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TRUNK MUSCLE ACTIVATION DURING DYNAMIC WEIGHT-TRAINING EXERCISES AND ISOMETRIC INSTABILITY ACTIVITIES

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ABSTRACT. Hamlyn, N., D.G. Behm, and W.B. Young. Trunk muscle activation during dynamic weight-training exercises and isometric instability activities. *J. Strength Cond. Res. 21(4): 1108–1112. 2007.*—The purpose of this study was to examine the extent of activation in various trunk muscles during dynamic weight-training and isometric instability exercises. Sixteen subjects performed squats and deadlifts with 80% 1 repetition maximum (1RM), as well as with body weight as resistance and 2 unstable calisthenic-type exercises (superman and sidebridge). Electromyographic (EMG) activity was measured from the lower abdominals (LA), external obliques (EO), upper lumbar erector spinae (ULES), and lumbar-sacral erector spinae (LSES) muscle groups. Results indicated that the LSES EMG activity during the 80% 1RM squat significantly exceeded 80% 1RM deadlift LSES EMG activity by 34.5%. The LSES EMG activity of the 80% 1RM squat also exceeded the body weight squat, deadlift, superman, and sidebridge by 56, 56.6, 65.5, and 53.1%, respectively. The 80% 1RM deadlift ULES EMG activity significantly exceeded the 80% 1RM squat exercise by 12.9%. In addition, the 80% 1RM deadlift ULES EMG activity also exceeded the body weight squat, deadlift, superman, and sidebridge exercises by 66.7, 65.5, 69.3, and 68.6%, respectively. There were no significant changes in EO or LA activity. Therefore, the augmented activity of the LSES and ULES during 80% 1RM squat and deadlift resistance exercises exceeded the activation levels achieved with the same exercises performed with body weight and selected instability exercises. Individuals performing upright, resisted, dynamic exercises can achieve high trunk muscle activation and thus may not need to add instability device exercises to augment core stability training.

KEY WORDS. electromyography, squats, deadlifts, erector spinae, abdominals

INTRODUCTION

Training the muscles surrounding the trunk region, otherwise known as the core stabilizer muscles, has gained greater emphasis in recent years. Developing core strength has been emphasized as a valuable component in general and sports conditioning programs in addition to active rehabilitation programs for individuals with low back pain (LBP). These muscles play an integral role in carrying out both simple and complex activities. To ensure that these activities are carried out without risk of injury or muscle soreness (i.e., low back pain), the core stabilizer muscles must be conditioned to endure the activities at hand.

Low back pain is the most common cause of musculoskeletal afflictions in North America for persons younger than 45 years of age (11). As of 1998, it was estimated that more than $24 billion is required each year to cover the medical costs associated with managing LBP and that at least a quarter of the working population has reported an episode of LBP (25). The development of many low back disorders arises as a result of a lack of strength and endurance of the trunk muscles. Numerous studies have placed individuals on trunk exercise programs that in turn resulted in a greater increase in endurance and decline in reports of LBP episodes (17).

Because LBP has been associated with poor physical conditioning, it is apparent that active exercise is an effective approach for both the prevention and the rehabilitation of low back injuries (11). However, the most efficient method of training the trunk muscles remains unclear, whether it be used to address LBP or improve athletic performance. It is apparent that training while under unstable conditions does increase the activity of these muscles. According to Anderson and Behm (2), the electromyographic (EMG) activity of the soleus, abdominal stabilizers, upper lumbar erector spinae (ULES), and lumbo-sacral erector spinae (LSES) significantly increased during an unstable squat movement when compared with a stable squat movement. In addition, Behm et al. (4) had subjects perform various trunk-stabilizing exercises with stable and unstable (Swiss ball) conditions. Results indicated that the abdominal stabilizers, LSES, and ULES exhibited significantly greater activity with the unstable conditions. The 2 most effective exercises for trunk activation were the sidebridge and superman. A study by Marshall and Murphy (15) found that performing tasks on a Swiss ball led to greater activation of the external obliques, transverse abdominus, internal obliques, erector spinae, and rectus abdominus levels when compared with stable surfaces.

A common sight in many fitness and rehabilitation centers is the various devices (e.g., Swiss balls, dyna discs, wobble boards) used to establish unstable conditions. Swiss balls have been incorporated into strength training programs on the belief that a labile surface will provide a greater challenge to the trunk muscles, increase the dynamic balance of the user, and possibly help to stabilize the spine in order to prevent injuries (14).

