was performed:

Ball full crunch (BFC): Subject was supine, with trunk supported by PhysioBall of 65 cm diameter, hips at 0 degrees, knees at 45 degrees, and feet flat on the floor (Figure 3). The BFC was standardized by having the subject perform trunk flexion up to the level that the inferior angle of the scapula was lifted off the ball. A wooden dowel rod was positioned above the subject's chest as a tactile cue for each crunch endpoint, so that the subject would perform a consistent range of motion with each repetition. The center of the ball was positioned at approximately the L1 vertebral level.

Ball neutral crunch (BNC): Subject was supine, with trunk supported by a PhysioBall of 65 cm diameter (also called an exercise or Swiss ball), hips at 0 degrees, knees at 45 degrees, and feet flat on the floor (Figure 4). The BNC was standardized by having the subject perform trunk flexion up to the level where the spine reached a position parallel to the floor. A wooden dowel rod was positioned above the subject's chest as a tactile cue for each crunch endpoint, so that the subject would perform a consistent range of motion with each repetition.

Figure 3. The PhysioBall full crunch (BFC) exercise. The isometric hold portion was measured at the full crunch position.

Figure 4. The PhysioBall neutral crunch (BNC) exercise. The isometric hold portion was measured at the neutral crunch position.

Trunk curl reach (TCR): Subject was supine, with hips at 45 degrees, knees at 90 degrees, and feet flat on the floor. Each subject performed alternating upward reaching movements (right arm first) with arms overhead at approximately 60 degrees flexion, elevating until the tip of the ipsilateral scapula was lifted off the floor (Figure 5).

Abench advanced crunch machine (Precor, Woodinville, WA) (AbM): Subject was supine, with hands gripping handles, hips approximately 90 degrees, knees approximately 90 degrees, and feet resting on footplate (Figure 6). Each subject was positioned to permit trunk flexion at approximately the T6–T7 level.

Three different exercise order sequences were used and randomized per subject to prevent any order effect. Surface EMG activity was sampled at a rate of 1024 Hz. Data were rectified and analyses were performed using the EMGworks® 3.0 signal analysis software (DelSys, Inc., Boston, MA). The root mean square (RMS) was calculated using a moving window and the following equation:

$$RMS = (1/S\ \Sigma\ f^2\ (s))^{1/2}$$

where S = window length of 0.125 seconds and f(s) = data within the window.

Figure 5. The trunk curl reach (TCR) exercise. The isometric hold portion was measured at the full crunch position with both hands extended skyward.

The integral (the area under the EMG curves) was calculated for an interval of two repetitions of a 10-repetition set, and for a 5-second interval of the 20-second isometric hold for each subject and exercise, as detailed in Figure 7. Data obtained from the above calculations were then normalized by subtracting the subject's baseline EMG peak amplitude or average integral and exported to Excel (Microsoft Corp., Redmond, WA) for graphic representation. Comparisons of EMG activity for 10-repetition and 20-second hold exercises by muscle group (Figures 8 and 9) as well as total EMG activity between 10-repetition and 20-second isometric hold exercises (Figure 10) were plotted. For the purposes of comparison, the individual muscles were grouped into URA, LRA, and EO.

Figure 6. The Abench advanced crunch machine (AbM) exercise. The isometric hold portion was measured at the full crunch position.

Statistical Methods

Statistical analyses were performed on the data using PC-SAS (SAS Institute, Cary, NC). Initially, univariate statistical analysis was performed for each condition and position to determine the frequency distributions and the suitability of using analysis of variance (ANOVA). A priori power analysis (alpha 0.05, power 0.80) of four pilot subjects (n=2 per gender) revealed that up to 10 subjects of each gender would be sufficient to reveal differences in muscle groups and exercises. The integral values of EMG activity for the repetitions and the isometric hold were compared according to gender, muscle group, and exercise with ANOVA using the Proc GLM (General Linear Model) in PC-SAS, as well as the comparison between repetitions and isometric hold. P values less than 0.05 were considered statistically significant.

