[RESEARCH REPORT]

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Core Muscle Activation During Swiss Ball and Traditional Abdominal Exercises

The "core" has been used to refer to the lumbopelvic-hip complex, which involves deeper muscles, such as the internal oblique, transversus abdominis, transversospinalis (multifidus, rotatores, semispinalis), quadratus lumborum, and psoas major and minor, and superficial muscles, such as the rectus abdominis, external oblique, erector spinae (iliocostalis, spinalis, longissimus), latissimus dorsi, gluteus maximus and medius, hamstrings, and rectus femoris.[2,24,25] Core muscle development is believed to be important in many functional and athletic activities, because core muscle recruitment should enhance core stability and help provide proximal stability to facilitate distal mobility. For optimal core stability, both the smaller, deeper core muscles and the larger, superficial core muscles must contract in sequence with appropriate timing and tension.[26,27] Enhanced stability and neuromuscular control of the lumbopelvic-hip complex has been shown to decrease the risk of knee injuries, especially in females.[29,37] Zazulak et al[37] reported that female athletes with less trunk control had a higher risk of knee injuries, especially anterior cruciate ligament injuries, compared to athletes who exhibited greater trunk control.

• **STUDY DESIGN:** Controlled laboratory study using a repeated-measures, counterbalanced design.

• **OBJECTIVES:** To test the ability of 8 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.

• **BACKGROUND:** Numerous Swiss ball abdominal exercises are employed for core muscle strengthening during training and rehabilitation, but there are minimal data to substantiate the ability of these exercises to recruit core muscles. It is also unknown how core muscle recruitment in many of these Swiss ball exercises compares to core muscle recruitment in traditional abdominal exercises such as the crunch and bent-knee sit-up.

• **METHODS:** A convenience sample of 18 subjects performed 5 repetitions for each exercise. Electromyographic (EMG) data were recorded on the right side for upper and lower rectus abdominis, external and internal oblique, latissimus dorsi, lumbar paraspinals, and rectus femoris, and then normalized using maximum voluntary isometric contractions (MVICs).

• **RESULTS:** EMG signals during the roll-out and pike exercises for the upper rectus abdominis (63% and 46% MVIC, respectively), lower rectus abdominis (53% and 55% MVIC, respectively), external oblique (46% and 84% MVIC, respectively), and internal oblique (46% and 56% MVIC, respectively) were significantly greater compared to most other exercises, where EMG signals ranged between 7% to 53% MVIC for the upper rectus abdominis, 7% to 44% MVIC for the lower rectus abdominis, 14% to 73% MVIC for the external oblique, and 16% to 47% MVIC for the internal oblique. The lowest EMG signals were consistently found in the sitting march right exercise. Latissimus dorsi EMG signals were greatest in the pike, knee-up, skier, hip extension right and left, and decline push-up (17%-25% MVIC), and least with the sitting march right, crunch, and bent-knee sit-up exercises (7%-8% MVIC). Rectus femoris 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 (6%-10% MVIC). Lumbar paraspinal EMG signal was relative low (less than 10% MVIC) for all exercises.

• **CONCLUSIONS:** The roll-out and pike were the most effective exercises in activating upper and lower rectus abdominis, external and internal obliques, and latissimus dorsi muscles, while minimizing lumbar paraspinals and rectus femoris activity. *J Orthop Sports Phys Ther 2010;40(5):265-276. doi:10.2519/jospt.2010.3073*

• **KEY WORDS:** *crunch, EMG, low back pain, lumbar spine, rectus abdominis, sit-up*

The use of Swiss ball training for core muscle development has been popular for several years.[8] Multiple studies have examined core muscle recruitment during varying types of Swiss ball abdominal exercises[8,28,35,36] and during traditional abdominal exercises like the crunch (abdominal curl-up) and bent-knee sit-up.[13,14,35,36] Most researchers who studied the use of Swiss ball exercises quantified abdominal muscle activity during the crunch, push-up, and bench press exercises, and typically investigated the recruitment patterns of only 1 or 2 mus-

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cles.[5,15,22,23,32] Numerous other Swiss ball exercises are used in training and rehabilitation to enhance core development and stability. For example, prone hip extension performed on a Swiss ball is commonly used for gluteus maximus and hamstrings development. However, the extent that performing prone hip extension on a Swiss ball recruits core muscles has not yet been investigated. Moreover, there are several additional higher-level Swiss ball exercises that are used by athletes, such as the roll-out, pike, knee-out, and skier, but their effectiveness in recruiting core muscles is unknown. Many of these exercises are chosen based on functionality or sport specificity. Nevertheless, it remains unclear how performing traditional abdominal-strengthening exercises, such as the crunch and bent-knee sit-up, compares to performing a progression of Swiss ball exercises, with respect to core muscle recruitment.

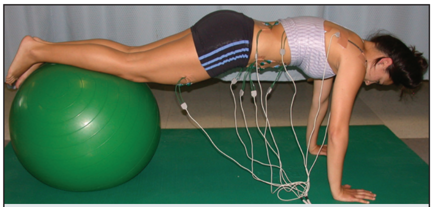

FIGURE 1. Starting position for the pike, knee-up, skier, decline push-up, hip extension right, and hip extension left.

FIGURE 2. Ending position for the pike.

FIGURE 3. Ending position for the knee-up.

FIGURE 4. Ending position for the skier.

Understanding which core muscles are recruited and how active they are while performing a variety of Swiss ball and traditional abdominal exercises is helpful to therapists and other healthcare or fitness specialists who develop specific abdominal exercises for their patients or clients to facilitate their rehabilitation or training objectives. The purpose of this study was to test the ability of 8 Swiss ball abdominal exercises and 2 traditional abdominal exercises on activating core muscles. It was hypothesized that normalized electromyographic (EMG) signals from core muscles would be significantly greater in Swiss ball exercises compared to traditional abdominal exercises, and would be significantly less in the sitting march right exercise compared to the remaining Swiss ball exercises.