It is important to recognize that for individuals to experience optimal performance, one must ensure that their training regimen incorporates training specificity (22). Thus, it is imperative for a training program to emulate the specific muscular actions and velocities that will be encountered in the particular sport or task at hand. The practical application of training the trunk stabilizers from a supine or prone position may not transfer effectively to the predominately erect activities of daily living. Dynamic resistance training exercises with free weights provide a modicum of instability. Perhaps a combination of relatively high-intensity resistance using free weights (light to moderate instability) can provide greater activation than the very popular instability exercises commonly used today.

To our knowledge, there are no studies that have attempted to compare trunk EMG activity between dynamic weight-training activities and isometric instability activities. Therefore, the objective of this study was to compare the extent of activation of various muscles of the trunk region during dynamic weight-training exercises and isometric instability activities. Based on previous research, it was hypothesized that the isometric activities on instability devices would produce greater EMG activity of the trunk stabilizers.

Methods

Experimental Approach to the Problem

The purpose of this experiment was to compare the activation of various trunk muscles with weight-training activities and selected unstable calisthenic-type exercises. For the dynamic weight-training exercises, the estimated 1 repetition maximum (1RM) for each subject was first determined. On a separate day, subjects performed a warm-up set (approximately 45% 1RM) for an Olympic bar free squat, which was followed by a set of 6 repetitions at 80% 1RM. The same format was followed for an Olympic bar deadlift. In addition, subjects were required to perform 2 trunk-specific calisthenic-type isometric activities using a Swiss ball. The chosen activities included the superman (4) and the side bridge (4, 7). These particular exercises were chosen because previous studies indicated that they provided the highest trunk EMG activation among a wide variety of exercises (4, 7). The subjects were required to maintain each contraction for 30 seconds. The degree of activation was monitored by examining changes in the mean root mean square (RMS) amplitude of the EMG activity of selected trunk muscles.

Subjects

Sixteen physically active people (8 men and 8 women; 24.1 years ± 6.8, 175.6 cm ± 5.9, 165.1 lbs ± 27.3) were chosen to take part in the experiment. All participants were chosen from a healthy population and had previous experience with weight-training and Swiss ball exercises. All participants were from a university population and completed a physical activity readiness questionnaire form (6) to identify any significant health problems. Exclusion criteria included any individual with known acute or chronic back pain. Each subject was required to read and sign a consent form prior to participating in the study. The university's Human Investigations Committee approved the study.

Measurements

Surface EMG electrodes were used to measure signals from the lower abdominals (LA), external obliques (EO), ULES, and LSES muscle groups. In preparation for the electrodes, the placement area was shaved, abraded, and cleansed with alcohol to improve the conductivity of the EMG signal. Due to opposing reports indicating that the use of intramuscular electrodes is necessary to measure the deep lumbar stabilizers accurately, electrodes were placed on the area referred to as the LSES muscles (2, 4, 26). Electrodes (Kendall Medi-trace 100 series, Chicopee, MA) were placed 2 cm lateral to the L5-S1 spinous processes for the LSES muscles and 6 cm lateral to the L1-L2 spinous processes for the ULES muscles. The muscles of the back can be categorized into local and global stabilizing groups (20). Deep muscles, such as the multifidus, are categorized as local, whereas more superficial muscles, such as the longissimus, are categorized as global stabilizers. The positioning of the ULES EMG electrodes was more lateral in order to decrease the activity of the deep multifidus and emphasize the activity of the longissimus (2, 4). Therefore, positioning for the LSES muscles attempts to represent activity of the local stabilizer group. Monitoring electrodes for the LA were placed superior to the inguinal ligament and medial to the anterior superior iliac spine (2, 4). Based on reports from McGill et al. (16), the surface electrodes can adequately represent the EMG activity from the deep abdominal muscles. In contrast, Ng et al. (19) indicated that if the electrodes are placed too close to the anterior superior iliac spine, there might be competing signals from the transverse abdominus and internal obliques. Therefore, the EMG activity for the lower abdominal stabilizers received EMG signals from both the internal obliques and the transverse abdominus.

