Isometric Squat Force Output and Muscle Activity in Stable and Unstable Conditions

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ABSTRACT. McBride, J.M., P. Cormie, and R. Deane. Isometric squat force output and muscle activity in stable and unstable conditions. J. Strength Cond. Res. 20(4):915-918. 2006.—The purpose of this study was to assess the effect of stable vs. unstable conditions on force output and muscle activity during an isometric squat. Nine men involved in recreational resistance training participated in the investigation by completing a single testing session. Within this session subjects performed isometric squats either while standing directly on the force plate (stable condition, S) or while standing on inflatable balls placed on top of the force plate (unstable condition, U). Electromyography (EMG) was recorded during both conditions from the vastus lateralis (VL), vastus medialis (VM), biceps femoris (BF), and medial gastrocnemius (G) muscles. Results indicated peak force (PF) and rate of force development (RFD) were significantly lower, 45.6% and 40.5% respectively, in the U vs. S condition (p ≤ 0.05). Average integrated EMG values for the VL and VM were significantly higher in the S vs. U condition. VL and VM muscle activity was 37.3% and 34.4% less in U in comparison to S. No significant differences were observed in muscle activity of the BF or G between U and S. The primary finding in this investigation is that isometric squatting in an unstable condition significantly reduces peak force, rate of force development, and agonist muscle activity with no change in antagonist or synergist muscle activity. In terms of providing a stimulus for strength gain no discernable benefit of performing a resistance exercise in an unstable condition was observed in the current study.

KEY WORDS. instability, strength, power, resistance training

INTRODUCTION

The influence of unstable resistance training on possible physiologic adaptations has been recently reviewed (2). However, limited studies have investigated the effect of instability during exercise and its influence on muscle activity and force output (2, 4, 5). Several investigations have examined muscle activity in unilateral vs. bilateral exercises which creates a certain level of instability (4, 5, 8, 11). It is often assumed that unstable environments create an increased level of muscle activation, especially in antagonist or synergist muscles. However, few data exist that actually substantiate this theory.

A standard type of resistance training is typically used to increase muscle strength (7). More importantly, the relationship between the intensity of training and gains in strength has been highlighted. It has been reported that intensities of less than 80% of 1 repetition maximum (1RM) strength result in decreases in electromyographic (EMG) activity of involved muscles, with a subsequent decrease in muscle strength (6, 7). As highlighted by Anderson and Behm (2), increased EMG activity of associated antagonist and synergist muscle in unstable exercises is not necessarily reflected in overall muscle force output. This was demonstrated in an investigation by Behm et al. (4) which reported that antagonist muscle activity was greater in an unbalanced resistance exercise. However, the force output was diminished by 20.2%. Thus, instability may result in increased activity of associated muscles but does not result in any appreciable gains in measured force output.

The muscle activity levels and kinetic variables associated with stable vs. unstable resistance exercise are, as mentioned above, limited. One recent investigation utilizing a dynamic bench press reported that force output in an unstable condition was 59.8% less than the force produced during the stable condition (1). Muscle activity of the pectoralis major, deltoids, and triceps was not significantly different between the stable and unstable conditions. The unstable condition was effective in decreasing force output considerably; however, it was not effective in increasing activity of either the prime mover muscle or associated stabilizer and synergist muscles. A similar result was also reported in a study involving dynamic leg extensions (4). In this study force output in the unstable condition was reduced by 20.2%. However, antagonist and synergist muscle activity did increase by 29.1% and 30.3%, respectively. It appears that the majority of this additional muscle activity most likely is contributing to joint stability and does not effectively contribute to overall force output in the movement.

The purpose of the current investigation was to assess the effect of stable vs. unstable conditions on force output and muscle activity in the lower body. This study utilized a multi-joint structural exercise, the isometric squat, to examine this phenomenon. An isometric action was chosen to increase the validity of the muscle activity measurements through EMG. If force output decreases appreciably in a resistance exercise performed in an unstable condition, it is questioned if this level of activation is sufficient to adequately stimulate strength gain in the context of a longitudinal training study.