METHODS

Subjects

To optimize the quality of the EMG signal collected, this study was limited to a convenience sample of 18 healthy, young subjects (9 male and 9 female) who had normal or below normal body fat for their age group, in accordance with standards set by the American College of Sports Medicine.[3] Baseline skin fold calipers (model 68900; Country Technology, Inc, Gays Mill, WI) and appropriate regression equations were used to assess percent body fat. Mean (SD) age, mass, height, and percent body fat for females were 27.7 (7.7) years, 61.1(7.8) kg, 165.0 (7.0) cm, and 18.7% (3.5%), respectively, and 29.9 (6.6) years, 73.3 (7.2) kg, 178.1 (4.3) cm, and 11.6% (3.6%) for males, respectively. All subjects provided written informed consent in accordance with the Institutional Review Board at California State University, Sacramento. Individuals were excluded from the study if they had a history of abdominal or back pain or were unable to perform all exercises pain-free, through their full range of motion, and with proper form and technique for 12 consecutive repetitions.

Exercise Descriptions

The 8 Swiss ball abdominal exercises are shown in **FIGURES 1 though 11. FIGURE 1** shows the starting position for the pike, knee-up, skier, decline push-up, hip extension right, and hip extension left. During these exercises, the subject assumed a prone, neutral spine and pelvis push-up position (hips, knees, elbows, and neck flexed approximately 0°, shoulders flexed approximately 90°, feet together, and hands shoulder width apart), with the center of the Swiss ball positioned under the legs approximately halfway between the knees and ankles. The pike was performed by flexing the hips approximately 90° to 100°, while keeping the knees fully extended (**FIGURE 2**). The knee-up was performed by flexing both the hips and knees approximately 90° to 100°, with the knees moving towards the chest (**FIGURE 3**). The skier was performed similarly to the knee-up, except that both knees moved towards the right shoulder as the hips and knees flexed (**FIGURE 4**). During the pike, knee-up, and skier it was natural for slight trunk (spine) flexion to occur. After the pike, knee-up, and skier movements were completed, the subject returned to the starting position.

During the decline push-up, simultaneous elbow flexion and shoulder horizontal abduction occurred until just before the subject's nose contacted the

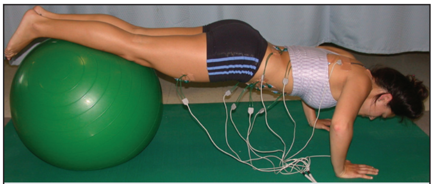

FIGURE 5. Ending position for the decline push-up.

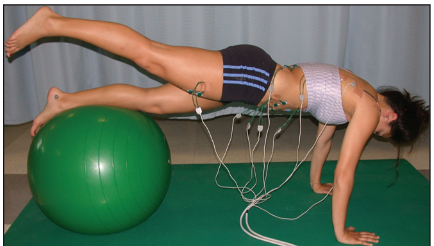

FIGURE 6. Ending position for the hip extension right.

FIGURE 7. Ending position for the hip extension left.

floor (**FIGURE 5**). During the hip extension right, the right hip was maximally extended (approximately 20°-30°), without trunk rotation, and with the right knee fully remaining extended (**FIGURE 6**). The hip extension left was performed similarly, but with the left hip maximally extended (**FIGURE 7**). During the decline push-up, hip extension right, and hip extension left, the trunk remained in a rigid position, with a neutral spine and pelvis throughout the movements. When the ending positions were obtained, the subject returned to the starting position.

The starting position for the roll-out involved kneeling with knees flexed approximately 90°, trunk erect, elbows fully extended, shoulder flexed approximately 30°, and both hands positioned approximately in the center of the Swiss ball (**FIGURE 8**). From this position, the subject rolled out on the Swiss ball (maintaining a neutral spine and pelvis) onto the forearms until the proximal forearms were approximately centered on the Swiss ball,

FIGURE 8. Starting position for the roll-out.

FIGURE 9. Ending position for the roll-out.

FIGURE 10. Starting position for the sitting march right.

with shoulders flexed approximately 90° to 100° (**FIGURE 9**), then returned to the starting position. The starting position for the sitting march right was sitting erect with the buttocks centered on the Swiss ball, with the hips and knee flexed approximately 90° and the feet flat on the floor (**FIGURE 10**). From this position the subject

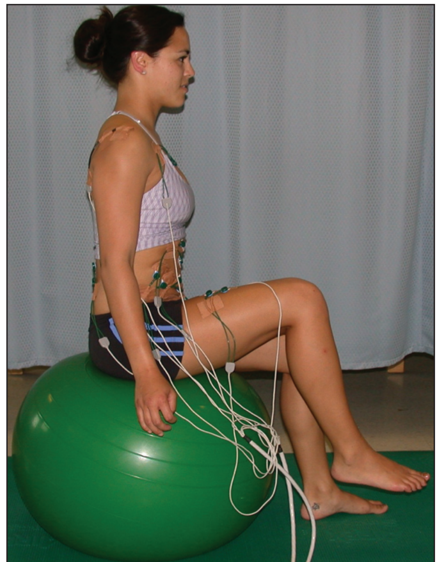

FIGURE 11. Ending position for the sitting march right.

FIGURE 12. Ending position for the crunch.

raised the right knee upwards, while flexing the right hip approximately 30° (**FIGURE 11**), then returned to the starting position.

The 2 traditional abdominal exercises performed were the crunch and bent-knee sit-up. These exercises began in a supine position, with the knees flexed approximately 90° and the thumbs positioned in the ears, hands relaxed against the head. The feet were supported and held down for the bent-knee sit-up but not for the crunch. To perform the crunch, the subject flexed the spine without hip flexion until both scapulae were off the ground (**FIGURE 12**), then returned to the starting position. During the bent-knee sit-up, the subject simultaneously flexed the spine and hips until the elbows were even with the knees (**FIGURE 13**), then returned to the starting position.

Procedures

No subject had prior experience in performing the 8 Swiss ball exercises, but all

FIGURE 13. Ending position for the bent-knee sit-up.

subjects had some experience in performing the crunch and bent-knee sit-up. All subjects became familiar with all exercises and the procedures to perform the maximum voluntary isometric contractions (MVIC) during a session that took place approximately 1 week prior to testing. During the pretest session, each subject received instructions from a physical therapist that explained and demonstrated proper execution of each exercise. An appropriately sized Swiss ball was used and adjusted in accordance with each subject's height: subjects with a height between 150 and 165 cm used a 55-cm ball, those with a height between 165 and 180 cm used a 65-cm ball, and those with a height greater than 180 cm used a 75-cm ball. The Swiss ball was also inflated according to the subject's weight, so that when a subject was sitting erect and centered on the ball, with feet together and flat on the ground, the subject's hips and knees were flexed approximately 90° and the thighs were parallel with the floor.