The EMG signals were monitored, amplified (Biopac Systems MEC 100 amplifier, Santa Barbara, CA), and directed through an analog-digital converter (Biopac MP100) and stored on a computer (Sona, St. John's, Newfoundland). AcqKnowledge software (AcqKnowledge III, Biopac System Inc., Holliston, MA) was used to filter the signal (10–500 Hz). Electromyographic activity was sampled at 2,000 Hz with a Blackman-61 dB band-pass filter between 10 and 500 Hz, amplified (Biopac Systems, input impedance = 2M, common mode rejection ratio >110 dB min (50/60), gain × 1,000, noise >5: V), and analog-to-digitally converted (12 bit) and stored on a personal computer (Sona) for further analysis. The EMG signal was rectified and smoothed (10 samples), and the amplitude of the RMS EMG signal was calculated.

Measurements were taken for 1 second during the eccentric (down-phase) and 1 second during the concentric (up-phase) portions of the squat and deadlift during the middle portion of the exercise set (i.e., repetitions 3, 4, and 5) vs. 5 to 7, 10 to 12, and 18 to 20 seconds of the superman and sidebridge exercises. The mean RMS activity of the 2 1-second periods (eccentric and concentric) during the squat and deadlift was used to compare to the 2-second periods analyzed during the instability exercises. These repetitions and times were chosen to reduce any instability at the beginning of the exercise and fatigue at the end. Although one normally should not directly compare dynamic contractions to isometric contractions, the trunk muscles would have been contracted isometrically during the squat and the deadlift exercises, as well as during the unstable isometric activities.

Exercise Protocol

After an adequate warm-up (10 repetitions that did not elicit failure), a resistance was estimated that would force the participant to fail to complete more than 6 repetitions. Participants' 1RM were calculated from National Strength and Conditioning Association tables (18). From the estimation, 45 and 80% 1RM were calculated for both exercises. A 1RM was not used so that the possibility of injury would be decreased and to allow multiple repetitions for analysis. The 45% 1RM was used as a warm-up resistance, and the 80% 1RM was used for testing. The 80% 1RM was utilized because the number of maximum repetitions estimated from this load is between 8 (18) and 12 (23), which is a typical range commonly utilized in many training regimens. Schimano et al. (23) also reported that there were no significant differences in the number of repetitions at 80% 1RM between trained and untrained individuals.

On a separate day, each subject first underwent a normalization procedure. This was achieved by performing a maximum voluntary contraction (MVC) for the various muscle groups that were measured for EMG activity. This included a prone MVC back extension following the Biering-Sorensen testing procedure (17) to measure the ULES and LSES muscles. In addition, an MVC abdominal crunch was used as the reference for the LA. Both MVCs were held for 5 seconds.

Subjects performed a randomized warm-up procedure consisting of 1 set of 6 repetitions at 45% 1RM for the Olympic bar free squat and 1 set of 6 repetitions at 45% 1RM for the Olympic bar deadlift. Each subject then proceeded to perform the following testing activities in a random order with 10-minute rest periods between exercises to ensure complete recovery: (a) 1 set of 6 repetitions at 80% 1RM for the Olympic bar free squat; (b) 1 set of 6 repetitions of a free squat using body weight and a broom stick as resistance (the squat movement descended until the thighs were parallel to the floor); (c) 1 set of 6 repetitions at 80% 1 RM deadlift; (d) 1 set of 6 repetitions of a deadlift using body weight and a broom stick as resistance (Each repetition of the squat and deadlift was performed with a 2-1-2 tempo as determined by a metronome. A 2-1-2 tempo of 6 repetitions provided 30 seconds of contractile activity equivalent to the unstable superman and sidebridge exercises.); (e) Swiss ball superman (4) maintained for 30 seconds; (f) Swiss ball side bridge (4) maintained for 30 seconds.

Statistical Analyses

Analysis was conducted with GB Stat: Dynamic Microsystems (Silver Springs, MD). Analysis was completed using a 3-way analysis of variance with repeated measures (2 × 6 × 3). Levels for analysis included 2 genders, the 6 exercises, and 3 test times (repetitions 3–5 of the squat and deadlift or 5–7, 10–12, and 18–20 seconds of the superman and side bridge exercises). A Tukey/Kramer post-hoc test was used to determine significant differences. Means and *SD*s are reported in the text and figures.

