COMPARISON OF MUSCLE FUNCTIONS DURING THREE CONTRASTING ABDOMINAL EXERCISES\textsuperscript{1, 2}

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Summary.—That different amplitudes of muscle activities during various abdominal exercises not only reflect the inherent differences in motor control but movement speed as well was hypothesized. 20 healthy adults (M age = 23 yr.) performed three exercises that involved varying amounts of trunk control: the partial sit-up, full sit-up, and AbSlide roll. Covariate analyses indicated that the amplitude of muscle activities could be partitioned into three categories: motor control and scaling (speed and amplitude), scaling only, and motor control only. Overall, the AbSlide exercise activated the most amount of muscular activity, followed by the full and partial sit-up exercises. Results are discussed in terms of how the various muscles contribute to motor control and velocity scaling.

Many styles of abdominal exercise movements can be performed to strengthen one’s midsection. Movements considered to be easy are those executed with partial lifting of the trunk with the hands on the thighs and the feet anchored (Safrit, Zhu, Costa, & Zhang, 1992). The more difficult ones involve sitting up into vertical with the hands held behind the head and the lower extremities extended and unsupported during the movement (Cordo, Gurfinkel, Smith, Hodges, Verschueren, & Brumagne, 2003). Despite some obvious differences among various sets of abdominal exercises, previous studies have not considered the inherent differences in movement pattern and speed when comparing relative muscular effort. Variations in movement patterns are not only due to the different available organizational solutions (Latash, Latash, & Meijer, 2000). Changes in muscle activation patterns cannot be easily predicted from simple stretches or loadings (Horak & Moore, 1993). That there are two major components which delineate differences in muscle activation was hypothesized. The first is differences in motor control or coordination, the organization of the temporal and spatial components of the various body segments to accomplish the movement (Jensen, Phillips, & Clark, 1994). The second is differences in the kinematics of the tasks. Muscle activities may be adjusted through amplitude scaling to match task kinematics (Horak, Frank, & Nutt, 1996; Cordo, Hodges, Smith, Bru-

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magne, & Gurfinkel, 2006). That is, a muscle may show greater activity in one task than another given differences in movement speed or amplitude of displacement. By analyzing the location of task differences, the mechanism underlying the dissimilarities in muscle activities among different types of abdominal exercises can be better understood. Three contrasting abdominal exercise movements requiring varying amounts of trunk control were analyzed: the partial sit-up (a.k.a. crunch, curl, curl-up), full sit-up, and the AbSlide exercise (Fig. 1 below).

Since the full sit-up and AbSlide exercises move the trunk at greater horizontal and vertical distances than the partial sit-up, the former two conditions must be performed at a higher speed to execute each cycle or repetition of the movement at the same unit time as the partial sit-up. Speed of performance has been suggested to be as important as the nature of the movement and support conditions in increasing muscle activities (Godfrey, Kindig, & Windell, 1977; Skoss, Cordo, Smith, & Gurfinkel, 2003). This would not be surprising if changes in movement speed arise not as a function of passive mechanical events but of active neural output. In addition, the three exercises, being clearly different in movement pattern, would also likely require different coordinative effort. Studying the role of muscle activities in motor coordination and regulation of speed would significantly increase understanding of how complex motor skills such as abdominal exercise activities can be used to improve or maintain the integrity of the spinal musculature. The hypothesis was that speed and coordinative differences among the three abdominal exercise conditions can explain differences in the amplitude of muscle activities.

Method

Subjects

Twenty healthy adults (10 men and 10 women, mean age 23 ± 2 yr.), reporting no neurological or musculoskeletal impairments, participated in the study approved by the Institute’s Human Assurance Committee. All subjects wore shorts (plus sports bras for the women) and flat shoes during the experiment. All could execute five cycles of the full sit-up movement without difficulty. None had any exercise experience with the AbSlide device.

Abdominal Exercise Protocol

Subjects performed five consecutive repetitions of the AbSlide, partial, and full sit-up exercise. For the AbSlide exercise, the manufacturer’s pamphlet was used to explain the proper technique to the subjects. Subjects knelt on the floor with the AbSlide close to the knees, hands resting on the handle bars, and body in a semi-upright posture (Fig. 1). The first cycle movement began when they rolled the device forward, moving the torso,
Fig. 1. (a) Demonstration of the AbSlide exercise. The left figure depicts the starting and ending posture of each cycle (repetition) of movement; the right figure illustrates the extended posture at mid-cycle; (b) kinematics of the movement.