RESULTS

Comparisons of EMG activity for the repetition integral by muscle group and exercise are shown in Figure 8. There was no significant difference found between male and female EMG activity. The three muscle groups were all significantly different from each other in EMG activity across all exercises; the URA activity was higher than the LRA ($p<0.01$) and the EO ($p<0.01$), and the LRA activity was higher than the EO ($p<0.01$). For the exercises, the Abench had significantly higher activity than the BNC ($p<0.01$) and the TCR ($p<0.01$), and the BFC was significantly higher than the BNC ($p<0.01$). There was no significant difference between the activities on the AbM when compared with the BFC; likewise, no statistical difference was found between the BFC and TCR.

The 20-second isometric hold results are shown in Figure 9 by muscle group and exercise. There was no significant difference found between male and female EMG activity. The three muscle groups were all significantly different from each other in EMG activity; the URA were higher than the LRA ($p=0.04$) and the EO ($p<0.01$), and the LRA were higher than the EO ($p<0.01$). For the exercises, the Abench had significantly higher activity than the BNC ($p<0.01$) and TCR ($p=0.04$), and the BFC was significantly higher than the BNC ($p=0.02$).

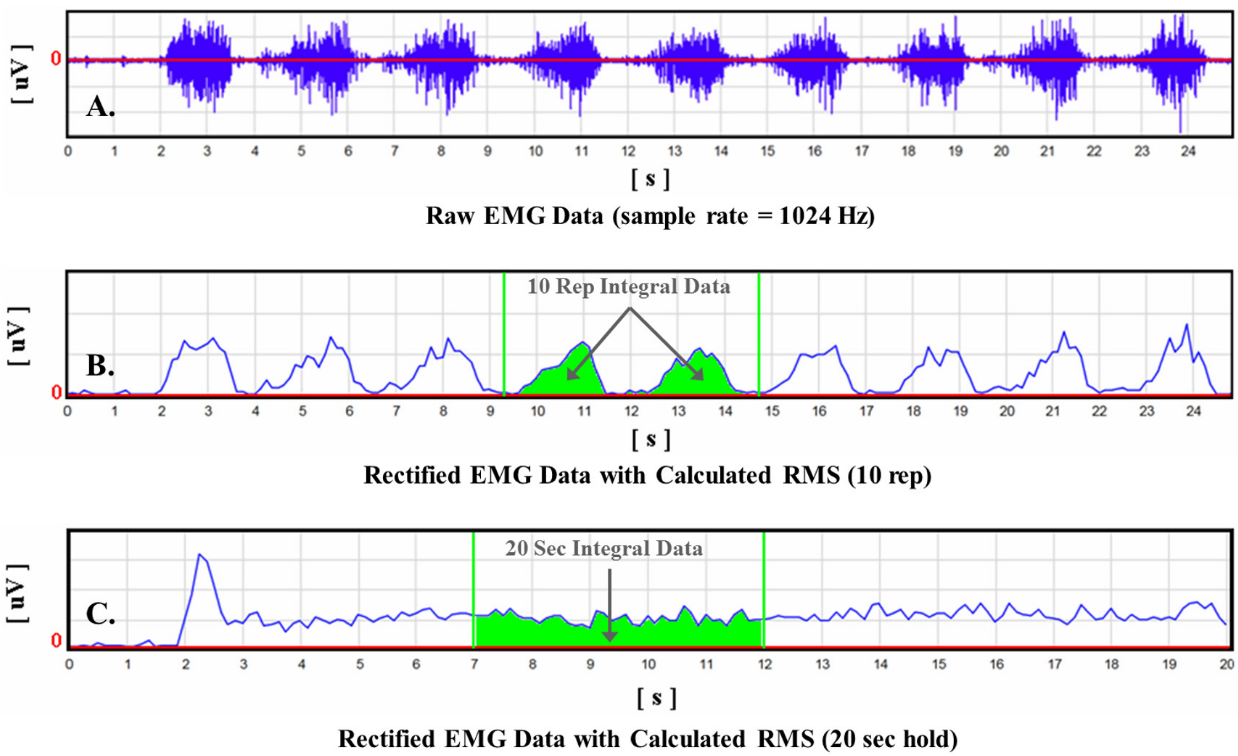

Figure 7. An example of the raw and rectified surface electromyography (EMG) data.