RESULTS

Because the repeated measures analysis of variance indicated there were no main effects for gender or test times, all data reported in the following sections are reported with the data collapsed over gender and test times. There was a main effect for type of exercise.

Lumbar-Sacral Erector Spinae

The 80% 1RM squat exercise exhibited significantly ($p = 0.0002$) greater LSES EMG activity than all other exercises (Figure 1). Squat LSES EMG activity at 80% 1RM significantly exceeded the 80% 1RM deadlift exercise by 34.5%. The 80% 1RM squat EMG activity also exceeded the body weight squat, deadlift, superman, sidebridge exercises by 56, 56.6, 65.5, and 53.1%, respectively. There were no significant LSES EMG differences between the body weight squat, deadlift, superman, and sidebridge exercises.

Upper Lumbar Erector Spinae

The 80% 1RM deadlift exercise exhibited significantly ($p = 0.001$) greater ULES EMG activity than all other exercises (Figure 2). The 80% 1RM deadlift ULES EMG activity significantly exceeded the 80% 1RM squat exercise by 12.9%. In addition, the 80% 1RM deadlift ULES EMG activity also exceeded the body weight squat, deadlift, superman, and sidebridge exercises by 66.7, 65.5, 69.3, and 68.6%, respectively. The 80% 1RM squat exceeded the body weight squat, deadlift, superman, and sidebridge exercises by 63.1, 61.8, 64.2, and 64.4, respectively. There were no significant ULES EMG differences between the body weight squat, deadlift, superman, and sidebridge exercises.

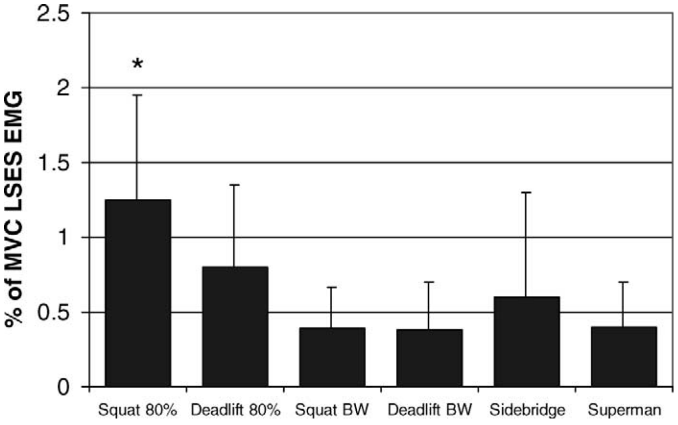

FIGURE 1. The graph depicts the mean normalized electromyographic activity of the lumbo-sacral erector spinae muscles during the performance of dynamic, weightlifting exercises and isometric instability exercises. Bars depict the mean combined data of the individual exercises. Asterisks indicate that the exercise was significantly different from all other exercises. X-axis titles represent the following: squat 80%: squat at 80% 1 repetition maximum (1RM), deadlift 80%: deadlift at 80% 1RM, BW: squat and deadlift using only body weight as a resistance. Vertical bars represent *SD*.

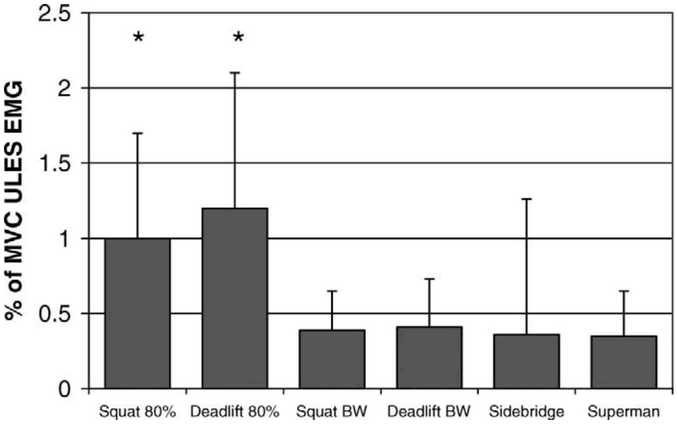

FIGURE 2. The graph depicts the mean normalized electromyographic activity of the upper lumbar erector spinae muscles during the performance of dynamic, weightlifting exercises and isometric instability exercises. Bars depict the mean combined data of the individual exercises. Asterisks indicate that the exercise was significantly differently from all other exercises. X-axis titles represent the following: squat 80%: squat at 80% 1 repetition maximum (1RM), deadlift 80%: deadlift at 80% 1RM, BW: squat and deadlift using only body weight as a resistance. Vertical bars represent *SD*.

