Research Report

Electromyographic Analysis of Traditional and Nontraditional Abdominal Exercises: Implications for Rehabilitation and Training

Background and Purpose. Performing nontraditional abdominal exercises with devices such as abdominal straps, the Power Wheel, and the Ab Revolutionizer has been suggested as a way to activate abdominal and extraneous (nonabdominal) musculature as effectively as more traditional abdominal exercises, such as the crunch and bent-knee sit-up. The purpose of this study was to test the effectiveness of traditional and nontraditional abdominal exercises in activating abdominal and extraneous musculature. **Subjects.** Twenty-one men and women who were healthy and between 23 and 43 years of age were recruited for this study. **Methods.** Surface electromyography (EMG) was used to assess muscle activity from the upper and lower rectus abdominis, external and internal oblique, rectus femoris, latissimus dorsi, and lumbar paraspinal muscles while each exercise was performed. The EMG data were normalized to maximum voluntary muscle contractions. Differences in muscle activity were assessed by a 1-way, repeated-measures analysis of variance. **Results.** Upper and lower rectus abdominis, internal oblique, and latissimus dorsi muscle EMG activity were highest for the Power Wheel (pike, knee-up, and roll-out), hanging knee-up with straps, and reverse crunch inclined 30 degrees. External oblique muscle EMG activity was highest for the Power Wheel (pike, knee-up, and roll-out) and hanging knee-up with straps. Rectus femoris muscle EMG activity was highest for the Power Wheel (pike and knee-up), reverse crunch inclined 30 degrees, and bent-knee sit-up. Lumbar paraspinal muscle EMG activity was low and similar among exercises. **Discussion and Conclusion.** The Power Wheel (pike, knee-up, and roll-out), hanging knee-up with straps, and reverse crunch inclined 30 degrees not only were the most effective exercises in activating abdominal musculature but also were the most effective in activating extraneous musculature. The relatively high rectus femoris muscle activity obtained with the Power Wheel (pike and knee-up), reverse crunch inclined 30 degrees, and bent-knee sit-up may be problematic for some people with low back problems. [Escamilla RF, Babb E, DeWitt R, et al. Electromyographic analysis of traditional and nontraditional abdominal exercises: implications for rehabilitation and training. *Phys Ther.* 2006;86:656–671.]

Key Words: *Back pain, Crunch, Electromyography, Lumbar spine, Normalization, Oblique musculature, Rectus muscle, Sit-up.*

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Understanding how different abdominal exercises elicit muscle activity is useful to therapists and other health care or fitness specialists who develop specific abdominal exercises for their patients or clients to facilitate their rehabilitation or training needs and objectives. For example, abdominal exercises that actively flex the trunk may be problematic for some people with lumbar disk pathologies because of increased intradiskal pressure[1] and lumbar spine compression[2] as well as people with osteoporosis because of the risk of vertebral compression fractures.[3] However, some of these same individuals may be asymptomatic during abdominal exercises that resist trunk extension and maintain a relatively neutral spine and pelvis. In contrast, some people with facet joint syndrome, spondylolisthesis, and vertebral or intervertebral foramen stenosis may not tolerate exercises that extend the trunk.

Strong abdominal muscles help stabilize the trunk and unload lumbar spine stress.[2,4] Abdominal muscles commonly are activated by active flexion of the trunk through a concentric muscle contraction. Trunk flexion occurs during traditional abdominal exercises, such as abdominal curl-up (crunch) or sit-up exercises, as a person raises the head and shoulders off the floor from a supine position toward a sitting position. During the crunch exercise, the hips remain at a constant angle and the pelvis does not rotate. In contrast, during the bent-knee or extended-knee sit-up exercise, the hips flex and the pelvis rotates.[5] Bent-knee and extended-knee sit-up exercises have been shown to be effective in activating the rectus abdominis and internal and external oblique musculature.[6–8] The crunch exercise has been recommended in place of sit-up exercises because the crunch has been shown to activate abdominal musculature as effectively as the sit-up but without the relatively high hip flexor activity that occurs during the sit-up.[2,8–10]

Nontraditional abdominal exercises activate abdominal musculature in a manner different from that of traditional crunch and sit-up exercises. An example of a nontraditional exercise is performing the traditional crunch in reverse (reverse crunch), which involves flexing the trunk by posteriorly rotating the pelvis and flexing the hips. Nontraditional abdominal exercises also may involve resisting trunk extension (through an external force, such as gravity) through isometric or eccentric muscle contractions, such as maintaining a push-up position by keeping a neutral spine and pelvis.

Many nontraditional exercises also may be performed with abdominal devices. Manufacturers of these abdominal devices often claim that their devices are more effective in activating abdominal musculature than are traditional abdominal exercises. However, there are limited electromyographic (EMG) data in the scientific literature for nontraditional abdominal exercises, performed with or without devices. A limited number of studies compared selected abdominal muscle activities during nontraditional abdominal exercises performed with various commercially available abdominal strengthening devices[9,11–14]; however, to our knowledge, no studies have quantified abdominal muscle activities during exercises performed with the Power Wheel,* Ab

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All authors provided concept/idea/research design, data collection and analysis, and consultation (including review of manuscript before submission). Dr Escamilla, Mr Babb, Mr Jew, Mr Kelleher, Ms Burnham, Ms Busch, Ms D'Anna, Mr Mowbray, and Dr Imamura provided project management and subjects. Dr Escamilla provided facilities/equipment. The authors acknowledge Bobby and Jon Hinds of Lifeline International, Inc, and Ralf Leszinski of Buckhead Marketing and Distribution, LLC, for their support throughout this project. The authors affirm that they have no financial affiliation (including research funding) or involvement with any commercial organization that has a direct financial interest in any matter included in the article.

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Revolutionizer,[†] and hanging-strap devices, which also are marketed for abdominal muscle strengthening.

Many traditional or nontraditional abdominal exercises also may activate extraneous (nonabdominal) muscles, such as the hip flexor and lumbar paraspinal musculature, a result that may or may not be beneficial. For example, high activation levels from the hip flexor and lumbar paraspinal muscles tend to generate a force couple that attempts to anteriorly rotate the pelvis and increase lumbar lordosis as well as to increase L4–L5 compression; when these conditions are coupled with weak abdominal musculature, the risk of low back pathologies increases.[3] The efficacy of recruiting extraneous musculature, such as lumbar paraspinal musculature or upper- and lower-extremity musculature, currently is unknown, because, to our knowledge, no studies have reported extraneous muscle activity during nontraditional abdominal exercises.

The purpose of this study was to compare the effectiveness of traditional and nontraditional abdominal exercises in activating abdominal and extraneous musculature. Traditional exercises included the crunch and bent-knee sit-up; nontraditional exercises included 2 variations of the reverse crunch, 4 variations of exercises performed with the Ab Revolutionizer device, 3 variations of exercises performed with the Power Wheel device, and 1 hanging knee-up exercise performed with an abdominal strap device. It was hypothesized that significant differences would be found in both abdominal and extraneous muscle activity with traditional and nontraditional abdominal exercises.

Method

Subjects

To achieve the best EMG signal possible and to minimize the attenuating effects of excess body fat on the EMG signal, this study was limited to a convenience sample of 21 healthy young subjects (10 men and 11 women) who had age-related average or below-average body composition, as reported in *ACSM's Guidelines for Exercise Testing and Prescription*.[15] Baseline skin-fold calipers (model 68900[‡]) and appropriate regression equations were used to assess body composition. Mean age, mass, height, and body fat measurements are shown in Table 1. All subjects provided written informed consent in accordance with the guidelines of the Institutional Review Board at California State University, Sacramento. Subjects were excluded from the study if they had a history of abdominal or back pain or were unable to perform all exercises pain free and with proper form and technique for 12 consecutive repetitions.

Table 1.
Subject Anthropometric and Body Composition Data[a]

Sex	Age (y)	Mass (kg)	Height (cm)	Body Fat (%)
Male	29.6±5.9	82.5±11.5	178.0±6.8	12.5±2.8
Female	26.0±3.3	58.6±4.9	164.8±4.1	17.7±1.7

[a] Data are reported as mean ± standard deviation.

Exercise Descriptions

The 10 nontraditional abdominal exercises were the Ab Revolutionizer double crunch (Fig. 1A), Ab Revolutionizer oblique crunch (Fig. 1B), Ab Revolutionizer reverse crunch (Fig. 1C), Ab Revolutionizer reverse crunch with weights (Fig. 1D), hanging knee-up with straps (Fig. 2), Power Wheel pike (Fig. 3A), Power Wheel knee-up (Fig. 3B), Power Wheel roll-out (Fig. 3C), reverse crunch flat (Fig. 4A), and reverse crunch inclined 30 degrees (Fig. 4B). The 2 traditional abdominal exercises were the bent-knee sit-up (Fig. 5) and the crunch (Fig. 6). Each subject had no prior experience in performing the nontraditional abdominal exercises and moderate experience in performing the traditional abdominal exercises.