"...from a curled position to an extended, uncurled position" (AbSlide) and then rolling the AbSlide back to the starting position. In the partial sit-up, subjects started from a supine position with the knees flexed at 90°, the hips flexed at 45°, upper extremities held across the chest and feet anchored flat on the floor by a spotter (Fig. 2). They then curled the trunk up until both scapulas at the level of the infrascapular angle barely cleared the floor. The trunk was then lowered on the return phase. The full sit-up had the same starting position as the partial sit-up, but subjects curled up and forward until a part of an upper extremity touched their knees, displacing the trunk into vertical orientation. Similar to the partial sit-up, the trunk was then lowered on the return phase. To standardize movement duration, all three abdominal exercise movements were executed at 40 cycles (repetitions) per minute. A metronome was set at a cadence of 80 beats per minute, thus pacing the subjects at two beats for each cycle of exercise movement. Subjects were instructed to begin the movement on the first beat and coincide the middle of the movement with the second beat, and began the return
phase of the movement without pausing. The next beat signaled the end of the cycle and the beginning of the next, with no deliberate pause between cycles. Subjects timed the start of the first cycle after listening to a few beats of the metronome. They practiced until they were familiar with the exercises. To minimize undue fatigue which could result in compensatory muscle recruitment (Szasz, Zimmerman, Frey, Brady, & Spalletta, 2002), each exercise was performed for five consecutive cycles. Subjects rested as long as they wanted between the exercises. Order of exercises was randomized.

Data Acquisition and Analyses

Ten muscle sites placed on the right side of the body were recorded using the RUN Technology MyoPac fiber optic (California, USA) surface electromyography (EMG) system sampled at 1,000 Hz, full-wave rectified and band-pass filtered at 10-500 Hz: upper rectus abdominal (midway between sternum and umbilicus), lower rectus abdominal (midway between pubis and umbilicus), external oblique, paraspinous, latissimus dorsi, upper trapezius, posterior deltoid, wrist flexors, rectus femoris, and biceps femoris. The skin overlying the targeted muscles to be assessed was cleansed by lightly rubbing with an alcohol swab and then shaved. A pair of EMG electrodes 4 cm apart was pasted to the skin overlying the belly of each muscle of interest to record the EMG signals. Electrode pairs were oriented parallel to the muscle fibers. Hypoallergenic adhesive tape was used to ensure that the EMG electrodes remained in place throughout the experiment.

The three abdominal exercises primarily involved moving the trunk segment. To judge whether movement speed and displacement can account for differences in muscle activities in these exercises, a reflective marker was placed on the right shoulder. A marker was also placed on the body of the AbSlide device to track its speed and distance traveled. The 6-camera 3-D real-time PEAK Motus motion analysis system (Colorado, USA) sampling at 120 Hz was used to capture and process the marker data. The following
shoulder variables measured during the first half of each exercise cycle were calculated as the average of the middle three cycles: horizontal displacement, horizontal velocity, horizontal peak velocity, vertical displacement, vertical velocity, vertical peak velocity, and time to perform one exercise cycle.

To compare the relative magnitude of muscle activities across the three exercises within each subject, the integrated EMG (IEMG) in each of the 10 muscles was computed for the middle three cycles. To test the main hypothesis that kinematic differences among the three abdominal exercises account for differences in muscular activities, the SAS multivariate analysis of covariance procedure (SAS Institute Inc., North Carolina, USA) was conducted by simultaneously analyzing the kinematic variables as covariates, with the three Abdominal exercises treated as the fixed factor and Subjects as the random factor. Significant effects were followed up with 1-way repeated measures of analyses of variance and simple effect analyses. Kinematic and IEMG data were expressed as a percentage of the partial sit-up exercise. The significance for all analyses was set at \( p < .05 \).

**Results**

A one-way multivariate analysis of covariance was conducted to assess whether muscle activities differed among the three abdominal exercises. Shoulder kinematic variables and exercise duration were used as covariates to control for kinematic differences among the exercises. The regression portion of the covariate analysis was significant (Wilks \( \lambda = .097; F_{70,217} = 1.52, p = .01 \)), indicating that the kinematic variables were significantly related to the IEMG measures.