External Obliques and Lower Abdominals

From the 4 exercises performed, no single exercise showed significant differences in the EO and LA EMG activity.

DISCUSSION

The most important findings of this study indicated that there was significantly greater EMG activity in the LSES and ULES muscle groups during the 80% 1RM squat and deadlift exercises respectively compared with body weight resistance squats and deadlifts or unstable superman and sidebridge exercises. Conversely, none of the exercises was able to produce significantly greater changes with the EO or LA. Previous instability training studies have shown greater, similar, and lesser muscle activation when comparing exercises performed with unstable bases compared vs. stable bases.

Training of the trunk muscles has been identified as an important consideration to provide an individual with a strong foundation and to prevent LBP. Somewhat contrary to the present findings, a number of studies proposed that the use of instability devices provides higher activation of trunk musculature. Marshall and Murphy (15) compared the activation patterns of muscles associated with the global and local stability systems during different core stability tasks on and off a Swiss ball. Their results indicated that the performance of tasks on the Swiss ball did lead to greater activation levels when compared with a stable surface. Additionally, a study by Cosio-Lima et al. (8) demonstrated that after 5 weeks of training with a Swiss ball, there were greater gains in torso balance and trunk EMG activity when compared with traditional floor exercises. Behm et al. (5) had subjects perform various trunk-stabilizing exercises with stable and unstable (Swiss ball) conditions. Results indicated that the abdominal stabilizers, LSES, and ULES exhibited significantly greater activity with the unstable condition.

Instability training has also been shown to increase the activation levels of other muscles besides those of the trunk region. A study by Kean et al. (13) examined the effects of fixed foot (wobble board) and functionally directed balance training (jumps and landings) on muscle activation and cocontraction during jump landings. There was a 33% increase in rectus femoris EMG activity upon landing from a jump in the fixed-foot balance-training group.

In many exercise regimens, instability training is incorporated into the program as a variation or modification from traditional resistance training exercises. With this in mind, it is important to establish which method will produce the greatest amount of activation within the muscles. Anderson and Behm (2) investigated the differences in EMG activity in 6 muscle groups, including the LA, ULES, and LSES groups, while performing squats of different stability and resistance. The squat movement was performed on a Smith machine, as a free squat, and while standing on 2 balancing discs. Results indicated that the LA, ULES, LSES, and soleus muscle groups were activated to a greater extent while performing the movement under unstable conditions. The authors attributed this finding to the stabilizing roles of these muscles.

However, most daily activities also involve the use of the upper and lower limbs. Therefore, how does the addition of limb movements change the activation of the trunk muscles? Behm et al. (4) compared EMG activity in the trunk muscles during popular resistance exercises and trunk strengthening exercises with stable and unstable bases. In addition, they compared the activation of the trunk muscles with modifications (unilateral and bilateral) of the resistance exercises to determine if the activity could be increased. Results indicated that there was an overall increase in lower abdominal muscle activation (EMG) levels during the unstable exercises. In addition, there was greater trunk activation during unilateral dumbbell press of the contralateral arm compared with the ipsilateral arm or bilateral press (5).

Not all instability studies have provided evidence of greater muscle activity. A study conducted by Anderson and Behm (1) had subjects perform chest press exercises under stable and unstable conditions. Electromyographic activity was measured from various muscles, including the pectoralis major, anterior deltoid, triceps brachii, latissimus dorsi, and rectus abdominus. Results showed that there were no significant differences in EMG activity between the stable and unstable chest presses. In addition, the unstable base elicited a 60% decrease in maximal isometric chest press forces. The researchers suggested that even though external forces are impaired by instability, the activation of muscles is still maintained due to the greater reliance of the limb muscles on joint stabilization (1).

On the contrary, a study by Behm et al. (3) showed that there was a decrease in quadriceps and plantar flexors muscle activity under unstable conditions. The study had subjects perform leg extensor and plantar flexion under stable and unstable conditions. Activation averaged 44.3 and 2.9% less, respectively, in comparison with the stable conditions. In addition, leg extensor force was 70.5% less under unstable conditions, whereas plantar flexor force decreased by 20.2%. It was suggested that under conditions of great instability, the increased stabilization function of the muscles was not enough to maintain balance and therefore decreased the overall activation (3).