The Ab Revolutionizer exercises started and ended in the supine position with the thumbs in the ears, the hands relaxed against the head, the trunk and head resting on the floor, the hips and knees flexed approximately 90 degrees, and the body positioned within the Ab Revolutionizer device as shown in Figure 1. From this starting position, all 4 exercise variations of the Ab Revolutionizer involved posterior pelvic tilt and flattening of the lumbar spine attained through hips being flexed 125 to 135 degrees. In addition to the posterior pelvic tilt and hip flexion motions, a curl-up motion (attained by lifting the head and both scapulae off the floor) was performed simultaneously during the Ab Revolutionizer double crunch (Fig. 1A), and a left trunk rotation motion (attained by lifting the right scapula off the floor and moving the right elbow toward the left knee) was performed simultaneously during the Ab Revolutionizer oblique crunch (Fig. 1B). Posterior pelvic tilt and hip flexion were the primary motions that occurred during the Ab Revolutionizer reverse crunch (Fig. 1C) and the Ab Revolutionizer reverse crunch with weights (Fig. 1D), with the only difference between these 2 variations being a higher intensity and difficulty level when weights were used. The amount of weight used for the Ab Revolutionizer reverse crunch with weights was normalized for all subjects by determining each subject's 20-repetition maximum weight for this exercise, which was based on recommendations from the manufacturer of the Ab Revolutionizer.

[†] Ralf Leszinski, Buckhead Marketing and Distribution, LLC (Ralf@bdistribution.com).
[‡] Country Technology Inc, PO Box 87, Gays Mill, WI 54631-0087.

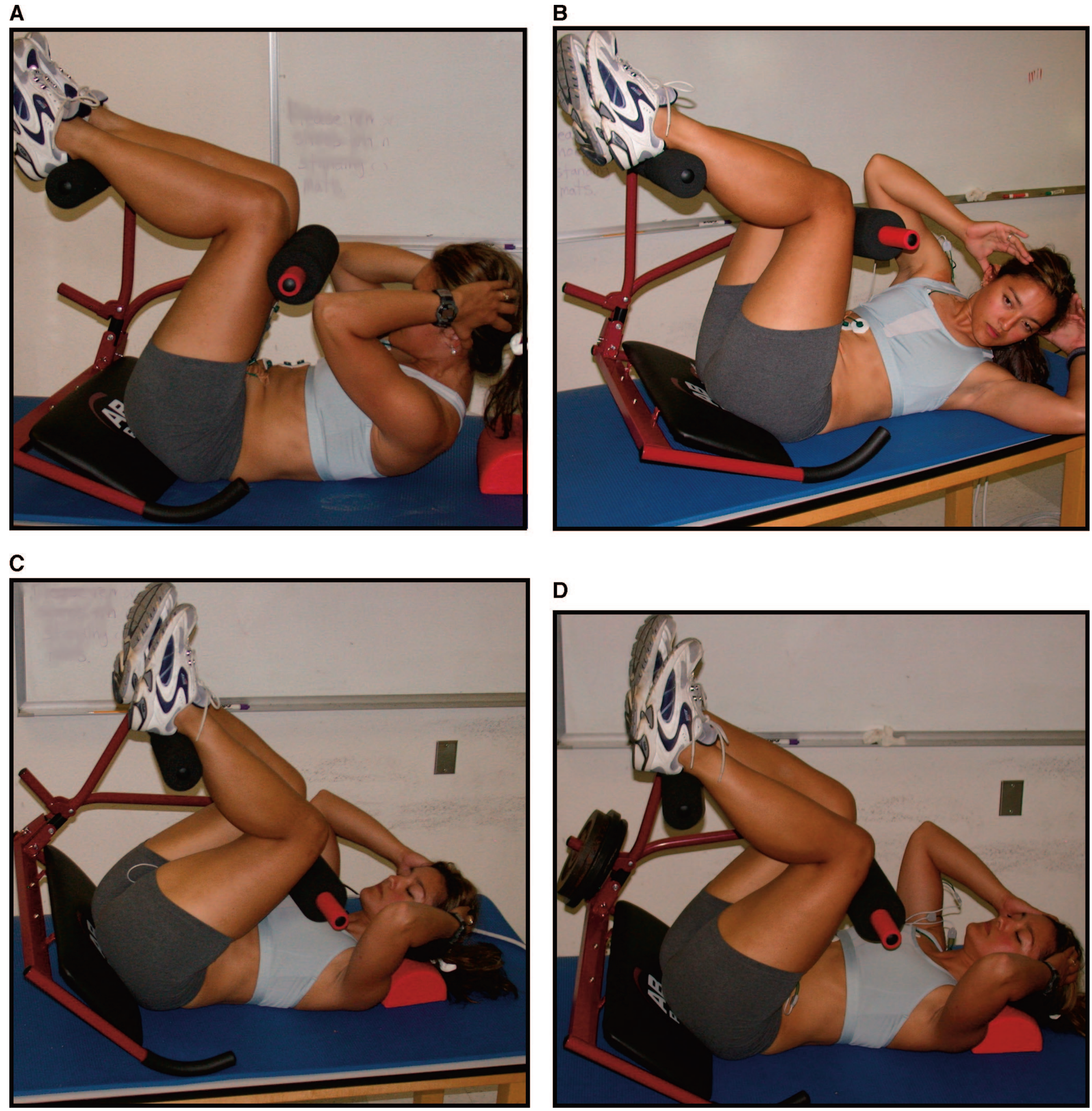

Figure 1.
Abdominal exercises. (A) Ab Revolutionizer double crunch, (B) Ab Revolutionizer oblique crunch, (C) Ab Revolutionizer reverse crunch, (D) Ab Revolutionizer reverse crunch with weights.

The hanging knee-up with straps exercise started and ended with the arms supported within the straps, the shoulders and elbows flexed approximately 90 degrees, and the body hanging in a vertical position with the trunk, hips, and knees in full extension. From this position, the subject maximally flexed the hips, resulting in 125 to 135 degrees of hip and knee flexion and a posteriorly tilted pelvis (Fig. 2). A tester maintained 1 hand on the lumbar spine throughout the movement to prevent the body from swaying back and forth.

The Power Wheel pike and power wheel knee-up exercises started and ended with the subject in the push-up position (trunk, hips, knees, and elbows in full extension, shoulders flexed 90°, and hands on the floor approximately a shoulder width apart), the feet above the floor and attached to Power Wheel straps, and the wheel in a vertical position on the floor (Figs. 3A and 3B). For the Power Wheel pike, from the starting position the wheel was rolled toward the hands as the subject performed a "body pike" by maximally flexing the hips

Figure 2.
Abdominal exercise. Hanging knee-up with straps.

(resulting in 110°–120° of hip flexion and a posteriorly tilted pelvis) while maintaining an extended-knee position (Fig. 3A). For the Power Wheel knee-up, from the starting position the wheel was rolled toward the hands as the subject maximally flexed the hips and knees (resulting in 125°–135° of hip and knee flexion and a posteriorly tilted pelvis) (Fig. 3B).

The Power Wheel roll-out exercise started and ended in the quadruped position (on hands and knees with hips and shoulders flexed approximately 90°) with a neutral spine and pelvis. From this position, the subject straightened out the body by rolling forward in a straight line while maintaining a neutral spine and pelvis (Fig. 3C).

The reverse crunch flat and reverse crunch inclined 30 degrees started and ended in the supine position on a flat surface (reverse crunch flat) or on a surface inclined 30 degrees from horizontal (reverse crunch inclined 30°), with hips and knees flexed approximately 90 degrees and the arms positioned as shown in Figure 4. From this starting position, the subject maximally flexed the hips (resulting in 125°–135° of hip and knee flexion and a posteriorly tilted pelvis) (Fig. 4).

The crunch and bent-knee sit-up exercises started and ended in a supine position with the thumbs positioned in the ears, the hands relaxed against the head, the knees flexed approximately 90 degrees, and the hips flexed approximately 45 degrees. During the crunch, the subject flexed the trunk by performing a curling-up motion until both scapulae were off the floor (Fig. 5). During the bent-knee sit-up, the feet were supported, and the subject simultaneously flexed the trunk and hips until the elbows were even with the knees (Fig. 6).

Procedure

All subjects became familiar with and practiced all abdominal exercises during a pretesting session that took place approximately 1 week before the testing session. During this time, each subject received instructional sessions explaining how to perform each of the abdominal exercises correctly (each abdominal device came with written or video instructions for its use). All exercises were performed with a 3-second cadence (1 second from start of exercise to end range, 1-second isometric hold at end range, 1 second to return to starting position) and a 1-second rest between repetitions. The subjects practiced multiple repetitions for each exercise under the supervision of trained research personnel. A metronome (set at 1 beat per second) was used to help ensure proper cadence during both the pretesting and the testing sessions. Once a subject was able to perform each exercise correctly with the proper cadence, a testing session was scheduled.