The analysis of variance portion of the analysis showed a main exercise condition effect (Wilks \( \lambda = .46; F_{10.36} = 4.23, p = .0006 \)), indicating that the different abdominal exercises were associated with different IEMG amplitudes, after adjusting for the covariate effects of the kinematic variables. Fig. 3 shows one subject's rectified EMG traces while performing five cycles of the AbSlide, full, and partial sit-up exercises. As can be seen, the AbSlide exercise recruited the most amount of muscle groups, followed by the full and the partial sit-up conditions. Notice that in the partial and the AbSlide exercises, the abdominal muscles showed a single burst of activity per cycle, whereas there is a biphasic burst pattern in the full sit-up.

Follow-up univariate \( F \) ratios indicated that all the 10 muscle IEMGs contributed to differences among the three abdominal exercises. When the effects of the shoulder kinematics were accounted for, the 10 muscle IEMGs fell into three categories. In the first category, three muscle activities were different among the exercises, suggesting that these are scaled not only to movement speed but to serve some general synergistic motor control or coordinative function, such as stabilizing joint segments during movements. These were the upper abdominal (\( F_{2,44} = 3.49, p = .04 \)), the lower abdominal
(F_{2,44} = 4.03, p = .03), and the wrist flexor (F_{2,44} = 24.43, p = .0001). In the second category, five muscle IEMGs became similar among the exercise conditions. Thus, their activities were scaled primarily to movement speed: external oblique (F_{2,44} = 0.01, p = .04), posterior deltoid (F_{2,44} = 1.41, p = .0001), upper trapezius (F_{2,44} = 1.05, p = .0003), rectus femoris (F_{2,44} = 0.68, p = .0006), and biceps femoris (F_{2,44} = 0.42, p = .01). No correlation was obtained among the shoulder kinematic variables and these five muscles, so the combined effect of the kinematic variables contributed to the covariate influence. The lower paraspinal and the latissimus dorsi muscles comprised the third category. Their activities were different among the exercises (F_{2,44} = 7.23, p = .0003; F_{2,44} = 5.24, p = .0001, respectively), but there were no associations with the kinematics. Thus, these muscle activities appeared to be mainly involved in motor control and were speed-independent. Table 1 summarizes the simple effect analyses on the kinematic and IEMG data.

**Discussion**

Comparing differences among tasks can be difficult because it is not apparent which aspects of motor control reliably distinguish the tasks (Cordo & Gurfinkel, 2004), and some have avoided doing such analyses (Warden, Wajswelner, & Bennell, 1999). Generally, motor coordination can be studied at the global as well as at the local level (Keele, 1981; Serrien, Steyvers, De-
TABLE 1
SUMMARY OF KINEMATIC AND EMG ANALYSES

Integrated EMG
- Category 1: motor control and amplitude scaling
  - Upper rectus abdominal: AS > FS & PS
  - Lower rectus abdominal: AS > FS & PS
  - Wrist flexor: AS > FS > PS
- Category 2: amplitude scaling only: AS = FS = PS
  - External oblique
  - Posterior deltoide
  - Upper trapezius
  - Rectus femoris
  - Biceps femoris
- Category 3: motor control only: AS > FS > PS
  - Lower paraspinale
  - Latissimus dorsi

Kinematics
- Time to complete one cycle (repetition): AS > PS & FS
- Shoulder horizontal peak velocity: AS > FS > PS
- Shoulder vertical peak velocity: FS > PS & AS
- Shoulder vertical displacement: FS > PS & AS
- Mean shoulder vertical velocity: FS > PS & AS
- Shoulder horizontal displacement: AS & FS > PS
- Mean shoulder horizontal velocity: FS > AS > PS

Note.—AS = AbSlide; FS = Full sit-up; PS = Partial sit-up; > = greater IEMG activity (p < .05).

Global organization involves the regulation of body center of mass, for example. In terms of local motor control, two strategies have been identified. The first is termed speed-sensitive, which is utilized when the speed of the movement is altered, and muscle activity must be scaled to match task requirements (Diener, Horak, & Nashner, 1988; Skoss, et al., 2003). The second is speed-insensitive, which is observed when the execution speed of the movement is stable. These two strategies are characterized by the modulation of spatial and temporal parameters, respectively (Gottlieb, Corcos, & Agarwal, 1989; Gottlieb, Corcos, Agarwal, & Latash, 1990; Juker, McGill, Kroepf, & Steffen, 1998).