The integrals of total EMG activity averaged over all muscles for each exercise are shown in Figure 10 to compare repetitions versus an isometric hold. When comparing the integrals of the repetition exercises and the integrals of the isometric holds, there were no differences found between the exercise types for EMG activity. Two male subjects did not have an Abench isometric hold exercise tracing because of software issues.

DISCUSSION

Examination of the eight abdominal exercises demonstrated that the Abench and ball full crunch exercises significantly produced the most EMG activity of all the exercises measured. This study also found no statistically significant difference in EMG activity when comparing repetitions exercise to an isometric hold exercise. A study by Warden et al. (11) compared the effectiveness of the Abshaper (model no. 9800, Copperart Stores, Glendenning, N.S.W., Australia) with the traditional abdominal crunch. The Abshaper resulted in significantly greater relative peak and mean EMG activity with the URA; however, there were no significant differences in either the LRA or the EO when compared with the traditional supine crunch. Cosio-Lima et al. (12) compared the effects of PhysioBall core stability and balance exercises with the same exercise regimen performed on the floor. They found significantly improved EMG flexion, EMG extension, and balance in the PhysioBall group. Axler and McGill (13) evaluated 9 subjects

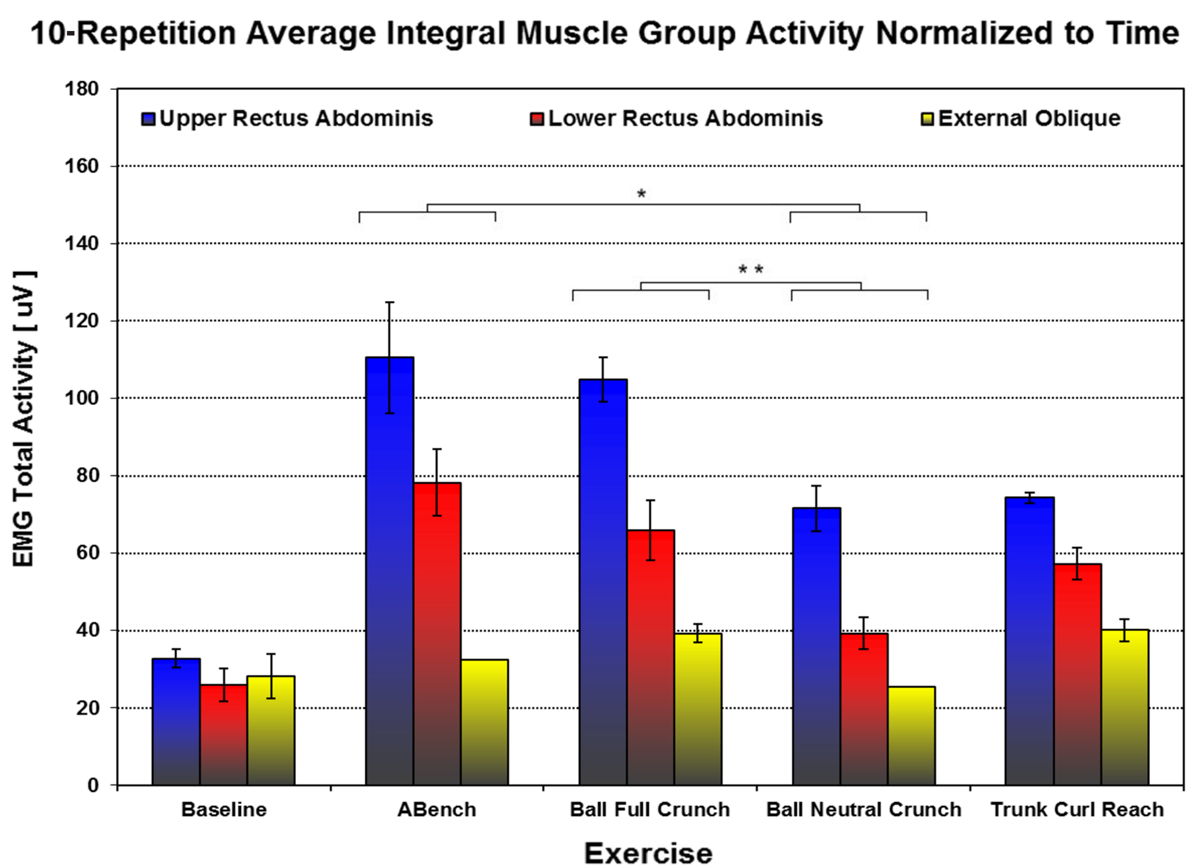