Blue Sensor disposable surface electrodes (type M-00-S[§]) were used to collect EMG data. These oval electrodes (22 mm wide and 30 mm long) were placed in a bipolar electrode configuration along the longitudinal axis of a muscle, with a center-to-center distance of approximately 3 cm between electrodes. Before the electrodes were positioned over each muscle, the skin was prepared by shaving, abrading, and cleaning with isopropyl alcohol wipes to reduce skin impedance values, which typically were <10 kΩ. Electrode pairs then were placed on the subject's right side (except for the internal oblique muscle electrode pair, which was positioned on the subject's left side because the rotational function of the internal oblique muscle is opposite that of the external oblique muscle) for the following muscles in accordance with procedures previously described[16–19]:

(1) upper rectus abdominis—positioned vertically and centered on the muscle belly (not on the tendinous intersection) near the midpoint between the umbilicus and the xiphoid process and 3 cm lateral from the midline;

(2) lower rectus abdominis—positioned 8 degrees from vertical in the inferomedial direction and centered on the muscle belly near the midpoint between the

§ Ambu Inc, 611 N Hammonds Ferry Rd, Linthicum, MD 21090-1356.

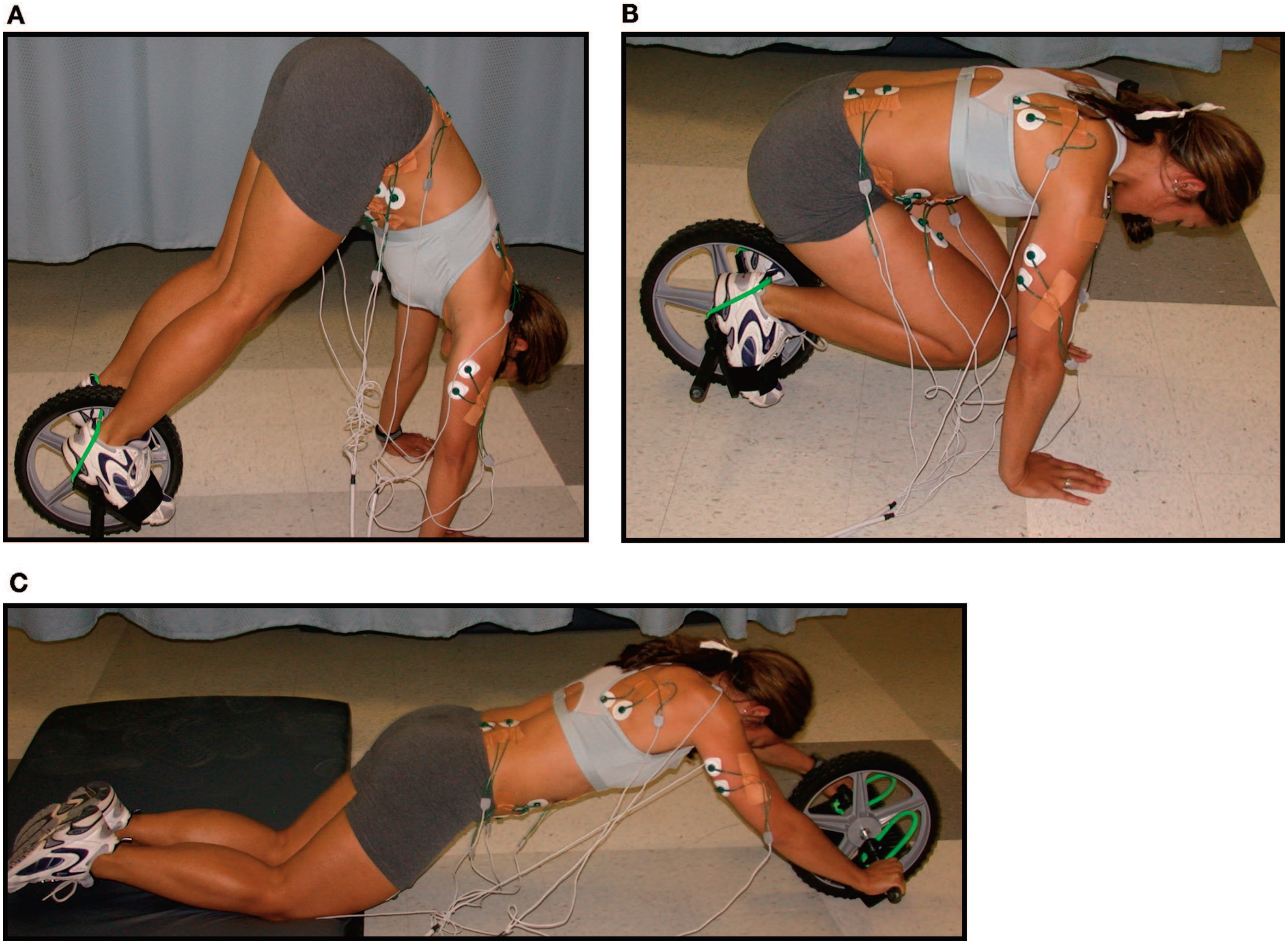

Figure 3.
Abdominal exercises. (A) Power Wheel pike, (B) Power Wheel knee-up, (C) Power Wheel roll-out.

umbilicus and the pubic symphysis and 3 cm lateral from the midline;

(3) external oblique—positioned obliquely approximately 45 degrees (parallel to a line connecting the most inferior point of the costal margin of the ribs and the contralateral pubic tubercle) above the anterior superior iliac spine (ASIS) at the level of the umbilicus;

(4) internal oblique—positioned horizontally 2 cm inferomedial to the ASIS within a triangle outlined by the inguinal ligament, the lateral border of the rectus sheath, and a line connecting the ASISs;

(5) latissimus dorsi—positioned obliquely (approximately 25° from horizontal in the inferomedial direction) 4 cm below the inferior angle of the scapula;

(6) rectus femoris—positioned vertically near the midline of the thigh, approximately halfway between the ASIS and the proximal patella; and

(7) lumbar paraspinal—positioned vertically 3 cm lateral to the spine and near the level of the iliac crest between the L3 and L4 vertebrae. A ground (reference) electrode was positioned over the skin of the right acromion. Electrode cables were connected to the electrodes and taped to 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, and then data collection commenced. The EMG data were collected by use of a Myosystem EMG unit.[||] The amplifier bandwidth frequency was 10 to 500 Hz, with an input

[||] Noraxon USA Inc, 13430 N Scottsdale Rd, Suite 104, Scottsdale, AZ 85254.