First Category of Muscles: Scaling and General Motor Control

The AbSlide exercise condition showed a higher IEMG activity than the full and partial sit-up exercises. The full sit-up showed similar IEMG activity to that of the partial sit-up, probably because a high upper shoulder elevation protocol for the partial sit-up exercise was used. In the AbSlide exercise, the motor control function of the abdominal muscles was probably different when the device was rolled out versus rolled in. When rolling out,
the abdominal muscles undergo eccentric contraction to assist in preventing the hips from collapsing. Concentric contraction of the abdominal muscles during the roll-in phase assisted in returning the body to its starting position. Wrist flexor activity was expected to be relatively quiet during the partial and full sit-ups. There was significant activity during the full sit-up, twice higher than that for the partial sit-up. Subjects may be attempting to keep their arms close to the chest as the trunk rises and falls during a cycle. In the AbSlide condition, considerable wrist flexor activity was expected, not only to assist in rolling the device out and back in but to control the device symmetrically so the body does not collapse or deviate to the side during the execution of the movement. In further studies the speed of the device during movement execution should be varied to assess how the muscles' IEMGs are scaled as a function of the speed.

Second Category of Muscles: Scaling Only

Faster movement was associated with greater muscle activation to keep the body in dynamic stability as well as to minimize extraneous off-plane movements. External oblique activities, if symmetrically activated, assist in trunk curling along the sagittal plane. Their recruitment as a function of movement speed assisted the upper and lower abdominal muscles in moving the trunk. Activation of the shoulder-stabilizing muscles, the posterior deltoid and upper trapezius, ensure that the upper trunk and extremities are adequately coordinated so that these are coupled to the lower trunk movement pattern. It is rather surprising that these two muscles were not recruited beyond the apparent speed-dependent function, especially during the AbSlide exercise. One would expect the shoulders to be substantially supported during the movement, independent of how fast the device is being moved, so that the amount of muscle activity should reflect the need to fulfill both functions. However, that did not appear to be the case. The remaining two muscles in the speed-dependent category were the thigh muscles, the rectus femoris and biceps femoris. Recall that subjects' feet were anchored during the partial and full sit-up exercises. Activation of these muscles during the partial sit-up was minimal. In the full sit-up, their recruitment probably served to assist in lifting and lowering the trunk by taking advantage of the leverage afforded by the anchoring of the feet, as well as controlling pelvic motion (LaPier, Creelman, Cunningham, Moore, & Whiles, 2000; Cordo & Gurfinkel, 2004; Cordo, et al., 2006). During the AbSlide movement, subjects knelt on the floor. Stabilization and pelvic motion control were also the likely function of these muscles in assisting rapid trunk movements.

Third Category of Muscles: General Motor Control But No Scaling

The three abdominal exercises chosen for measurement show clear dif-
ferences in motor control. The partial sit-up does not require the trunk to be curled past the infraspinular angle, so activities in the lower paraspinal and latissimus dorsi were expected to be low. That was what was found. In the full sit-up, increased activation of the muscles helped to maintain the structural integrity of the trunk including the spinal column. In the AbSlide movement, the trunk and upper extremities must be extended on the way out, and be quickly brought back on the return phase. Based on the shoulder kinematics and muscle IEMGs, the motor coordination requirement in this exercise was the highest, resulting in higher activation of the two muscles relative to the other two exercises.

General Comments

Muscle activities.—Exercise performed while using the AbSlide elicited greater activity in both the upper and lower abdominal muscles than in the partial and full sit-ups. In terms of the latter exercises, a previous study showed comparable muscular activity in the rectus abdominal and internal obliques between these two exercises, with a trend towards greater activation of the external obliques in the full sit-up exercise (Juker, et al., 1998). This study also suggested activity of the abdominal muscles during the full sit-up to be higher than during the partial sit-up. The difficulty in finding a reliable significance in the amount of activity of the abdominal muscles should not be surprising because the partial sit-up, like the full sit-up, requires significant abdominal muscle activity to curl the upper trunk up off the floor (Cordo, et al., 2003). Further lifting of the trunk into vertical alignment in the full sit-up primarily involves the hip flexors rather than greater recruitment of the abdominal muscles (Juker, et al., 1998). These results suggest that the partial sit-up is not necessarily always easier to perform than the full sit-up.