Typically, unstable calisthenic-type exercises are performed while in a supine or prone position. However, these activities do not mimic many of the movements of daily life (e.g., lifting), whereas other traditional dynamic resistance training exercises (e.g., squats, deadlifts) do more closely resemble these actions. In addition, the use of free weights does incorporate a degree of instability into the squat and deadlift exercises (27). However, proponents of instability devices suggest that instability training device exercises are necessary additions to the traditional resistance training program to ensure training adaptations for the trunk musculature (10). Hence, does the stress associated with stabilizing the trunk with dynamic, resisted exercises, such as the squat and deadlift, result in greater, similar, or lesser activation than calisthenic-type exercises performed on a Swiss ball?

The results of the present study indicate that the use of moderately high (80% 1RM) intensity resistance while performing dynamic exercises, such as the squat and deadlift, can provide greater dorsal trunk activation than similar exercises without external resistance or calisthenic-style instability activities. It is plausible that the increased EMG activity of the LSES and ULES during the 80% 1RM squat may be due to the participants' attempting to counterbalance their body and the resistance during the movement. The LSES muscle group has been shown to be very active as a stabilizer during the squat movement (2). Because the body acts as an inverted pendulum, there is a tendency for the center of gravity to sway (21). Balance is maintained by controlling the extent of sway. Placing a resistance above the center of gravity, as with the squat exercise, increases the disruptive torques associated with the body sway. This study demonstrates the substantial activity of the LSES and ULES needed to counterbalance the destabilizing torques of the swaying body and suspended resistance. In addition to the counterbalancing action of the torso during the squat movement, the LSES also involves handling compressive forces. Although the local stability muscles of the spine have a role in maintaining segmental stability, they often need the aid of the large global muscles during certain movements, such as the squat exercise. More global muscles represented in the present study by the ULES EMG activity help to provide the bulk of stiffness to the spine, as well as generate force to control range of motion (9). Thus, while a person performs a movement (e.g., squat, deadlift), the local stabilizers help to maintain mechanical ability and posture of the lumbar spine and the global muscles function to balance the external load that is being applied to the trunk region and generate force in order to maintain the range of motion for the exercise (9).

With the deadlift exercise, it is plausible that the greater activation of the ULES was evoked due to the recruitment of the upper back muscles in order to both dynamically lift the weight off the floor and stabilize the thoracic and lumbar vertebrae. In the current study, subjects used a quarter-squat position to lift the weight off the floor. In the quarter-squat position, the hips are placed in a higher position during the initial pull of the weight compared with a half-squat position, in which the hips are lower, thus putting the initial load of the pull onto the quadriceps muscles with less stress on the lower lumbar region of the spine (12). Similar to many activities of daily living, the deadlift necessitates the integration of vertebral muscles for mobilization and stabilization.

It was also apparent that performing such movements as squats and deadlifts without external resistance provided similar trunk activation as the selected unstable exercises. As previously mentioned, the sway associated with the inverted pendulum-like action of the body would necessitate corrective muscular actions by the dorsal trunk musculature.

CONCLUSION

The current study indicates that dynamic exercises, such as the squat and deadlift, incorporating high-intensity resistance paired with moderate instability can increase the muscle activity of the trunk region to a greater degree than selected calisthenic instability exercises. Thus, it may be unnecessary to add calisthenic-type instability exercises to a training program to promote core stability if full-body, dynamic, upright exercises are implemented in the program.

PRACTICAL APPLICATIONS

Whereas a number of studies have demonstrated greater trunk muscle activation when comparing similar unstable with stable exercises (5, 15), the present study illustrates the high trunk muscle activation needed to stabilize external resistance during traditional weight-training exercises, such as the squat and deadlift. The common notion regarding the necessity to add instability device exercises to a traditional resistance training program to accentuate trunk activation has been shown to be unnecessary if such exercises as the 80% 1RM squat and deadlift are included in the program. Individuals who do not incorporate such resisted compound muscle actions in their training or those who wish to provide activation over a greater range of motion (24) may wish to add instability device exercises.

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