A

B

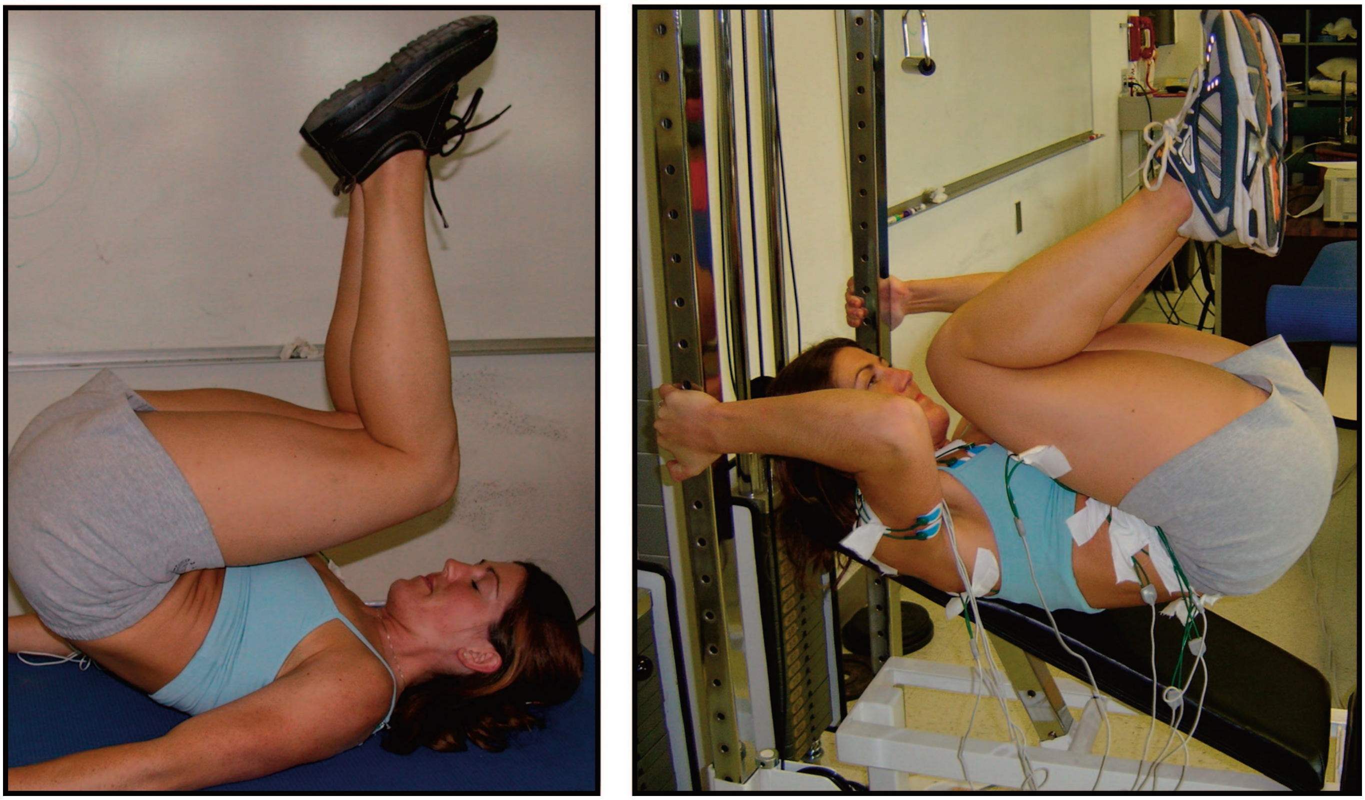

Figure 4.
Abdominal exercises. (A) Reverse crunch flat, (B) Reverse crunch inclined 30 degrees.

Figure 5.
Abdominal exercise. Bent-knee sit-up.

voltage of 12 V (direct current) at 1.5 A. The input impedance of the amplifier was 20,000 kΩ, and the common-mode rejection ratio was 130 dB. The EMG data were sampled at 1,000 Hz, and the recorded signals were processed through an analog-to-digital converter by use of a 16-bit analog-to-digital board.

The EMG data were collected during 5 repetitions of each exercise, with all exercises being performed in a randomized order. Each repetition was performed in a slow and controlled manner with the 3-second cadence previously described and a 1-second rest between repetitions. With the relatively small number of repetitions performed, all subjects acknowledged that fatigue was minimal. A testing session took 30 to 45 minutes to complete.

Randomly interspersed within the exercise testing session, EMG data from each muscle tested were collected during two 5-second maximum voluntary

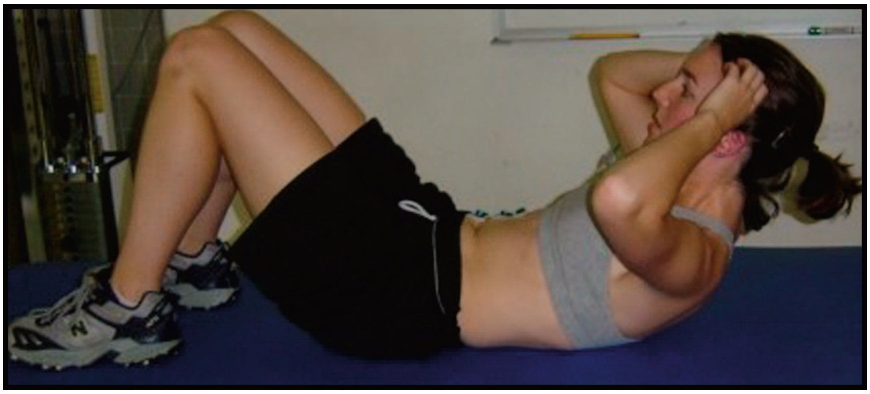

Figure 6.
Abdominal exercise. Crunch.

isometric contractions (MVICs). After conducting pilot work, we adopted for MVIC testing the following protocols, which were based on the positions that elicited the highest MVIC for each respective muscle (all MVICs were collected on a plinth with the subject in a prone, supine, or short sitting position):

(1) upper and lower rectus abdominis—body supine with hips and knees flexed 90 degrees, feet supported, and trunk maximally flexed (ie, curl-up position), with resistance at the shoulders in the trunk extension direction;

(2) external and internal oblique—body supine with hips and knees flexed 90 degrees, feet supported, and trunk maximally flexed and rotated to the left, with resistance at the shoulders in the trunk extension and right rotation directions;

(3) latissimus dorsi—body prone with right shoulder abducted 0 degrees and extended maximally, with resistance at the right distal arm in the direction of shoulder flexion;

(4) lumbar paraspinal—body prone with trunk fully extended and hands clasped behind head, with resistance at the shoulders in the direction of trunk flexion; and

(5) rectus femoris—body in short sitting position with hips and knees flexed 90 degrees, with resistance at the distal leg in the knee flexion direction.

The MVICs were collected to normalize the EMG data from the abdominal exercises in order for the activity of a muscle during exercise to be compared with the activity of that same muscle during MVIC. Subjects were given similar verbal encouragements for each of the MVICs to help ensure a maximum effort throughout the 5-second duration, and the subjects was asked after each MVIC if they thought it required maximum effort. If not, the MVIC was repeated. Approximately 1 minute of rest was given between the MVICs, and approximately 2 minutes of rest were given between the exercise trials.

Data Processing

Raw EMG signals were full-wave rectified, smoothed with a 10-millisecond moving average window, and then averaged over the entire duration of each exercise repetition or MVIC performed. For each repetition, the EMG data were normalized for each muscle and expressed as a percentage of the EMG data for a subject's highest corresponding MVIC trial, determined by calculating throughout the 5-second MVIC the highest average EMG signal over a 1-second interval. Normalized EMG data then were averaged over the 5 repetition trials performed for each exercise and used in statistical analyses.

Data Analysis

A 1-factor, repeated-measures analysis of variance was used to assess differences in normalized EMG muscle activity among the different exercise variations, and *post hoc* analyses were performed with the Bonferroni test to evaluate the significance of between-exercise pair-wise comparisons. The significance level was set at $P<.01$.

Results

Normalized EMG data for each muscle and exercise are shown in Table 2. Among all exercises tested, upper rectus abdominis muscle EMG activity was highest for the Power Wheel roll-out, hanging knee-up with straps, and reverse crunch inclined 30 degrees and lowest for the Ab Revolutionizer reverse crunch. Lower rectus abdominis muscle EMG activity was highest for the Power Wheel roll-out and hanging knee-up with straps and lowest for the Ab Revolutionizer reverse crunch. Graphical representations of upper and lower rectus abdominis muscle activity ranked from highest to lowest among all exercises are shown in Figures 7 and 8.

External oblique muscle EMG activity was highest for the Power Wheel pike, Power Wheel knee-up, and hanging knee-up with straps and lowest for the crunch. Internal oblique EMG activity was highest for the Power Wheel roll-out, Power Wheel pike, Power Wheel knee-up, hanging knee-up with straps, and reverse crunch inclined 30 degrees and lowest for the 7 remaining exercises. Graphical representations of external and internal oblique muscle activity ranked from highest to lowest among all exercises are shown in Figures 9 and 10.

Table 2.
Electromyographic (EMG) Activity for Each Muscle and Exercise Expressed as a Percentage of the Maximum Isometric Voluntary Contraction

	Muscle						
Exercise	**Upper Rectus Abdominis***	**Lower Rectus Abdominis***	**External Obliques***	**Internal Obliques***	**Latissimus Dorsi***	**Lumbar Paraspinals***	**Rectus Femoris***
Power Wheel roll-out	76±26	81±29	64±27[b]	66±25	15±7[b,c,f]	5±2[b,c,d,e]	6±4[b,c,d,e,h,i]
Power Wheel pike	41±11[a,d,e,g]	53±16[a,d]	96±32	83±31	27±16	8±3	26±11[c]
Power Wheel knee-up	41±18[a,d,e,g]	45±12[a,d]	80±30	72±32	25±12	8±4	43±18
Hanging knee-up with straps	69±21	75±16	79±25	85±40	21±12	7±3	15±8[b,c]
Reverse crunch inclined 30°	77±27	53±13[a,d]	50±19[b,c,d]	86±37	14±8[b,c,f]	8±4	22±12[c]
Reverse crunch flat	41±20[a,d,e,g]	30±13[a,b,c,d,e,g]	39±16[a,b,c,d]	52±24[b,c,d,e]	23±14	6±3[b,c,e]	11±5[b,c,e,h]
Crunch	56±17[a,e]	48±13[a,d]	27±16[a,b,c,d,e,h,i,k]	42±10[b,c,d,e]	5±3[a,b,c,d,e,f]	3±1[b,c,d,e,f,h,i]	3±3[b,c,d,e,h,i]
Bent-knee sit-up	39±9[a,d,e,g]	38±11[a,b,d,e]	50±16[b,c,d]	49±22[b,c,d,e]	6±3[a,b,c,d,f]	6±3[b,c,e]	22±12[c]
Ab Revolutionizer reverse crunch with weights	44±18[a,d,e]	40±17[a,b,d,e]	55±24[b,c,d]	51±22[b,c,d,e]	4±2[a,b,c,d,e,f]	6±3[b,c,e]	16±13[b,c]
Ab Revolutionizer double crunch	53±17[a,e]	40±16[a,b,d,e]	34±18[a,b,c,d,i]	51±25[b,c,d,e]	4±2[a,b,c,d,e,f]	4±2[b,c,d,e,f,h,i]	7±6[b,c,d,e,h,i]
Ab Revolutionizer oblique crunch	49±14[a,d,e]	39±12[a,b,d,e]	49±20[b,c,d]	48±25[b,c,d,e]	7±3[a,b,c,d,f]	4±2[b,c,d,e,f,h,i]	5±5[b,c,d,e,h,i]
Ab Revolutionizer reverse crunch	30±13[a,d,e,g,i,j,k]	24±10[a,b,c,d,e,g,h,i,j,k]	38±16[a,b,c,d]	33±19[b,c,d,e]	3±2[a,b,c,d,e,f]	4±2[b,c,d,e,f,h,i]	6±5[b,c,d,e,h,i]