All exercises were performed with an approximately 3-second cadence: an approximately 1-second movement from the start position to the end position, approximately 1-second isometric hold at the end position, and approximately 1-second return to the start position. An approximately 1-second rest was given between repetitions. A metronome (set at 1 beat per second) was used to help ensure proper cadence both during the pretest and testing sessions, and subjects were also given the following verbal commands to assist in maintaining a proper cadence: "up 1000, hold 1000, down 1000, rest 1000." Once a subject demonstrated the ability to correctly perform each exercise through an appropriate range of motion and with proper cadence, a testing session was scheduled.

Blue Sensor (Ambu Inc, Linthicum, MD) disposable surface electrodes (type M-00-S) were used to collect EMG data. These oval-shaped electrodes (22 mm wide and 30 mm long) were placed in a bipolar configuration along the longitudinal axis of each muscle, with a center-to-center distance of approximately 3 cm. Prior to applying the electrodes, the skin was prepared by shaving, abrading, and cleaning with isopropyl alcohol wipes to reduce skin impedance. Electrode pairs were then placed on the muscles on the right side only, as left- and right-side EMG signal symmetry has been demonstrated in core muscles during supine and prone position exercises.[4,13,14,24,31] The muscles monitored were as follows: upper rectus abdominis, with electrodes positioned vertically and centered on the muscle belly, with 1 electrode just above and 1 electrode just below the midpoint between umbilicus and xiphoid process (but not on tendinous intersection), and 3 cm lateral from midline; lower rectus abdominis, with electrodes positioned 8° from vertical in an inferomedial direction and centered on the muscle belly near the midpoint between umbilicus and pubic symphysis and 3 cm lateral from midline; external oblique, with electrodes positioned obliquely approximately 45° (parallel to a line connecting the most inferior point of the costal margin of the ribs and the contralateral pubic tubercle) superior to the anterior superior iliac spine (ASIS), near the level of the umbilicus; internal oblique, with electrodes positioned horizontally 2 cm inferomedial to the ASIS, within a triangle confined by the inguinal ligament, lateral border of the rectus sheath, and a line connecting each ASIS, where only the aponeurosis of the external oblique and not the external oblique muscle covers the internal oblique[31]; latissimus dorsi, with electrodes positioned obliquely (approximately 25° from horizontal in an inferomedial direction) 4 cm below the inferior angle of the scapula; rectus femoris, with electrodes positioned vertically near midline of the thigh, approximately halfway between ASIS and the proximal pole of the patella; and the lumbar paraspinals, with electrodes positioned vertically 3 cm lateral to the spine and nearly level with the iliac crest between the L3 and L4 vertebrae. A ground (reference) electrode was positioned over the skin of the right acromion process. Electrode cables were connected to the electrodes and taped to the skin appropriately to minimize pull on the electrodes and movement of the cables.

Once the electrodes were positioned, the subject warmed up and practiced the exercises as needed, then data collection commenced. EMG data were sampled at 1000 Hz using a Noraxon Myosystem unit (Noraxon USA, Inc, Scottsdale, AZ). The EMG amplifier bandwidth frequency was 10 to 500 Hz, with an input impedance of 20 000 kΩ and a common-mode rejection ratio of 130 dB.

EMG data were collected during 5 repetitions for each exercise, with the exercises performed in a randomized order. Each repetition was performed in a slow and controlled manner, using the 3-second cadence and 1-second rest between repetitions as previously described. After each exercise was completed, the subject was asked to rate the perceived exertion for the exercise using a 15-point rating of perceived exertion (Borg Scale) from 6 to 20, where 6 was no perceived exertion, 7 was very, very light, 9 was very light, 11 was fairly light, 13 was somewhat hard, 15 was hard, 17 was very hard, 19 was very, very hard, and 20 was maximum perceived exertion.[3] Each testing session took approximately 45 minutes to complete.

Randomly interspersed within the exercise testing session, EMG data for two 5-second MVICs were collected to nor-

TABLE 1 Mean (SD) EMG for Each Muscle and Exercise Expressed as a Percent of Each Muscle's MVIC

Exercise	Upper Rectus Abdominis*	Lower Rectus Abdominis*	External Oblique*	Internal Oblique*	Lumbar Paraspinal*	Latissimus Dorsi*	Rectus Femoris*
Roll-out	63 (30)	53 (23)	46 (18)†,‡	46 (21)	6 (2)†	12 (9)†,‡,§,‖	8 (5)†,‡,§,‖,¶
Pike	47 (18)	55 (16)	84 (37)	56 (22)	8 (3)	25 (11)	24 (6)‖
Knee-up	32 (15)#,**	35 (14)†	64 (39)	41 (16)	6 (3)	22 (13)	23 (8)‖
Skier	38 (17)#	33 (8)†,#	73 (40)	47 (18)	6 (3)	21 (10)	19 (8)‖
Hip extension right††	43 (21)#	44 (11)	56 (32)†	40 (26)†	7 (3)	17 (13)	9 (5)†,‡,§,‖,¶
Hip extension left††	41 (24)#	39 (19)†	39 (19)†,‡,§	45 (25)	6 (3)	21 (14)	35 (18)
Decline push-up	38 (20)#	37 (16)†	36 (24)†,‡,§	33 (18)†	6 (2)	18 (12)	10 (6)†,§,‖,¶
Crunch	53 (19)	39 (16)†	28 (17)†,‡,§,‡‡	33 (13)†	5 (2)†,‡‡	8 (3)†,‡,§,‖,‡‡,§§	6 (4)†,‡,§,‖,¶
Bent-knee sit-up	40 (13)#	35 (14)†,#	36 (14)†,‡,§	31 (11)†	6 (2)	8 (3)†,‡,§,‖,‡‡,§§	23 (12)‖
Sitting march right	7 (6)†,‡,§,‖,¶,#,**,‡‡, §§	7 (6)†,‡,§,‖,¶,#,**,‡‡,§§	14 (6)†,‡,§,‖,#,‡‡,§§	16 (11)†,‡,§,‖,#,**,‡‡,§§	5 (2)†	7 (3)†,‡,§,‖,‡‡,§§	18 (7)†,‖

