**Trunk Muscle Activity Increases With Unstable Squat Movements**

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**Abstract/Résumé**

The objective of this study was to determine differences in electromyographic (EMG) activity of the soleus (SOL), vastus lateralis (VL), biceps femoris (BF), abdominal stabilizers (AS), upper lumbar erector spinae (ULES), and lumbo-sacral erector spinae (LSES) muscles while performing squats of varied stability and resistance. Stability was altered by doing the squat movement on a Smith machine, a free squat, and while standing on two balance discs. Fourteen male subjects performed the movements. Activities of the SOL, AS, ULES, and LSES were highest during the unstable squat and lowest with the Smith machine protocol (p < 0.05). Increased EMG activity of these muscles may be attributed to their postural and stabilization role. Furthermore, EMG activity was higher during concentric contractions compared to eccentric contractions. Performing squats on unstable surfaces may permit a training adaptation of the trunk muscles responsible for supporting the spinal column (i.e., erector spinae) as well as the muscles most responsible for maintaining posture (i.e., SOL).

Cette étude se propose de présenter les différences d’activité myoélectrique (EMG) des muscles soléaire (SOL), vaste externe (VL), biceps fémoral (BF), stabilisateurs de l’abdomen (AS), érecteur du rachis lombaire supérieur (ULES), et érecteur du rachis lombo-sacré...
(LSES) au cours de flexions accroupies, de stabilité et de résistance variables. La stabilité est modifiée lors de flexions exécutées sur un appareil de marque Smith, exécutées librement ou exécutées debout sur deux disques d’équilibre. Quatorze sujets masculins participent à l’expérience. Les activités des SOL, AS, ULES, et LSES sont plus élevées quand la condition d’exécution est instable et plus faibles quand le mouvement est accompli sur la machine de marque Smith (p < 0,05). L’augmentation de l’activité myoélectrique de ces muscles est probablement due à leur rôle postural et de stabilisation. De plus, l’activité myoélectrique est plus grande au cours des actions miométriques qu’au cours des actions pliométriques. L’exécution des flexions accroupies sur des surfaces instables peut offrir un stimulus d’entraînement aux muscles du tronc qui soutiennent la colonne vertébrale (érecteur du rachis) et aux muscles qui contribuent au maintien de la posture (soléaire).

Introduction

It is purported that greater instability of the human-surface interface will stress the neuromuscular system to a greater extent than traditional resistance training methods using more stable benches and floors (Kornecki and Zschorlich, 1994). However, it is important to identify to what extent instability will influence the acute response of muscle. The advantage of an unstable training environment would be based on the importance of neuromuscular adaptations with increases in strength. Strength gains can be attributed to increases in muscle cross-sectional area and to improvements in neuromuscular coordination (Behm, 1995). A number of researchers have reported that neural adaptations play the most important role in strength gains in the early portion of a resistance training program (Behm, 1995; Sale, 1988). Rutherford and Jones (1986) suggested that the specific neural adaptation occurring with training was not increased recruitment or activation of motor units but rather an improved coordination of agonist, antagonist, synergists, and stabilizers. Thus the inherently greater instability of the body-surface interface would challenge the neuromuscular system to a greater extent, possibly enhancing strength gains attributed to neural adaptations.

To our knowledge, few studies have examined the effect of unstable resistance training movements on muscle activation and force. Vera-Garcia et al. (2000) identified higher electromyographic (EMG) activity when performing a sit-up on an unstable surface vs. a flat surface. Siff (1991) found that the wider range of movement with Swiss balls is preferable to similar actions performed in most circuit training gyms. Behm et al. (2002) reported that the decreases in quadriceps and plantar-flexor force and activation with unstable conditions were dependent on the degree of instability. Their research suggested that strength training adaptations of the limbs is possible if the degree of instability is moderate as opposed to severe. Perhaps the importance of instability training is not only the unique stress placed on the limb musculature but also its impact on trunk musculature responses. Thus the objective of this study was to examine the effect of differing levels of instability on trunk and limb muscle activation during a closed kinetic chain activity (squat). It was hypothesized that as stability decreased, trunk muscle activity would increase.
Materials and Methods

SUBJECTS

Fourteen physically active young men (25.2 ± 6.2 yrs, 175.3 ± 6.5 cm, 82.6 ± 9.7 kg) from Memorial University of Newfoundland participated in the study. All were competitive athletes (i.e., hockey, soccer, squash) with experience in resistance training (mean = 7.8 yrs ± 6.4); they were presently actively engaged with resistance training activities involving free weights, resistance machines, and instability devices. Six of the subjects only used instability devices such as Swiss balls for trunk endurance activities such as sit-ups. All subjects read and signed a consent form prior to the experiment. Memorial University of Newfoundland’s human investigation committee approved the study.