* There was a significant difference ($P<.001$) in EMG activity among the abdominal exercises.

Pair-wise comparisons ($P<.01$):
[a] Significantly less EMG activity than obtained with the Power Wheel roll-out.
[b] Significantly less EMG activity than obtained with the Power Wheel pike.
[c] Significantly less EMG activity than obtained with the Power Wheel knee-up.
[d] Significantly less EMG activity than obtained with the hanging knee-up with straps.
[e] Significantly less EMG activity than obtained with the reverse crunch inclined 30 degrees.
[f] Significantly less EMG activity than obtained with the reverse crunch flat.
[g] Significantly less EMG activity than obtained with the crunch.
[h] Significantly less EMG activity than obtained with the bent-knee sit-up.
[i] Significantly less EMG activity than obtained with the Ab Revolutionizer reverse crunch with weights.
[j] Significantly less EMG activity than obtained with the Ab Revolutionizer double crunch.
[k] Significantly less EMG activity than obtained with the Ab Revolutionizer oblique crunch.
[l] Significantly less EMG activity than obtained with the Ab Revolutionizer reverse crunch.

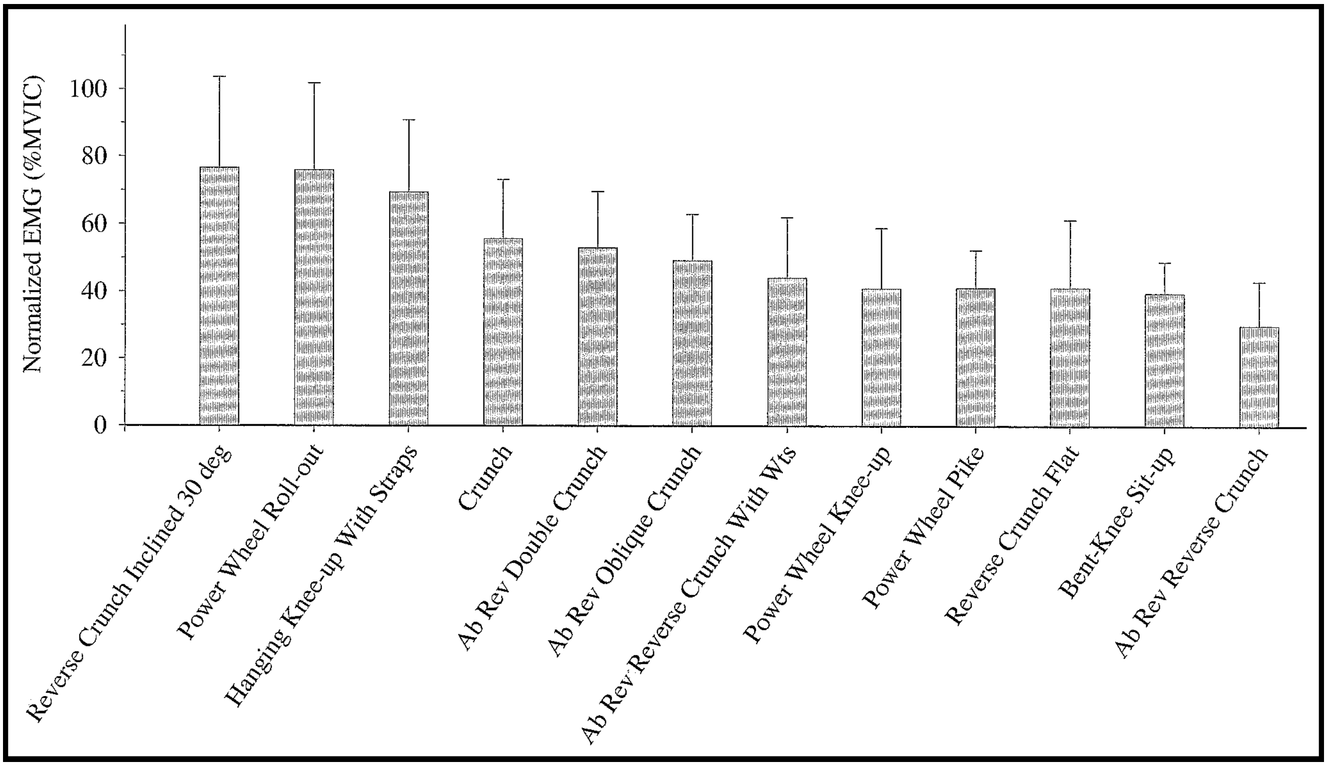

Figure 7.
Upper rectus abdominis muscle normalized electromyographic (EMG) activity (mean ± SD) among exercises. MVIC=maximum voluntary isometric contraction, deg=degrees, Ab Rev=Ab Revolutionizer, Wts=weights.

Latissimus dorsi muscle EMG activity was highest for the Power Wheel pike, Power Wheel knee-up, hanging knee-up with straps, and reverse crunch flat and lowest for the crunch, Ab Revolutionizer double crunch, Ab Revolutionizer reverse crunch, and Ab Revolutionizer reverse crunch with weights. Lumbar paraspinal muscle EMG activity was highest for the Power Wheel pike, Power Wheel knee-up, hanging knee-up with straps, and reverse crunch inclined 30 degrees and lowest for the crunch, Ab Revolutionizer double crunch, Ab Revolutionizer reverse crunch, and Ab Revolutionizer oblique crunch. Rectus femoris muscle EMG activity was highest for the Power Wheel knee-up and lowest for the Power Wheel roll-out, crunch, Ab Revolutionizer double crunch, Ab Revolutionizer reverse crunch, and Ab Revolutionizer oblique crunch.

Discussion

Biomechanical Differences Between Trunk Flexion and Extension Exercises

Understanding biomechanical differences between exercises is important because trunk flexion, like that used in traditional exercises, such as the crunch or bent-knee sit-up, may be a contraindication or precaution in certain populations (eg, those with lumbar disk pathologies or osteoporosis). In such individuals, it may be more beneficial to maintain a neutral pelvis and spine, like that used in the Power Wheel roll-out, than to use forceful flexion of the lumbar spine, like that used in the bent-knee sit-up. In contrast, some people with facet joint pain, spondylolisthesis, and vertebral or intervertebral foramen stenosis may not benefit from exercises that maintain the spine and pelvis in a neutral or extended position, because these exercises may contribute to spinal cord or nerve root compression. However, trunk flexion exercises, such as the crunch or reverse crunch, may decrease facet joint pain and increase vertebral or intervertebral foraminal openings, decreasing the risk of spinal cord or nerve root impingement.