Abbreviations: EMG, electromyographic signal; MVIC, maximal voluntary isometric contraction.
* *Significant difference (P<.001) in EMG among abdominal exercises based on a 1-way repeated-measures analysis of variance.*
† *Significantly less EMG compared to the pike.*
‡ *Significantly less EMG compared to the skier.*
§ *Significantly less EMG compared to the knee-up.*
‖ *Significantly less EMG compared to the hip extension left.*
¶ *Significantly less EMG compared to the bent-knee sit-up.*
\# *Significantly less EMG compared to the roll-out.*
** *Significantly less EMG compared to the crunch.*
†† *Because muscle activity was only measured on the right side of the body, contralateral muscle activity was measured during the hip extension left and ipsilateral muscle activity was measured during the hip extension right.*
‡‡ *Significantly less EMG compared to the hip extension right.*
§§ *Significantly less EMG compared to the decline push-up.*

malize the EMG signal collected during the exercises. The following standardized positions were employed for MVIC testing[13,14]: for the upper and lower rectus abdominis the subject was in supine, with hips and knees flexed 90°, feet supported, and trunk maximally flexed (ie, curl-up position), with resistance provided at the shoulders by a tester pushing in the trunk extension direction; for the external oblique the subject was in supine, with hips and knees flexed 90°, feet supported, and trunk maximally flexed and rotated to the left, with resistance at the shoulders by a tester pushing in the trunk extension and right rotation directions; for the internal oblique the subject was in supine, with hips and knees flexed 90°, feet supported, and trunk maximally flexed and rotated to the right, with resistance at the shoulders by a tester pushing in the trunk extension and left rotation directions; for the latissimus dorsi the subject was prone, with right shoulder abducted 0°, internally rotated, and extended maximally, with resistance at the right distal arm by a tester pushing in the direction of shoulder flexion; for the lumbar paraspinals the subject was prone, with trunk fully extended and hands clasped behind head, with resistance at the shoulders by a tester pushing in the direction of trunk flexion; and for the rectus femoris the subject was in short sitting, with hips and knees flexed 90° and resistance at the distal leg by a tester pushing in the knee flexion direction. Each subject was asked to give a maximal effort prior to performing each MVIC and was given verbal encouragement during the MVIC to help ensure a maximum effort throughout the 5-second duration. Each subject acknowledged that he/she provided maximal effort during each MVIC. An approximately 1-minute rest was given between each MVIC, and an approximately 2-minute rest was given between each exercise trial. A resting EMG trial was also collected for each muscle to exclude ambient noise. These resting values represented baseline activity for each muscle and were used to zero muscle activity during each exercise and MVIC trial.

Data Processing

Raw EMG signals were full-waved rectified, smoothed with a 10-millisecond moving-average window, and linear enveloped, then averaged over the entire duration of each exercise repetition or MVIC performed.[13,14] The beginning and end of each repetition for each exercise were manually determined by assessing when muscle activity was at baseline during the rest periods, when muscle activity began to rise during the beginning of a repetition and at the end of the rest interval, and when muscle activity returned back to baseline at the end of the repetition and at the beginning of the rest interval. For each repetition, the EMG data were normalized for each muscle and expressed as a percentage of a subject's highest corresponding MVIC trial, which was determined by calculating throughout the 5-second MVIC the highest average EMG signal over a 1-second interval. Normalized EMG data were then averaged over the 5-repetition trials performed for each exercise and used in statistical analyses. Variability in EMG data among each subject's 5 repetitions was typically very low for each muscle and exercise, varying less than 10%.

Data Analysis

A 1-factor repeated-measures analysis of variance (ANOVA) was employed to assess differences in normalized EMG signals among the exercises, while Bonferroni *t* tests were used to assess pairwise comparisons. To minimize the probability of type I errors secondary to the use of a separate ANOVA for each of the 7 muscles, a Bonferroni adjustment was performed (0.05/7). The adjusted level of significance employed was $P = .007$.

RESULTS

Significant differences were observed in normalized EMG data among exercises (**TABLE 1**). Upper rectus abdominis EMG signal was significantly greater with the roll-out compared to all remaining exercises except the pike and crunch, and significantly less with the sitting march right compared to all other exercises. Lower rectus abdominis EMG signal was significantly greater with the pike compared to all exercises except the roll-out and hip extension right, and significantly less with the sitting march right compared to all other exercises. External oblique EMG signal was significantly greater with the pike, knee-up, and skier compared to the hip extension left, decline push-up, sitting march right, crunch, and bent-knee sit-up, and significantly less with the sitting march right compared to all other exercises except the crunch and bent-knee sit-up (additional differences among exercises are indicated in **TABLE 1**). The internal oblique EMG signal was significantly greater with the pike compared to the hip extension right, decline push-up, sitting march right, crunch, and bent-knee sit-up, and was significantly less with the sitting march right compared to all exercises except the bent-knee sit-up. Graphical representations of upper rectus abdominis, lower rectus abdominis, external oblique, and internal oblique EMG signals, ranked from highest to lowest among all exercises, are shown in **FIGURES 14 to 17**, and the relative intensities

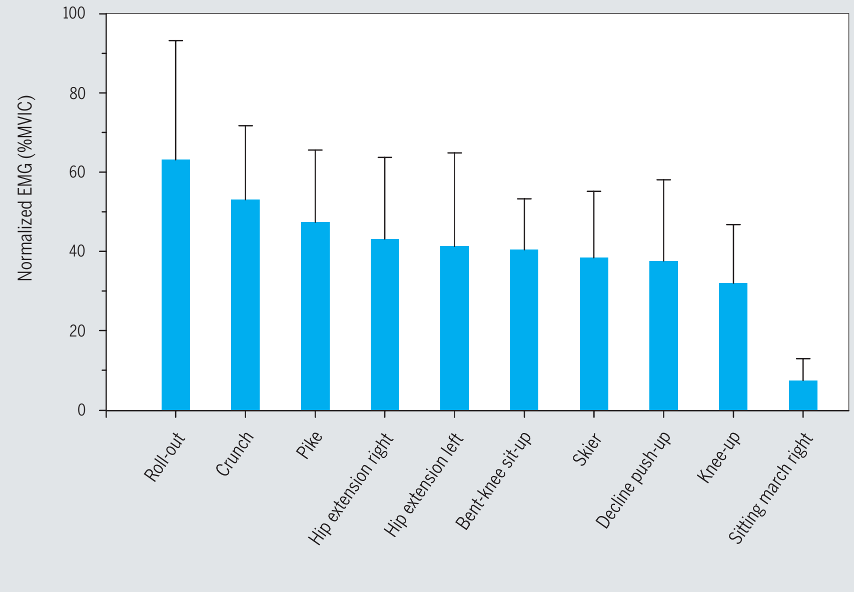

FIGURE 14. Upper rectus abdominis normalized mean (SD) electromyographic signal among exercises.