Other variables were not investigated in this study, for example, the temporal patterns of muscular activations. Analyzing the sequencing of muscle activity could provide insight into how the onset latencies of muscle activity may be grouped to function as a unit, commonly referred to as a synergy (Chong & Franklin, 2001). Muscles active over a cycle of movement may also serve different functions during that cycle, such as moving a body segment in the early phase of activity and then stabilizing in the later phase (Cordo, et al., 2003). For example, the abdominal muscles, although active throughout the cycle in all three abdominal exercises, probably served at least three functions: assisting in curling the upper trunk off the floor in the early phase, then acting to stabilize the trunk, and to control pelvic motion in the second half of the trunk lift. Visual inspection of the data in the present study suggests that the AbSlide activates the entire body musculature nearly simultaneously. The pattern of activation in the partial and full
sit-up conditions contain a combination of coactivation and sequential activation, consistent with those observed previously (Cordo, et al., 2003).

The apparent simultaneous firing supports previous research that it is difficult to isolate preferentially upper from lower abdominal activation (Piering, Janowski, Moore, Snyder, & Wehrenberg, 1993; Warden, et al., 1999). In addition, EMG activity of the external obliques was correlated with the lower and upper abdominal activity in the partial sit-up. Activity of the external oblique also was correlated with that of the lower abdominals in the full sit-up but not in the AbSlide condition. One may conclude that there was no significant crosstalk of the muscle activities of the external oblique with the upper and lower abdominals since initial analyses showed no correlation between these muscles during the AbSlide exercise. Because there was a difference in activity of the abdominal muscles and external oblique, one can assume that, if a separation of the upper and lower abdominal muscles were present, it would have been detected, assuming appropriate sensitivity of the equipment measurements.

The abdominal musculature showed the greatest amount of activity during the AbSlide, followed by the full and partial sit-ups. Thus, greater trunk control was necessitated when performing the AbSlide than when performing traditional sit-ups. Deep muscles such as the psoas may also be significantly involved in control of the trunk during abdominal exercises (Juker, et al., 1998). Overall, the IEMG and kinematic analyses also showed that the AbSlide required the most effort, involving muscles of the upper extremities, back and thigh more than the traditional sit-ups. These findings disclaim the AbSlide brochure’s statement on its sensitivity in isolating the abdominal muscles. The results of this study suggest the body workout to be overall relative to what is required in the partial and full sit-up exercises. Because of the large number of muscles needed to exercise with the AbSlide, this product may be more appropriate for a healthy and fit population, such as our subjects. The AbSlide may be contraindicated for someone who has knee or shoulder injuries or a history of low back pain because bearing weight through the knees and shoulders is required and there is strain placed on the lower back to complete the exercise.

Kinematics.—Overall effort can also be inferred from the differences in shoulder kinematics among the exercises. Although a metronome was used to pace the subjects, the AbSlide exercise condition took the longest to complete per cycle than the partial and full sit-ups. The AbSlide also moved the trunk at a higher horizontal velocity and longer distance than the other two exercises, whereas the full sit-up moved the trunk at a higher vertical velocity and distance than the AbSlide and partial sit-up. The partial sit-up was the easiest to perform although the abdominal muscles were activated by the same amount as in the full sit-up. It showed the slowest trunk velocity and the shortest distance moved.
Further studies.—This study was limited to novice users of the AbSlide. To evaluate whether the AbSlide is truly a better exercise, these results need to be tested with long-term users as well. The same phenomenon should be found. Where differences are found, the principle of exercise specificity will likely prevail more than issues relating to exercise efficiency or even safety. For example, the partial sit-up is thought to be as effective as the full sit-up in training the mid-section. A study using a maximal 2-min. full sit-up test showed, however, that subjects who trained the full sit-up for 6 wk. performed better than those who trained the partial sit-up (Baxter, Moore, Pendergrass, Crowder, & Lynch, 2003). How different abdominal exercises relate to functional movement patterns must now be studied.

Another suggestion for research concerns rotational movements during the traditional sit-ups and sideward motions of the AbSlide as independent variables. Based on present results, the AbSlide exercise activates many muscle groups. The additional benefits of upper extremity involvement and, more importantly, trunk control make this device a valuable tool for use in developing an exercise program. However, present results also suggest that this high-level activity requires significant motor coordination and coactivation of the spinal musculature and may therefore not be the exercise of choice for everyone.

REFERENCES