Although the Power Wheel roll-out and hanging knee-up with straps were both effective in activating abdominal musculature, these 2 exercises were performed in different manners. During the roll-out portion of the Power Wheel roll-out exercise, the abdominal musculature contracts eccentrically or isometrically to resist the attempt of gravity to extend the trunk and rotate the pelvis. During the return motion, the abdominal musculature contracts concentrically or isometrically. If the pelvis and spine are stabilized and maintained in a neutral position throughout the roll-out and return movements, then the abdominal musculature contracts primarily isometrically. While subjects were performing the roll-out exercise, a relatively neutral pelvis and spine were maintained throughout the move-

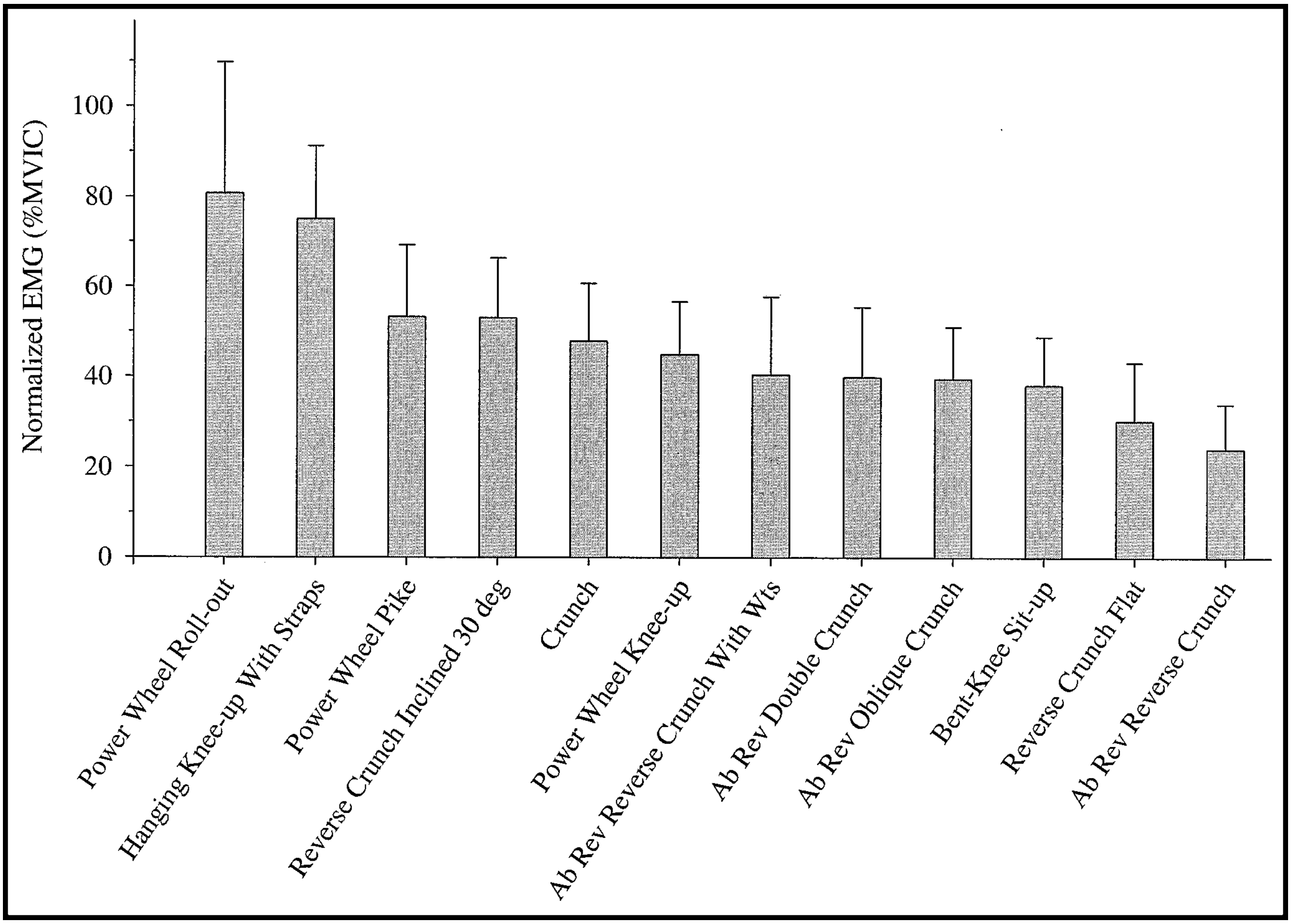

Figure 8.
Lower rectus abdominis muscle normalized electromyographic (EMG) activity (mean ± SD) among exercises. MVIC=maximum voluntary isometric contraction, deg=degrees, Ab Rev=Ab Revolutionizer, Wts=weights.

ments. In contrast, during the hanging knee-up exercise with straps, the abdominal musculature contracts concentrically initially as the hips flex, the pelvis rotates posteriorly, and the lumbar spine is flattened and moves toward lumbar flexion. As the knees are lowered and the hips are extended, the reverse movements occur, and the abdominal musculature contracts eccentrically to control the rate of return to the starting position.

The hanging knee-up with straps exercise and the Power Wheel pike and Power Wheel knee-up exercises all were performed similarly by flexing the hips, posteriorly rotating the pelvis, and flattening the lumbar spine—basically the reverse of what occurs during the crunch and bent-knee sit-up exercises, which involve trunk flexion followed by hip flexion (bent-knee sit-up only). One limitation to the hanging knee-up with straps exercise is the occurrence of relatively high L4–L5 disk compression.[2] However, L4–L5 disk compression has been shown to be slightly higher in the bent-knee sit-up exercise than in the hanging knee-up with straps exercise.[2] Furthermore, in the present study, EMG values from the upper and lower rectus abdominis and internal and external oblique muscles all were significantly higher in the hanging knee-up with straps exercise than in the bent-knee sit-up exercise. Therefore, the hanging knee-up with straps exercise may be preferred over the bent-knee sit-up exercise for more fit individuals who want to elicit a high-level challenge to the abdominal musculature. Neither exercise, however, may be appropriate for some people with low back pathologies because of the relatively high L4–L5 compression.

In general, all exercise variations of the Ab Revolutionizer device produced abdominal muscle activity similar to that produced by the crunch, bent-knee sit-up, and reverse crunch flat exercises. Therefore, purchasing this abdominal device does not appear to offer any advantage in recruiting abdominal musculature over performing traditional exercises that require no additional equipment, such as the crunch, bent-knee sit-up, and reverse crunch flat exercises. However, one advantage of the Ab Revolutionizer device is that external weight can be added, thereby allowing exercise intensity to be varied. The reverse crunch flat and Ab Revolutionizer reverse crunch exercises were performed nearly identi-

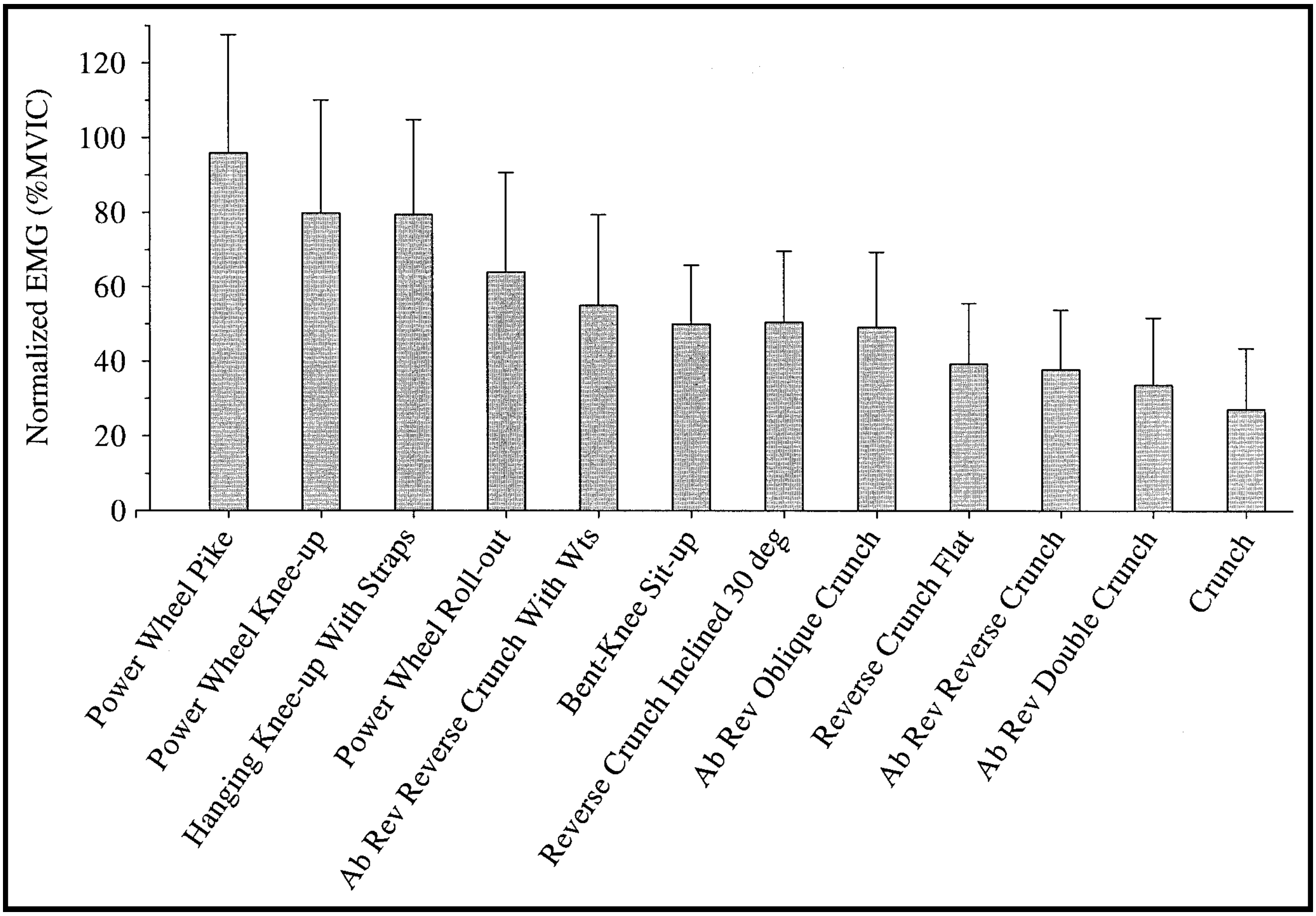

Figure 9.
External oblique muscle normalized electromyographic (EMG) activity (mean ± SD) among exercises. MVIC=maximum voluntary isometric contraction, deg=degrees, Ab Rev=Ab Revolutionizer, Wts=weights.

cally, with the only difference being that the reverse crunch flat exercise was performed without the use of an abdominal device.