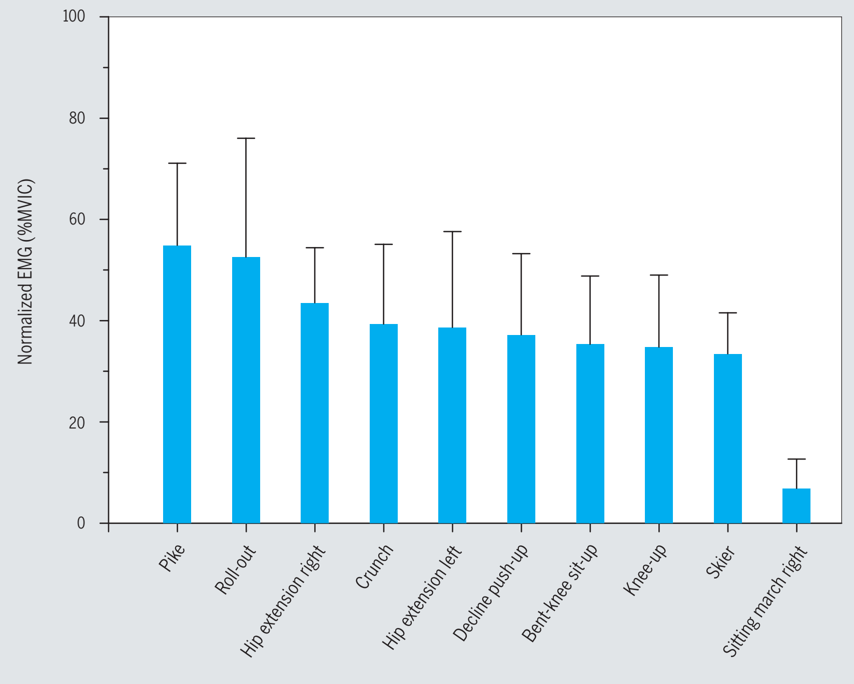

FIGURE 15. Lower rectus abdominis normalized mean (SD) electromyographic signal among exercises.

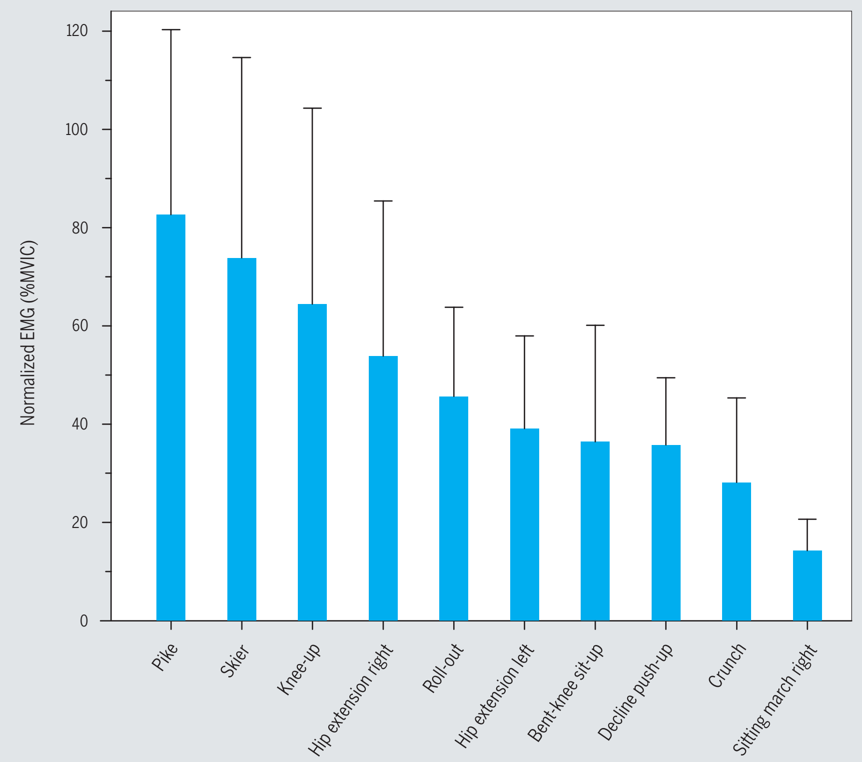

FIGURE 16. External oblique normalized mean (SD) electromyographic signal among exercises.

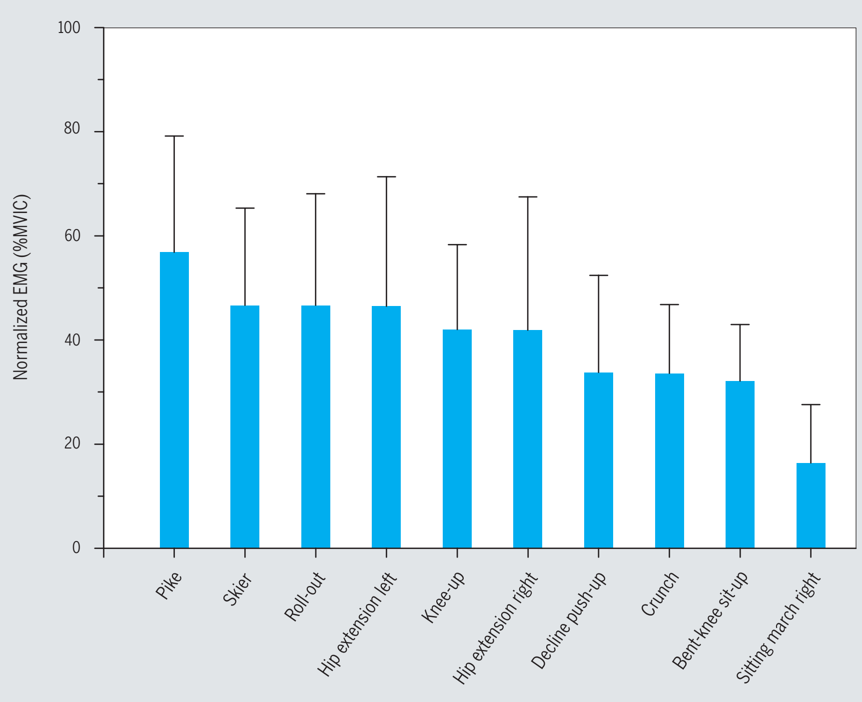

FIGURE 17. Internal oblique normalized mean (SD) electromyographic signal among exercises.

of the exercises with respect to core muscle recruitment are shown in **TABLE 2**.