Figure 8. The 2-repetition average integral of EMG activity for the 10-repetition exercises by muscle group, URA (upper rectus abdominis), LRA (lower rectus abdominis), and EO (external obliques). *The Abench and the BFC (ball full crunch) both showed higher activation for the URA, ULA, and EO muscle groups than did the BNC (ball neutral crunch), statistically significant at $p<0.05$. ** The BFC showed higher activation for the URA, ULA, and EO muscle groups than did the BNC, statistically significant at $p<0.05$.

performing 12 different abdominal exercises to assess which exercises provided greatest abdominal activation while imposing a minimal load penalty to the lumbar spine. Partial curl-ups generated the best challenge-to-cost index; however, no single exercise optimally trained all abdominal muscles while equally minimizing intervertebral joint loads. Clark et al. (14) found significantly higher mean EMG amplitude of the URA and LRA during the Sissel exercise ball curl-up than during the conventional curl-up on the floor, use of the Ab Trainer device, the leg-lowering exercise, the Sissel ball roll-out, or the reverse Sissel ball curl-up.

A study by Olson et al. (15) involving 15 subjects, evaluated muscle activity using surface EMG for the RA and EO to compare conventional exercises with an upright commercial abdominal training device (CoreMaster). For the RA, all exercises on the CoreMaster produced significantly higher EMG values compared with the conventional trunk lift. For the EO, trunk rotation on the CoreMaster elicited the highest EMG values. However, no significant difference was found for EO between trunk rotation to opposite knee and trunk rotation