MEASUREMENT AND INSTRUMENTATION

EMG activity was measured during all protocols of varied stability and resistance. Surface EMG signals were measured from 6 muscle groups: mid-belly of vastus lateralis (VL), mid-belly of biceps femoris (BF), midline of soleus (SOL), upper lumbar erector spinae (ULES) at L1–L2 (6 cm lateral to the L1–L2 spinous processes), lumbo-sacral erector spinae (LSES) at L5–S1 (2 cm lateral to L5–S1 spinous processes), and abdominal stabilizers (AS), positioned superior to the inguinal ligament and medial to the anterior superior iliac spine. As McGill et al. (1996) reported that surface electrodes could represent the activation profiles of deep abdominal muscles over a broad variety of tasks, and Ng et al. (1998) identified possible contamination of EMG signals from more than one muscle (internal obliques and transverse abdominus), the term abdominal stabilizers will be used to refer to the EMG measured at the lower dorsal trunk position.

A number of studies have used a similar L5–S1 electrode placement (LSES) to measure the EMG activity of the multifidus (Danneels et al., 2001; Hermann and Barnes, 2001; Hodges and Richardson, 1996; Ng et al., 1998). In contrast, Stokes et al. (2003) reported that accurate measurement of the multifidus requires intramuscular electrodes. Thus the EMG detected by these electrodes in the present study is referred to as LSES muscle activity. Erector spinae muscles, according to anatomic nomenclature, include both superficial (spinalis, longissimus, iliocostalis) and deep (multifidus) vertebral muscles (Jonsson, 1969; Martini, 2001). Back muscles have also been described as local and global stabilizing muscles based on their role in stabilizing the trunk (Berkmark, 1989). The multifidus is described as a component of the local stabilizing system while the longissimus contributes to the global stabilizing system. The ULES EMG electrode positioning was more lateral than the LSES EMG positioning in order to diminish the detection of multifidus activity and thus emphasize the measurement of global stabilizing muscles (longissimus).

EMG location sites were identified, shaved, sanded (to remove dead epithelial cells), and cleansed with rubbing alcohol to reduce resistance and achieve maximal adhesion of the electrode (Kendall® Medi-trace 100 series, Chikopee, MA). To maximize EMG sensitivity, the electrodes were aligned parallel to muscle fiber orientation rather than in a perpendicular position (Ng et al., 1998). EMG
Electrodes were placed collar to collar at a 2-cm distance. All muscles monitored were from the subject’s dominant side as determined by the leg preferentially used to kick a soccer ball. EMG signals were then amplified (1000x), filtered (10–1000 Hz) and smoothed (10 samples) (Biopac Systems MEC 100 amplifier, Santa Barbara, CA), and stored on computer after being directed through an analog-digital converter (Biopac MP100).

All data were recorded at a sampling rate of 2,000 Hz and analyzed with a software program (Acqknowledge 3.7.2., Biopac Systems). The maximum amplitude of the smoothed root mean square (RMS) of the EMG signal was evaluated over the duration of the concentric and eccentric contractions of the squat. The duration of eccentric and concentric activity was ascertained by using a marker on a separate channel controlled by the researcher to indicate the start and finish of the eccentric and concentric phases, respectively. The quadriceps EMG activity also gave a clear indication of the different phases. There was no need to normalize the signal since the experiment was a repeated-measures design comparing within individuals with all conditions performed in one session.

**Protocol**

Prior to experimental data collection, subjects were given a 2-week orientation session in which they performed both stable and unstable squats (on balance discs) using only body mass for 3 sets of 10 repetitions on six occasions. Immediately prior to data collection, they underwent a 5-minute warm-up on a cycle ergometer at 70 rpm with a resistance of 1 kp. All testing was conducted in a single session.