Lumbar paraspinal EMG signal was less than 10% MVIC, with the greatest activity noted with the pike exercise. Latissimus dorsi EMG signal was significantly greater with the pike, knee-up, skier, hip extension right, hip extension left, and decline push-up, compared to the sitting march right, crunch, and bent-knee sit-up, and significantly greater in the pike, knee-up, skier, and hip extension left, compared to the roll-out. Rectus femoris EMG signal was highest with the pike, knee-up, skier, hip extension left, and bent-knee sit-up compared to the roll-out, hip extension right, and crunch (additional differences among exercises are indicated in **TABLE 1**).

From the 15-point (6-20) Borg Scale, the mean (SD) perceived exertion from highest to lowest was 14.6 (2.1) for the pike, 13.3 (1.5) for the skier, 12.9 (1.4) for the decline push-up, 12.9 (1.8) for the hip extension exercises, 12.7 (1.5) for the knee-up, 12.6 (2.2) for the roll-out, 10.4 (2.5) bent-knee sit-up, 10.2 (2.2) for the crunch, and 9.2 (2.2) for the sitting march.

DISCUSSION

To help classify low to high muscle activities from **TABLES 1 and 2**, 0% to 20% MVIC was considered low muscle activity, 21% to 40% MVIC was considered moderate muscle activity, 41% to 60% MVIC was considered high muscle activity, and greater than 60% MVIC was considered very high muscle activity.[11] The exercises that generated muscle activity greater than 60% MVIC may be more conducive to developing muscular strength for that muscle, while the exercises that resulted in muscle activity less than 20% MVIC may be more conducive to developing muscular endurance for that muscle, assuming repeated contractions occur (typically greater than 12 consecutive repetitions is desired for muscular endurance).[12]

TABLE 2 Relative Muscle Recruitment

	Very High (>60% MVIC)	High (41%-60% MVIC)	Moderate (21%-40% MVIC)	Low (0%-20% MVIC)
Upper rectus abdominis	Roll-out	Crunch, pike, hip extension right,* hip extension left*	Bent-knee sit-up, skier, decline push-up, knee-up	Sitting march right
Lower rectus abdominis		Pike, roll-out, hip extension right*	Hip extension left,* crunch, decline push-up, knee-up, skier, bent-knee sit-up	Sitting march right
External oblique	Pike, skier, knee-up	Hip extension right,* roll-out	Hip extension left,* decline push-up, bent-knee sit-up, crunch	Sitting march right
Internal oblique		Pike, skier, roll-out, hip extension left,* knee-up	Hip extension right,* decline push-up, crunch, bent-knee sit-up	Sitting march right
Lumbar paraspinals				Pike, roll-out, hip extension right,* hip extension left,* crunch, decline push-up, knee-up, skier, bent-knee sit-up, sitting march right
Latissimus dorsi			Pike, knee-up, skier	Roll-out, hip extension right,* hip extension left,* crunch, decline push-up, bent-knee sit-up, sitting march right
Rectus femoris			Hip extension left,* pike, knee-up, bent-knee sit-up	Skier, sitting march right, decline push-up, hip extension right,* roll-out, crunch

** During the 2 hip extension exercises (hip extension right and left), the right hip flexors (rectus femoris) exhibited moderate muscle activity when the left hip extended (hip extension left) and low muscle activity when the right hip extended (hip extension right). The right internal oblique exhibited high muscle activity during the hip extension left and moderate muscle activity during the hip extension right. The right external oblique and right lower rectus abdominis exhibited high muscle activity during the hip extension right and moderate muscle activity during the hip extension left. The right upper rectus abdominis exhibited high muscle activity during both the hip extension right and hip extension left. And the right lumbar paraspinals and right latissimus dorsi exhibited low muscle activity during both the hip extension right and hip extension left.*

Pike, Roll-out, Knee-up, and Skier Exercises

The relatively high core muscle activity during the pike, roll-out, knee-up, and skier exercises, compared to the crunch and bent-knee sit-up exercises, suggests that these exercises are good alternatives to traditional abdominal exercises for core muscle recruitment. Moreover, 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. These exercises may also achieve a greater energy expenditure compared to the traditional crunch and bent-knee sit-up because of the greater number of muscles recruited, and relatively high muscular activity, and this should be the focus of future research. In addition, tension in the latissimus dorsi and internal oblique (and presumably the transversus abdominis), which all tense the thoracolumbar fascia, may enhance core stability while performing these exercises compared to performing the crunch and bent-knee sit-up.

The pike and roll-out were the most effective Swiss ball exercises in recruiting core musculature, but these exercises also required the greatest effort and were among the most difficult to perform among the 8 exercises. From the perceived exertion ratings scale,[3] the mean (SD) perceived exertion of 14.6 (2.1) for the pike is classified as hard, which was the highest rating for all exercises. In contrast, the mean (SD) perceived exertions of 12.6 (2.2), 12.7 (1.5), and 13.3 (1.5), respectively, for the roll-out, knee-up, and skier exercises are classified as somewhat hard. Exercises such as the pike may be appropriate for highly fit individuals in the latter stages of a progressive abdominal strengthening or rehabilitation program. In choosing which abdominal exercise to use, it is important to consider the functionality of the exercises, or in the case of athletes, the sport specificity of the exercises. For example, the pike may be most appropriate for a diver who is performing the pike maneuver during the dive.