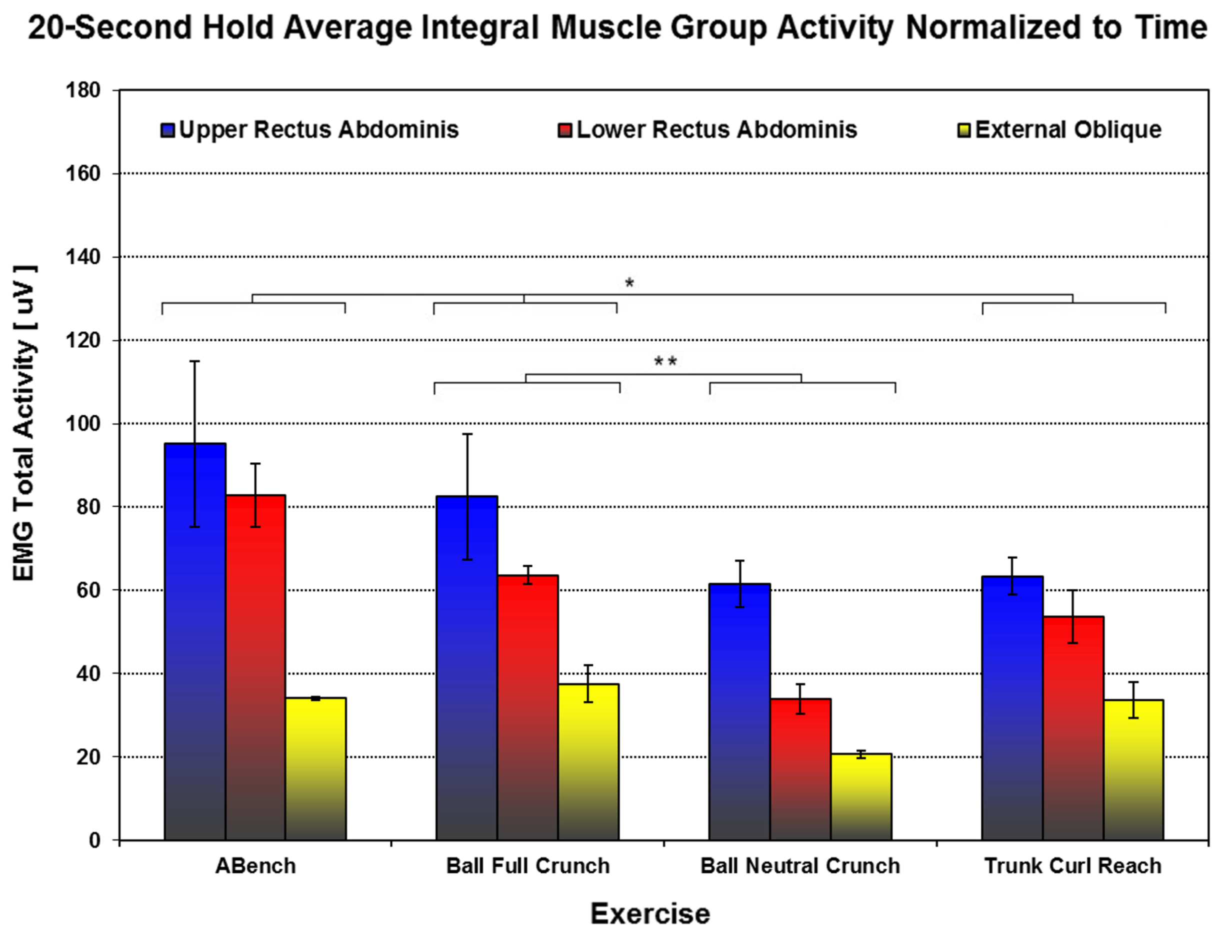

Figure 9. The 5-second interval average integral of EMG activity for the 20-second isometric hold exercises by muscle group, URA (upper rectus abdominis), LRA (lower rectus abdominis), and EO (external obliques). *The Abench and the BFC (ball full crunch) both showed higher activation for the URA, ULA, and EO muscle groups than did the TCR (trunk curl reach), statistically significant at p<0.05. **The BFC showed higher activation for the URA, ULA, and EO muscle groups than did the BNC, statistically significant at p<0.05.