The squat was performed under three levels of stability: relatively unstable, relatively stable, and very stable. The relatively unstable squat was undertaken with a balance disc under each foot, the relatively stable used a regular squat (standard Olympic bar on shoulders behind head), and very stable squat was performed with a Smith machine (bar sliding on rails) (Figures 1a, 1b, and 1c). The balance discs were made of dense rubber and were highly inflated with air to ensure that even the heaviest subjects could not entirely compress the disc.

Each movement had contractions involving three intensities: no external resistance (body mass); 29.5 kg (weight of Smith machine bar); and 60% of body mass (standardized resistance which permitted the subjects to complete the movement on the balance discs safely). For safety reasons, maximal loads were not used. Subjects were instructed to maintain a 1-second down-phase, 1-s transition phase, and 1-s up-phase cadence for the squat movement with the assistance of a metronome. They were permitted to do a practice repetition immediately prior to testing with each type of squat to familiarize themselves with the balance, resistance, and timing. Torso angle throughout the squat movement and knee angle at the bottom of the movement were visually monitored and based on the subjective decision of the researcher; any excessive deviation of form was omitted from analysis. Typically only 1 or 2 repetitions were undertaken, with data acquired and analyzed from the repetition adhering most closely to the time constraints (1-s down, 1-s up). The order of stability condition and intensity were randomly assigned with 2 minutes rest given between repetitions to prevent a fatigue effect.

Subjects stood with feet approximately shoulder width apart and toes pointed
Figure 1. Squat methods. (top): Smith; (middle): Free; (bottom): Unstable.
straight ahead. The barbell was held behind the neck, across the shoulders and resting on the upper trapezius muscle. The grip was a little wider than shoulder width. Subjects held their breath during the down-phase of the lift and exhaled during the up-phase. They were instructed to maintain heel contact with the floor. Escamilla (2001) reported peak quadriceps EMG activity occurring at approximately 80–90° of knee flexion. Quadriceps activity remained fairly constant beyond 80–90° of knee flexion, hence descending beyond 90° flexion (parallel squat) may not enhance quadriceps development (Escamilla, 2001). Therefore, subjects were instructed to begin the up-phase once the upper leg was parallel to the floor (90° knee flexion).

STATISTICAL ANALYSIS

A three-way ANOVA (3 × 3 × 2: squat method {Smith machine, free squat, unstable}, resistance {body mass, 29.5 kg, 60% body mass} and contraction type {eccentric-down, concentric-up}) repeated-measures was used (GB-STAT for MS Windows, Version 7.0. Silver Springs, MD). Upon review of collected data, the AS appeared to become highly active during the transition from eccentric to concentric phases and the temporal data were analyzed with a repeated-measures one-way ANOVA. Differences were considered significant at $p < 0.05$. If significant differences were detected, a Bonferroni (Dunn’s) procedure was used to identify group differences. Reliability was assessed using an alpha (Cronbach) model intraclass correlation coefficient (ICC) (Cohen, 1988) with all subjects. Repeated tests were conducted during the experimental session. Data were reported as means ± SD.

Results

EXTENT OF STABILITY

Trunk Muscles. The EMG activity of the AS during the Smith and free squat were 29.6% ($p < 0.01$) and 18.6% ($p < 0.05$), respectively, less than during the unstable squat, while differences between the Smith and free squat were not significant. EMG activity of the LSES was 22.9% and 20% (both $p < 0.05$) lower in the free and Smith squat, respectively, compared to the unstable squat; however, no significant differences between the Smith and free squat were identified. The ULES experienced a 33.8% ($p < 0.01$) decrease in the Smith compared to unstable squat and a 22.9% ($p < 0.05$) decrease in the free compared to the unstable squat (Figure 2). There was also a 29% ($p < 0.05$) decrease in activity of the ULES during the Smith compared to the free squat. All 14 subjects experienced increases in ULES and LSES activation with the unstable squat vs. the Smith and free squat, whereas 12 of them experienced increased LAS activation with the unstable condition.