Decline Push-up and Hip Extension Exercises

The decline push-up and hip extension exercises produced similar amounts of rectus abdominis and external and internal oblique activity compared to the crunch and bent-knee sit-up, despite the primary purpose for performing the push-up being upper extremity development, and the primary purpose for hip extension exercises being hip extensor development. Several studies have reported similar or greater amounts of abdominal muscle activity when push-up exercises are performed on an unstable surface (eg, Swiss ball) compared to a flat stable surface.[15,22,23] This provides limited evidence for using a Swiss ball when performing push-up and similar type exercises when the goal is to maximize core muscle recruitment while performing these exercises. It is also noted that both the hip extension exercises and the decline push-up produced similar and relatively high amounts of latissimus dorsi activity. Therefore, hip extension exercises as performed in the current study can be effective exercises in recruiting upper and lower rectus abdominis, internal and external obliques, and latissimus dorsi, in addition to hip extensor musculature. From the perceived exertion ratings scale,[3] the mean (SD) perceived exertions of 12.9 (1.4) and 12.9 (1.8), respectively, for the decline push-up and hip extension exercises are classified as somewhat hard.

In contrast to other exercises, the hip extension exercises were performed with both the left and right lower extremities, because it was logical to expect that muscle activity would differ between sides. In the starting position of the hip extension exercises (**FIGURE 1**), there were 4 points of contact (each hand and each leg) to support the subject's weight. When the left hip was extended (**FIGURE 7**), there were only 3 points of contact to support the subject's weight, and a torque about the body's longitudinal axis was generated that must be balanced to maintain a static trunk position. This requires the force applied to the ball by the right leg to increase, which explains why right rectus femoris activity was significantly greater when performing the hip extension left exercise compared to hip extension right exercise. To better understand muscle recruitment patterns between the left and right sides of the body during prone hip extension exercises on a Swiss ball, future studies are needed to monitor the EMG from both sides of the body, as well as the forces applied at the points of contact with the ground.

Crunch and Bent-knee Sit-up Exercises

The crunch and bent-knee sit-up were both effective in recruiting abdominal musculature. Previous studies have shown higher external oblique activity during the bent-knee sit-up compared to the crunch.[2,13,14,20] In the current study, no statistically significant difference was found for the mean (SD) external oblique activity between the bent-knee sit-up (36% [14%] MVIC) and the crunch (28% [17%] MVIC). Conversely, previous studies have shown that the upper and lower rectus abdominis were more active during the crunch compared to the bent-knee sit-up.[6,13,14,17] In the current study, no statistically significant difference was found for upper and lower rectus abdominis activity between the crunch (53% [19%] and 39% [16%] MVIC, respectively) compared to the bent-knee sit-up (40% [13%] and 35% [14%] MVIC, respectively). Similar to previous studies, our data show that rectus femoris activity is statistically greater during the bent-knee sit-up compared to the crunch.[2,13,14,20]

Halpern and Bleck[17] have demonstrated that lumbar spinal flexion was only 3° during the crunch but approximately 30° during the bent-knee sit-up. In addition, the bent-knee sit-up has been shown to generate greater intradiscal pressure[30]; and lumbar compression[2] compared to exercises similar to the crunch, largely due to increased lumbar flexion and hip flexor activity. This implies that the crunch may be a safer exercise to perform than the bent-knee sit-up for individuals who need to minimize lumbar spinal flexion or compressive forces because of lumbar pathology.

From the perceived ratings scale,[3] the mean (SD) perceived exertions of 10.2 (2.2) and 10.4 (2.5), respectively, for the crunch and bent-knee sit-up are classified between very light to fairly light. This suggests that traditional abdominal exercises require lower demands of effort compared to some Swiss ball exercises, such as the pike and knee-up, but higher than other Swiss ball exercises, such as the sitting march, which exhibited a mean (SD) perceived exertion of 9.2 (2.2), which is classified as very light.

Sitting March Exercise

The sitting march was the least effective exercise in recruiting the upper and lower rectus abdominis and external and internal obliques. The sitting march was a relatively easy exercise to perform, which suggests that it may be appropriate during the early stages of abdominal strengthening or rehabilitation programs. Moreover, the sitting march may also be an alternative for individuals unable to perform higher-demand abdominal exercises, such as the pike, knee-up, and roll-out.

Prone Versus Supine Exercises

All of the Swiss ball exercises, except the sitting march right, involved maintaining a prone position with a neutral spine and pelvis. During the prone exercises, the pelvis and spine are stabilized and maintained in a neutral position throughout the movements through isometric actions from the rectus abdominis and oblique musculature, which counteract the forces of gravity to extend the trunk and rotate the pelvis. In contrast, the bent-knee sit-up and crunch activated abdominal musculature by actively flexing the trunk by concentric muscle action during the upward portion of the motion, isometric contractions during the hold portion, and eccentric muscle actions during the return to the starting position.

Clinical Applications

As core muscles contract, they help stabilize the core by compressing and stiffening the spine.[26,27] This is important, because the osteoligamentous lumbar spine buckles under compressive loads of only 90 N (approximately 20 lb), and core muscles act as guy wires around the human spine to stabilize the spine and prevent spinal buckling.[26,27] This illustrates the importance of core muscle strengthening, which has been shown to decrease injury risk and enhance performance.[2,18,29] Moreover, strong abdominal muscles help stabilize the trunk and unload the lumbar spine.[2]

For optimal core stability to occur, it

appears that numerous core muscles, including both smaller, deeper core muscles (eg, transversospinalis, such as the multifidus, as well as transversus abdominis, internal oblique, and quadratus lumborum) and larger superficial core muscles (eg, erector spinae, external oblique, rectus abdominis), must contract in sequence with appropriate timing and tension.[26,27] Cholewicki and VanVliet,[7] who investigated the relative contribution of core muscles to lumbar spine stability, reported that no single core muscle can be identified as most important for lumbar spine stability. Moreover, the relative contribution of each core muscle to lumbar spine stability depends on trunk loading direction and magnitude (spinal instability is greatest during trunk flexion, such as during the bent-knee sit-up), and no one muscle contributes more than 30% to overall spine stability.[7] Therefore, trunk stabilization exercises may be most effective when they involve the entire spinal musculature and its corresponding motor control under various spine loading conditions.[7] However, it should be emphasized that exercises that demand high core muscle activity not only enhance core stability but also generate higher spinal compressive loading,[21] which may have adverse effects in individuals with lumbar spine pathology.