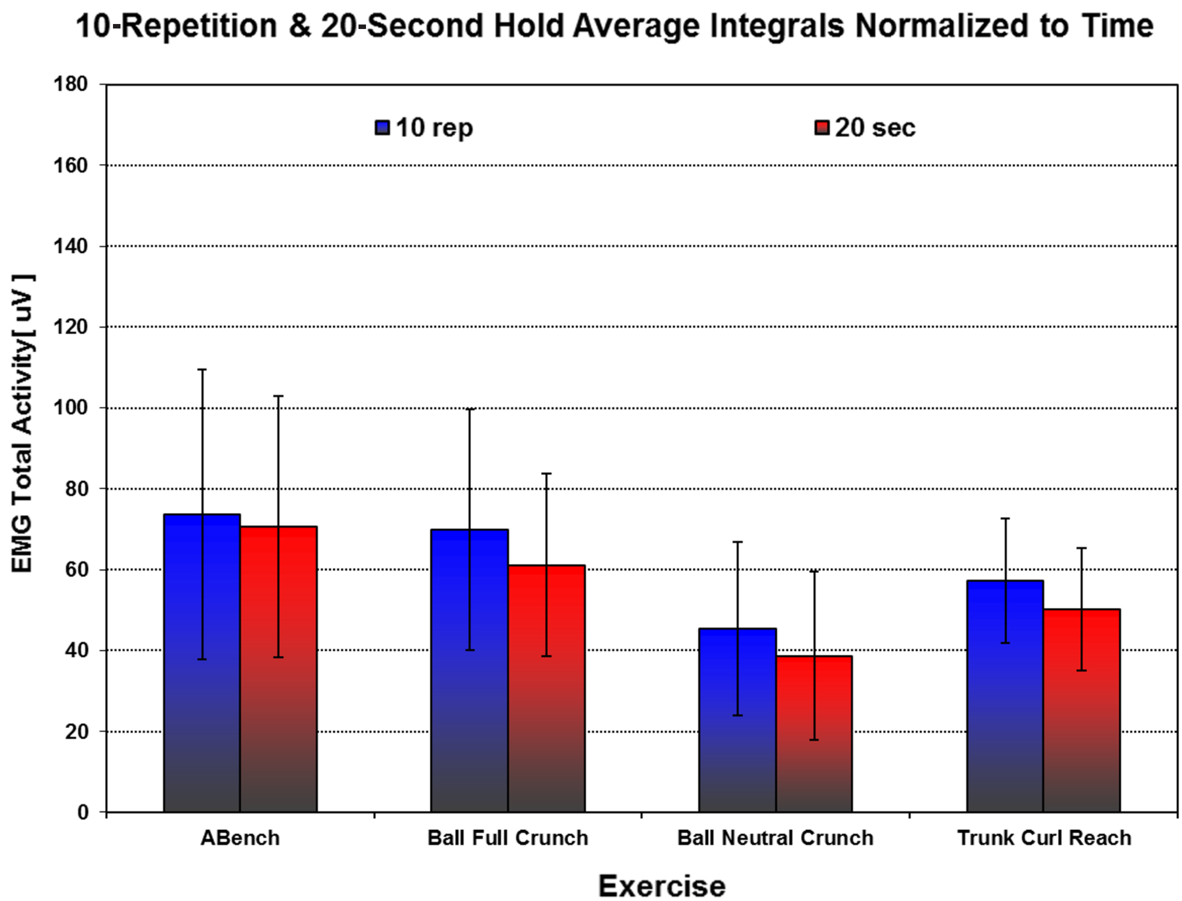

Figure 10. The average integrals of all muscle EMG activity of the repetition and isometric hold exercises normalized to time. There were no difference found between repetitions and isometric hold for the different exercises.

with a leg lift on the CoreMaster. The authors concluded that the CoreMaster elicited a greater challenge to the RA. For the EO, the CoreMaster yielded optimal effects for exercises that required pronounced rotation.

A study comparing abdominal muscle activity while performing a crunch on an exercise ball with a traditional crunch was performed by Sternlicht et al. (16). Muscle activity for the upper and lower portions of the RA and EO for a traditional crunch was significantly lower than for the crunch performed in the SB-low position but significantly greater than the SB-high position. Abdominal muscle activity doubled when the stability ball was moved from the upper to the lower back position.

Escamilla et al. (2) tested the effectiveness of seven commercial abdominal machines (Ab Slide, Ab Twister, Ab Rocker, Ab Roller, Ab Doer, Torso Track, SAM) and two common abdominal exercises (crunch, bent-knee sit-up) on activating abdominal and extraneous (non-abdominal) musculature. They concluded that the Ab Slide and Torso Track were the most effective exercises in activating abdominal and upper extremity muscles while minimizing low back and rectus femoris (hip flexion) activity.

Marshall and Murphy evaluated core stability exercises on and off a Swiss ball: inclined press-up, upper body roll-out, single-leg hold, and quadruped exercise (17, 18). Surface EMG evaluated the RA, external and internal obliques, transverse abdominis, and erector spinae, demonstrating a significant increase in the activation of the RA with performance of the single-leg hold and at the top of the press-up on the Swiss ball.

In the present study, the Abench and ball full crunch exercises showed significantly higher activation ($p<0.05$) of both the URA and LRA when compared with ball neutral crunch, and trunk curl reach exercises. No single exercise was able to significantly activate the EO when compared with baseline activation despite the inclusion of the trunk curl reach exercise.

Limitations with the current study include a small sample size, healthy individuals without low back pain who were involved in a regular exercise regimen, and the inclusion of four exercises performed in two different manners. Surface EMG also has limitations in that electrical activity is only measured under the electrode, and not in the entire muscle, as well as artifacts related to skin, underlying tissues, and cross-talk from other muscles.

CONCLUSIONS

A regimen combining the Abench or ball full crunch may be the most beneficial for effective rectus abdominal muscle recruitment and strengthening in healthy adults.

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