Biomechanical Differences Between Crunch and Bent-Knee Sit-up Exercises

Not all abdominal exercises involve the same degree of flexion of the lumbar spine. Halpern and Bleck[7] demonstrated that lumbar spinal flexion was only 3 degrees during the crunch exercise but was approximately 30 degrees during the bent-knee sit-up exercise. In addition, the bent-knee sit-up exercise has been shown to generate greater lumbar intradiskal pressure[1,20] and compression[2] than have exercises similar to the crunch exercise, largely because of increased lumbar flexion and muscle activity from the rectus femoris and psoas muscles.[8,10] These findings suggest that the crunch exercise may be a safer exercise to perform than the bent-knee sit-up exercise for some people who need to minimize lumbar spinal flexion or compressive forces because of lumbar pathologies.[2]

Although both the crunch and the bent-knee sit-up exercises were effective in recruiting abdominal musculature, there were some differences. Several studies, including the present study, have shown that external oblique muscle activity and, to a lesser extent, internal oblique muscle activity are significantly greater in the bent-knee sit-up exercise than in the crunch exercise.[2,8,21,22] However, upper and lower rectus abdominis muscle activity have been shown to be greater in the crunch exercise than in the bent-knee sit-up exercise.[7,9] In addition, rectus femoris and psoas muscle activity have been shown to be greater in the bent-knee sit-up exercise than in the crunch exercise,[8,10] findings that are consistent with the rectus femoris muscle EMG data from the present study. Increased muscle activity from the rectus femoris and psoas muscles may exacerbate low back pain in some people with low back pathologies.

Abdominal and Oblique Muscle Recruitment in Crunch and Reverse Crunch Exercises

There are beliefs that performing reverse crunch exercises activates the lower abdominal muscles to a greater

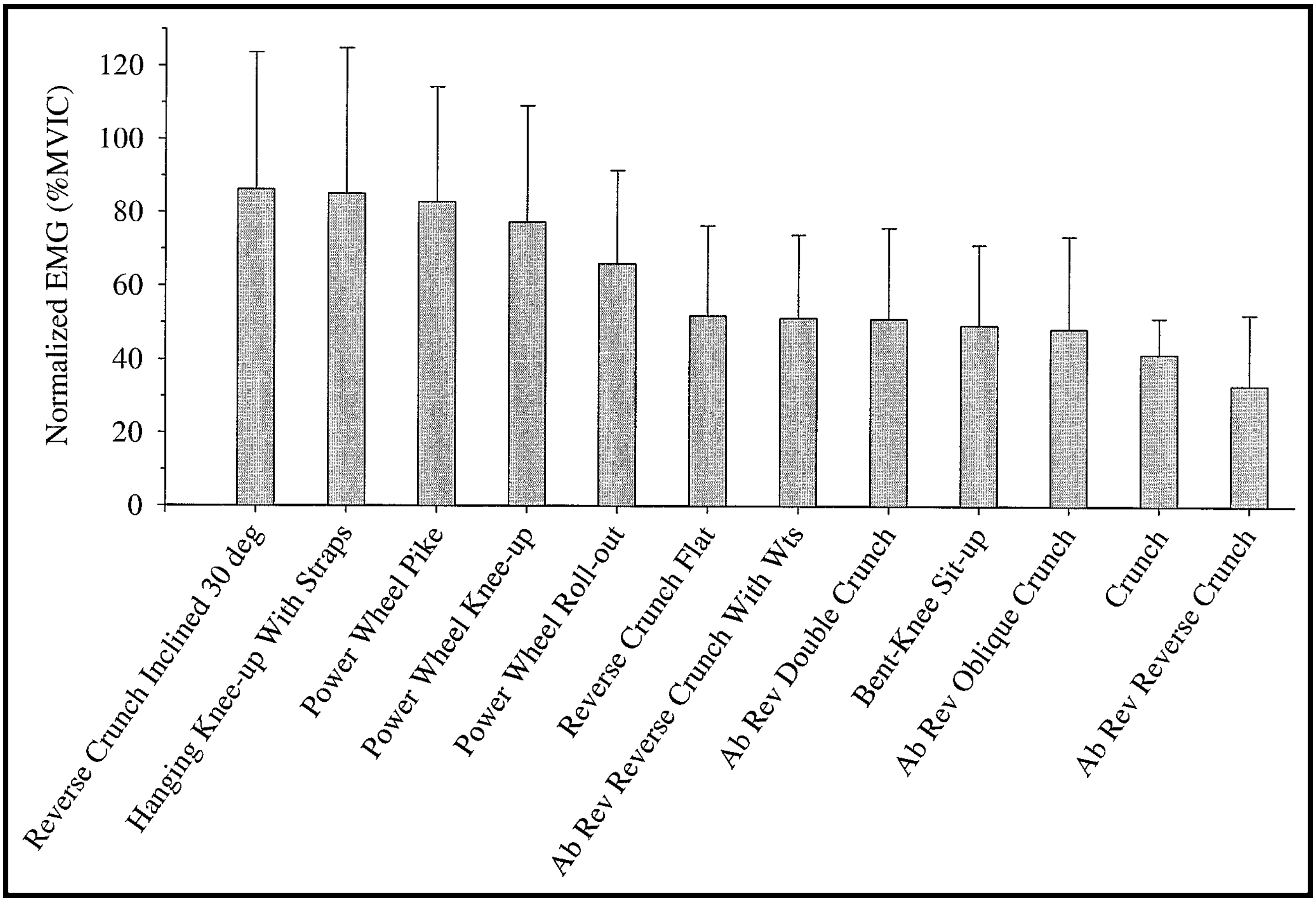

Figure 10.
Internal oblique muscle normalized electromyographic (EMG) activity (mean ± SD) among exercises. MVIC=maximum voluntary isometric contraction, deg=degrees, Ab Rev=Ab Revolutionizer, Wts=weights.

extent than does performing crunch exercises and that performing crunch exercises activates the upper abdominal muscles to a greater extent than does performing reverse crunch exercises, but the results from the present study do not substantiate these beliefs. In a comparison of the crunch and reverse crunch flat exercises, both upper and lower rectus abdominis muscle EMG activity were significantly greater during the crunch, whereas the external and internal oblique muscle EMG activity were not significantly different between the 2 exercises. Our data are similar to the findings reported by Clark et al[11] but different from the abdominal muscle EMG data reported by Willett et al,[23] who found greater lower rectus abdominis and external oblique muscle activity with the reverse crunch exercise than with the crunch exercise. These discrepancies may have been attributable to methodological differences among the studies. For example, in the study of Willett et al,[23] the reverse crunch exercise was performed by having subjects raise the lower half of the body off the table as far as possible, whereas in the present study, subjects were instructed to maximally posteriorly tilt the pelvis and flex the hips. However, significantly greater upper rectus abdominis, internal oblique, and external oblique muscle activity was seen when the reverse crunch inclined 30 degrees was performed rather than the crunch exercise, but the lower rectus abdominis muscle activity was not significantly different between the 2 exercises.

Role of Abdominal Muscles in Trunk Stability

The role of the abdominal muscles, especially the transverse abdominal and internal oblique muscles, in enhancing spinal and pelvic stabilization and increasing intra-abdominal pressure is well known.[24–28] Intra-abdominal pressure unloads the spine by generating a trunk extensor moment and tensile loading to the spine and reduces spinal axial compression and shear loads.[29] The attachments of the transverse abdominal and internal oblique muscles to the thoracolumbar fascia further enhance spinal and pelvic stabilization, because when these muscles contract, they tense the thoracolumbar fascia. The transverse abdominal muscle, which is the deepest of the abdominal muscles, exhibits a muscle activation pattern and an amplitude similar (within 15%) to those of the internal oblique muscle during many of the same trunk flexion movements as those used in the present study.[8,18] The highest EMG activity from the internal oblique muscle was obtained with the following exercises: the Power Wheel roll-out, Power Wheel pike, Power Wheel knee-up, hanging knee-up with straps, and reverse crunch inclined 30 degrees; these data suggest that these exercises also may offer more effective stabilization to the spine and pelvis than may other exercises used in the present study, assuming that transverse abdominal muscle activity is similar to internal oblique muscle activity during these exercises.