Understanding biomechanical differences between exercises is important, because trunk flexion may be contraindicated in certain populations. For example, maintaining a neutral pelvis and spine (eg, decline push-up and hip extension exercises), rather than forceful flexion of the lumbar spine (eg, bent-knee sit-up), may be more desirable for individuals with lumbar disk pathologies or osteoporosis. With forceful lumbar spine flexion, intradiscal pressure can increase several times above normal intradiscal pressure from a resting supine position.[30] In contrast, individuals with facet joint pain, spondylolisthesis, and vertebral or intervertebral foramen stenosis may better benefit from exercises that incorporate some amount of trunk flexion, while minimizing trunk extension.

The role of deeper abdominal muscles (eg, transversus abdominis and internal oblique) in enhancing spinal and pelvic stabilization and increasing intra-abdominal pressure has been well studied but still remains controversial.[9,10] Some studies have suggested that the transversus abdominis is important in enhancing spinal stabilization,[19,33] but other studies have questioned the importance of this muscle as a major spinal stabilizer.[1,26,27] Isolated contractions from the transversus abdominis have not been demonstrated during functional higher-demand activities (such as those that occur during sports) that require all abdominal muscles to become active.[16] Intra-abdominal pressure has been shown to unload the spine by generating a trunk extensor moment and tensile loading to the spine.[9,10] By the trunk becoming a more solid cylinder by the intra-abdominal pressure mechanism, there is a reduction in spinal axial compression and shear loads. The attachments of the transversus abdominis and internal oblique into the thoracolumbar fascia may enhance spinal and pelvic stabilization, because when these muscles contract they tense the thoracolumbar fascia. The transversus abdominis has been shown to exhibit a similar (within 15%) muscle activation pattern and amplitude as the internal oblique during abdominal exercises performed similarly to those in the current study.[20,24] The highest activity from the internal oblique occurred during the pike, roll-out, knee-up, skier, and hip extension left, which implies that these exercises may also be effective in recruiting the transversus abdominis, although future studies are needed to test this hypothesis. Therefore, exercises such as the pike, knee-up, and roll-out may offer more effective stabilization to the spine and pelvis compared to exercises that recruit lower levels of internal oblique and transversus abdominis activity, such as the sitting march, bent-knee sit-up, and crunch.

Performing exercises that require high activity from the hip flexors and lumbar paraspinals may not be desirable for those with weak abdominal muscles or lumbar instability, because the forces generated from these muscles tend to anteriorly rotate the pelvis and may increase lordosis in the lumbar spine. In exercises performed similarly to those in the current study, psoas and iliacus EMG signals have been shown to be of similar magnitudes (within 10%) and recruitment patterns as rectus femoris activity.[24] It has also been demonstrated that the psoas muscle generates considerable spinal compression and anterior shear forces at L5-S1.[20,34] Shear force may be problematic for individuals with lumbar disk pathologies. Individuals with weak rectus abdominis and external and internal oblique musculature or lumbar instability may want to avoid the bent-knee sit-up, skier, knee-up, pike, sitting march, and hip extension exercises, due to moderate levels of hip flexor activity. In contrast, more appropriate exercises include the roll-out, decline push-up, and crunch, which all generated relatively low rectus femoris and lumbar paraspinal activities and relatively high rectus abdominis and external and internal oblique activity.

Cocontraction of the lumbar paraspinal muscles with rectus abdominis, external and internal oblique, and latissimus dorsi musculature may enhance trunk stability and spine stiffness. Although excessive activity from the lumbar paraspinals can cause high compressive and shear (especially L5-S1) forces on the lumbar spine,[20,34] the relatively low lumbar paraspinal activity in all 10 exercises ($<$10% MVIC) is likely not high enough to cause deleterious effects to the healthy or pathologic lumbar spine.

Limitations

Cross talk was minimized by using standardized electrode positions that have been tested previously.[4,31] This is especially of concern for the internal oblique, which was the only muscle tested that was not superficial. Because the internal oblique is deep to the external oblique, it is potentially susceptible to considerable

EMG cross talk from the external oblique. However, surface EMG electrodes are considered appropriate for monitoring the internal oblique when they are located within the triangle confined by the inguinal ligament, lateral border of the rectus sheath, and a line connecting the ASISs, and especially when clinical questions are being discussed and a small percentage of EMG cross talk is acceptable. In fact, when performing abdominal exercises similar to the exercises in the current study, mean internal and external oblique EMG data from surface electrodes (similarly located as in the current study) were only approximately 10% different compared to mean internal and external oblique EMG data from intramuscular electrodes.[24] McGill et al[24] have concluded that appropriately placed surface electrodes accurately reflect (within 10%) the muscle activity within the internal or external oblique muscles.

Another limitation from the current study is being able to interpret how the EMG signal is related to muscle force. The clinician should be cautious when relating the EMG amplitude with muscle force and strength during dynamic exercises, as eccentric muscle actions can result in lower activity but higher force, while concentric muscle actions can result in higher muscle activity but lower force.[20,34] Linear, quasi-linear (near linear), and nonlinear correlations have been reported in the literature between EMG amplitude and muscle force (strength) during isometric muscle actions.[20,34] Generally, the relationship between EMG amplitude and muscle force is most linear during isometric muscle actions or during activities when muscle length is not changing rapidly during concentric and eccentric muscle actions, which occurred while performing the exercises in the current study. In contrast, the relationship between EMG amplitude and muscle force is most often nonlinear during activities in which muscles change length rapidly or during muscle fatigue, which did not occur in the current study.

CONCLUSIONS

Swiss ball exercises employed in a prone position were as effective or more effective in generating core muscle activity compared to the traditional crunch and bent-knee sit-up. The roll-out and pike were the most effective exercises in activating the core muscles compared to all exercises. Lumbar paraspinal activity was relatively low for all exercises. The sitting march exercise generated the lowest core muscle activity compared to all exercises. ◉

KEY POINTS

FINDINGS: Swiss ball exercises provided a wide range of activation of the core musculature.

IMPLICATION: Our findings can be used to help guide core stability training and rehabilitation, using a variety of Swiss ball and traditional abdominal exercises.

CAUTION: The clinician should be cautious when relating the EMG amplitude with muscle force and strength during dynamic exercises.

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