Limb Muscles. EMG of the SOL during the Smith and free squats were 73.1% and 58.5% less, respectively, than during the unstable squat ($p < 0.0001$). Muscle activity of the VL was 4.8% ($p < 0.05$) lower in the unstable compared to the Smith squat while the VL activity during the free squat was 14.3% ($p < 0.01$) lower than during the Smith squat. There were no significant BF differences between the three squat protocols (Figure 3).
Figure 2. Mean (±SD) of trunk muscle EMG (MT, AS, ES) over the 3 squat movements. Muscle group and squat technique are labeled on the x-axis with root mean squared (RMS) EMG (mV) on the y-axis. *Significant differences at $p < 0.05$.

Figure 3. Mean (±SD) of limb muscle EMG (SOL, VL, BF) over the 3 squat movements. Muscle group and squat technique are identified on the x-axis with RMS EMG (mV) on the y-axis. Significant differences: *between unstable and other squats, $p < 0.05$; **between Smith squat and others, $p < 0.01$. 

As resistance increased, there were significant increases in EMG activity of the SOL ($p < 0.01$), VL ($p < 0.0001$), LSES ($p < 0.001$), and ULES ($p < 0.0001$). Increases in the BF and AS were not significant (Table 1).

EMG activity was significantly greater during the concentric phase compared to the eccentric phase of the squat protocols (SOL 37%, $p < 0.006$; VL 44%, $p < 0.0001$; BF 93%, $p < 0.04$; ULES 29%, $p < 0.01$; and AS 31%, $p < 0.0002$). The LSES showed a trend ($p < 0.08$) for increased activity (14%) during the concentric phase of the lift (Figure 4).

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**ABDOMINAL STABILIZER CONTRACTION DURATION**

Upon review of the data, there was an apparent alteration in the duration of abdominal stabilizer (AS) activity during the transition phase. There was a significant increase ($p < 0.005$) in the duration of AS activation from the eccentric to concentric phase of the lifts in the unstable protocols compared to the more stable movements (0.66 s for unstable squat, 0.54 s for Smith squat, 0.51 s for free squat). There were no significant differences in the duration of EMG activity for any other muscles tested.

**Discussion**

This was the first study, to our knowledge, to examine multiaxial joint resistance training movements under stable and unstable conditions. The proponents of training under unstable conditions claim that resistance training under those conditions provides a greater stress to the overall musculature (Gantchev and Dimitrova, 1996; Ivanenko et al., 1997; Sheth et al., 1997; Wester et al., 1996). The trunk muscles (LSES, ULES, AS) were more active during the unstable squat, followed by the free squat and Smith machine squat, respectively. This may be explained by the
stabilizing roles of these muscles (Arokoski et al., 2001; De Troyer et al., 1990; Gardner-Morse et al., 1995). As subjects became more unstable with the balance disc squats, the LSES, ULES, and AS and were recruited more to maintain stability of the spine and torso. Whereas Behm et al. (2002) reported that moderate instability can still utilize resistance intensities that would enhance limb strength, the present study emphasized the more pronounced activity of the trunk stabilizers with changes in stability. Therefore, performing unstable squat movements may not only develop the prime movers but may also develop the trunk stabilizers.

It could be argued that changes in body position (i.e., torso angle) in response to the instability could have contributed to the changes in EMG activity. As mentioned in the Methods, torso angle was visually monitored and based on the subjective decision of the researcher; any excessive deviation of form was omitted from analysis. However, torso angle could not be entirely controlled since the anthropometrics and balance strategies of each individual varied. Greater degrees of instability inevitably result in greater movement fluctuations, which can only be controlled by adding stability. With the impact of researcher control (visual inspection) and the random movement strategies among individual subjects, it is unlikely that a main effect for torso position was present.

EMG activity in the SOL was also greater during the unstable squat movement compared to the more stable movements. The SOL is an important muscle in maintaining erect posture, as it has a major role in controlling the ankle joint which is often one of the first joints to help return the body to equilibrium after perturbation (Ivanenko et al., 1997). This is relevant in that strengthening of the SOL muscles may help persons with balance difficulties to lessen the number of falls attributed
to uneven surfaces. Furthermore, sports performed on level (basketball, volleyball) or irregular (football, rugby) surfaces could also benefit from instability training.