Exercise Intensity

The exercises used in the present study provide a continuum of lower- to higher-intensity exercises through which patients or clients can progress within a training or rehabilitation program. Exercises involving the Ab Revolutionizer and abdominal crunch typically were easier for the subjects to perform than were exercises involving the hanging knee-ups with straps, Power Wheel pike and knee-up, and reverse crunch inclined 30 degrees. However, because external weights could be added to the Ab Revolutionizer, this exercise could be used to allow a person to progress from lower- to higher-intensity exercises. The subjects participating in the present study were all relatively young, active people who were all able to perform both easier and more difficult abdominal exercises. However, older, less active, or weaker people or people with trunk pathologies may not be able to perform the more difficult exercises used in the present study correctly. These higher-intensity exercises may be reserved for more fit patients and clients, such as athletes who are involved in rehabilitation and whose desire is to return to playing sports.

Extraneous (Nonabdominal) Muscle Activity

To our knowledge, no studies have reported extraneous muscle activity for any of the exercises used in the present study, except for the traditional crunch and bent-knee sit-up exercises, for which rectus femoris and psoas muscle activity have been reported.[8,10,18] To our knowledge, no studies have reported latissimus dorsi or lumbar paraspinal muscle activity for any of the exercises used in the present study. Interestingly, the Power Wheel roll-out, Power Wheel pike, Power Wheel knee-up, hanging knee-up with straps, and reverse crunch inclined 30 degrees exercises not only were the most effective exercises in activating abdominal musculature but also were the most effective exercises in activating the latissimus dorsi muscle. However, all of these exercises, except for the Power Wheel roll-out, also exhibited relatively high rectus femoris and lumbar paraspinal muscle activity compared with the other exercises, a finding that may be problematic for some people with low back pathologies. Therefore, the Power Wheel roll-out may be the most effective exercise in recruiting abdominal and latissimus dorsi musculature while minimizing rectus femoris and lumbar paraspinal muscle activity.

During the Power Wheel roll-out exercise, the latissimus dorsi muscle contracts eccentrically during the initial roll-out phase to control the rate of shoulder flexion attributable to gravity and concentrically in the return phase as the shoulder extends. Although the rectus femoris muscle appears to contract eccentrically during the initial roll-out phase (to control the rate of hip extension) and concentrically during the return phase to aid in hip flexion, we did not expect to find very low rectus femoris muscle activity during the Power Wheel roll-out exercise. Although the psoas muscle EMG magnitudes were not measured in the present study because it is a deep muscle, it has been demonstrated that during exercises performed in a position and manner similar to those of the Power Wheel roll-out exercise, psoas muscle EMG magnitudes are low and typically are within approximately 10% of rectus femoris muscle EMG magnitudes.[8,18] From these data, it can be hypothesized that both psoas and rectus femoris muscle activity is relatively low during the Power Wheel roll-out exercise and that the latissimus dorsi muscle may have a greater role than the rectus femoris and psoas muscles in controlling and causing exercise movements during the Power Wheel roll-out exercise.

Because of the effectiveness of the Power Wheel roll-out, Power Wheel pike, Power Wheel knee-up, hanging knee-up with straps, and reverse crunch inclined 30 degrees exercises in recruiting abdominal and extraneous musculature, these exercises may be beneficial for some people who have limited workout time and whose goal is to perform exercises that provide not only an abdominal workout but also more of a total-body workout. The greater relative intensity and number of muscles used during these exercises suggest that these exercises also may achieve a greater energy expenditure than may other exercises used in the present study. Moreover, tension in the latissimus dorsi muscle in addition to the internal oblique muscle (and presumably the transverse abdominal muscle), each of which tenses the thoracolumbar fascia, may enhance trunk stabilization during these exercises.

Performing exercises that recruit the rectus femoris and lumbar paraspinal muscles may not be advantageous for those with weak abdominal muscles or lumbar instability, because the forces generated when these muscles contract act to anteriorly rotate the pelvis and increase the lordotic curve of the lumbar spine. Some people with weak abdominal muscles or lumbar instability may want to avoid the bent-knee sit-up, Power Wheel pike, Power Wheel knee-up, and reverse crunch inclined 30 degrees exercises because of the relatively high rectus femoris and lumbar paraspinal muscle activity obtained with these exercises compared with other exercises. In addition, exercises performed in a manner similar to that of the aforementioned exercises exhibited psoas and iliacus muscle EMG magnitudes and recruitment patterns similar to the EMG magnitudes and recruitment patterns of the rectus femoris muscle.[18,21,22]

These data suggest that the 3 primary hip flexors—the psoas, iliacus, and rectus femoris muscles—may exhibit similar EMG recruitment patterns and magnitudes when the exercises used in the present study are performed. The psoas muscle, through its attachments to the lumbar spine, attempts to hyperextend the spine as it helps flex the hip, and this action may be detrimental to some people with lumbar instability. In addition, it has been demonstrated that the psoas muscle can generate lumbar compression and anterior shear force at L5–S1[8,30]; these effects may be problematic for some people with lumbar disk pathologies. Although muscle force from the lumbar paraspinal muscle also can increase the compression of the lumbar spine, it should be noted that all exercises used in the present study generated relatively low muscle activity (<10% of an MVIC) from the lumbar paraspinal muscle.

Effects of Electrode Placement on EMG Cross Talk

The electrode positions used in the present study have been shown to minimize EMG cross talk from other muscles.[15,17,19] This is especially true for the internal oblique muscle, the only muscle tested that was not a superficial muscle. The internal oblique muscle normally lies deep in relation to the external oblique muscle and therefore is susceptible to considerable EMG cross talk from this muscle. However, it has been shown that the internal oblique muscle is covered only by the aponeurosis of the external oblique muscle and not the external oblique muscle, within the triangle outlined by the inguinal ligament, the lateral border of the rectus sheath, and a line connecting the ASISs.[19] Therefore, surface electrodes appear to be appropriate for use with the internal oblique muscle when electrode placement is within this area, especially when clinical questions are being considered and when a small percentage of EMG cross talk is acceptable. It was shown that for trunk flexion exercises similar to the exercises performed in the present study, mean internal and external oblique muscle EMG data obtained from surface electrodes were only approximately 10% different from mean internal and external oblique EMG data obtained from intramuscular electrodes.[18] These authors demonstrated that appropriately placed surface electrodes accurately reflect (within 10%) the muscle activity within the internal or external oblique muscle.

Correlation Between EMG Amplitude and Muscle Force

Linear, quasi-linear (nearly linear), and nonlinear correlations have been reported for EMG amplitude and muscle force (strength) in the literature.[31,32] In general, the relationship between EMG amplitude and muscle force is most linear during isometric contractions or during activities in which muscle length is not changing rapidly, which is what occurred with the exercises used in the present study. In contrast, the relationship between EMG amplitude and muscle force is most nonlinear during activities in which muscles change length rapidly or during muscle fatigue. Therefore, the clinician should be cautious when relating EMG amplitude to muscle force and strength during dynamic exercises.

Conclusion

The exercises used in the present study activated abdominal muscles by flexing the trunk (crunch and bent-knee sit-up), by flexing the hips with posterior pelvis rotation (Power Wheel pike, Power Wheel knee-up, hanging knee-up with straps, reverse crunch inclined 30 degrees, reverse crunch flat, Ab Revolutionizer reverse crunch with weights, and Ab Revolutionizer reverse crunch), by a combination of flexing the trunk and flexing the hips with posterior pelvis rotation (Ab Revolutionizer double crunch and Ab Revolutionizer oblique crunch), and by resisting trunk extension (Power Wheel roll-out). The Power Wheel roll-out exercise was the most effective exercise in activating abdominal and latissimus dorsi muscles while minimizing lumbar paraspinal and rectus femoris muscle activity. The Power Wheel roll-out, Power Wheel pike, Power Wheel knee-up, hanging knee-up with straps, and reverse crunch inclined 30 degrees exercises were the most effective exercises in recruiting both abdominal musculature and extraneous musculature. Although both the bent-knee sit-up and the crunch involved similar amounts of abdominal muscle activity, the crunch may be a safer exercise for people with low back pathologies because of the relatively high rectus femoris muscle activity. Moreover, the bent-knee sit-up, Power Wheel pike, Power Wheel knee-up, and reverse crunch inclined 30 degrees exercises may be problematic exercises for people with low back pathologies because of the relatively high rectus femoris and lumbar paraspinal muscle activity.

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