Limb muscles including the BF and the VL did not show similar changes in the amplitude of EMG activity under the unstable conditions as did the trunk and postural muscles. There was no significant difference in the BF EMG amplitude between all three squat protocols, indicating that with this squat movement, varied stability had minimal effect on hamstring activity. There were similar findings with the VL. As these muscles are primarily identified as prime movers in the squat movement, with a minimal role in stability, the varied stability had little effect on the amplitude of the EMG activity. However, the elevated EMG activity of the VL during the Smith machine protocol may have been a result of foot placement and the stability (bar guided on rails) of the Smith machine. Subjects may have been able to use the VL to push posteriorly and vertically against the bar in order to push backward as well as up.

The increased resistance placed on all movements resulted in a corresponding rise in EMG activity, as would be expected with the classic force:EMG relationship (Bigland and Lippold, 1954; Genadry et al., 1988; Komi and Viitasalo, 1976; Lippold, 1952). However, a similar increase in EMG was not identified in the AS muscle. One possible explanation for the lack of increase in AS activity is that it aids in spinal stabilization by increasing intra-abdominal pressure (IAP) (Rab et al., 1977). Cresswell and Thorstensson (1994) found that among the abdominal muscles, the highest level of activity and the best correlation to variations in IAP was demonstrated by the transverse abdominus. Thus there may be a maximum threshold for the AS in increasing IAP in untrained individuals.

Another hypothesis is that the AS “turn off” as part of a protective mechanism, whereas trunk flexion increases, increased abdominal activity can create a shearing moment at the lumbar spine. An alternate explanation may be that there is not a linear relationship between increases in external resistance and IAP. However, some authors (Cresswell and Thorstensson, 1994; Harmon et al., 1988) suggest that increased resistance does not result in elevated IAP, but there is no direct correlation of this elevated IAP to AS activation. Therefore, increasing resistance may not lead to a corresponding rise in AS activity.

Significant differences were also found in muscle activation between concentric and eccentric phases of the movement. The SOL, VL, BF, ULES, and AS had significantly ($p < 0.05$) greater EMG activity during the concentric phase of the lifts compared to the eccentric phase, which are consistent with findings by Grabiner and Owings (2002) and Cresswell and Thorstensson (1994). However, only a trend ($p < 0.08$) for higher EMG during the concentric phase was evident in the LSES. Since the LSES is a spinal stabilizer, it contracts isometrically during both the concentric and eccentric phases of the lifts, thus producing lower recognizable differences. Furthermore, one may argue that as the ULES and AS are also stabilizers, why was there a change between contractions? McGill and Norman (1986) provide one explanation, that the ULES also contributes to spinal extension as it works in unison with other spinal extensors to overcome the spinal bending moment resulting from the load. Delitto et al. (1987) state that the increased activity of the AS during the concentric phase may be a requisite for increased IAP needed to protect the spine due to the considerable degree of anterior shear force
that can be generated by the upper body while extending the torso and combating inertia.

The AS were most active at the bottom of the movement with the transition from eccentric to concentric phases (Figure 5). The possible mechanism responsible is known as the flexion-relaxation phenomenon (Newman and Gracovetsky, 1995). McGill and Kippes (1994) found that during hip flexion, the lumbar extensors relaxed, as they were still able to generate substantial force elastically through stretching. In the case of the squat, as subjects reached the bottom (lumbar flexion), LSES activity decreased (relying on elastic component) which resulted in increased AS activity to maintain support to the spinal column anteriorly (Figure 5). It would be interesting to discover whether individuals who are trained to activate their LSES and AS (via trunk training) would show similar responses.

**Conclusion**

It was clear in this study that as subjects became more unstable, the activity of their trunk stabilizers and postural muscles increased whereas only negligible increases were observed in activity of the prime movers. Since previous studies (Behm et al., 2002) have shown significant decreases in force and activation of prime movers with unstable conditions, the use of unstable resistance training modalities
may prove to be of more benefit to trunk stabilizers than prime movers. It should be pointed out, however, that as only the acute response to an unstable movement was measured, one should be cautious about making inferences as to possible training effects.

References


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