METHODS

Experimental Approach to the Problem

The subjects completed 1 testing session. Within this session subjects performed isometric squats either while standing directly on the force plate (stable condition, S) or while standing on inflatable balls placed on top of the force plate (unstable condition, U) (Figure 1). EMG was recorded during both conditions from the vastus lateralis (VL), vastus medialis (VM), biceps femoris (BF), and medial gastrocnemius (G) muscles. Following a 5-minute bicycle ergometer warm-up, the subject was exposed to each condition in a randomized fashion. Subjects were allowed
4 trials for each condition. Adequate rest (3 minutes) was allowed between each effort. Twenty-five minutes of rest were allowed between conditions and another 5-minute bicycle ergometer warm-up was completed before the second bout of squats.

**Subjects**

This study involved 9 athletic male college students (age, 22.4 ± 2.7 years; height, 175.61 ± 5.34 cm; weight, 85.5 ± 19.14 kg; percent body fat, 15.06 ± 5.39%). Subjects were involved in resistance training and some type of recreational sporting activities. The volunteers were notified about the potential risks involved and gave their written informed consent, approved by the Institutional Review Board at Appalachian State University.

**Procedures**

**Isometric squat.** The isometric squat was performed by having the subject stand on a force platform (BP6001200; AMTI, Watertown, MA) under a fixed bar position at a 100° knee angle (10) while performing a maximal isometric contraction for 3 seconds. An isometric action was chosen to increase the fidelity of the muscle activity measurements obtained. The S condition was performed while standing directly on the force plate. The U condition was performed while standing on inflatable balance disks (circumference 90 cm). Utilization of the inflated balance disks on the force plate was validated in the laboratory to ensure that a force exerted against the disks was equal to that same force applied directly to the force plate (in

terclass correlation coefficient between S and U conditions $R^2 = 1.0$; Figure 2). In addition, Barnett et al. (3) demonstrated that no differences existed in force output between cushioned or uncushioned shoes measured via an in-shoe transducer and a force plate. Thus, any change in force-time related measurements during U or S was a representation of true changes in muscle force output. A minimum of a 3-second isometric contraction was also utilized to ensure that in the unstable condition the inflatable disks were maximally compressed and the maximal force had reached a plateau before recording peak force (PF) values used for comparison between conditions. The bar height was adjusted so that the knee angle was 100° for each condition. Each individual's bar height and foot placement remained constant during the testing session and remained constant under each condition. The vertical force-time curve was recorded using a shielded BNC adapter chassis (BNC-2090; National Instruments, Austin, TX) and an analog-to-digital (A/D) card (NI PCI-6014; National Instruments) at 1000 Hz. LabVIEW (version 7.1; National Instruments) was used for recording and analyzing the data. PF of the whole 3-second contraction and average rate of force development (RFD) for the first 400 ms of the force-time curve were calculated.

**Electromyography.** The EMG of the VL, VM, BF, and G muscles was completed at 1,000 Hz using a telemetry transmitter (8-channel, 12-bit analog-to-digital converter; Noraxon USA Inc., Scottsdale, AZ). A disposable surface electrode (2-cm interelectrode distance, 1-cm circular conductive area; Noraxon USA) was attached to the skin over the belly of each measured muscle, distal to the motor point, and parallel to the direction of muscle fibers. The amplified myoelectric signal, recorded during each of the trials in both S and U was detected by the receiver-amplifier (Telemyo 900, gain = 2,000, differential input impedance = 10 MΩ, bandwidth frequency 10–500 Hz, common mode rejection ratio = 85 dB; Noraxon USA) and then sent to an A/D card (KPCMCLA-12AI-C; Keithley, Cleveland, OH) and analyzed using MyoResearch software (version 4.6; Noraxon USA). The signal was full wave rectified and filtered (6-pole Butterworth, notch filter 60 Hz, band pass filter 10–200 Hz). The integrated value ($\mu$V-s) was calculated and then averaged over the 3-second isometric contraction ($\mu$V).
peak force. In addition, unstable isometric squatting does squatting in an unstable condition significantly reduces DISCUSSION
tivity of the BF or G between U and S. No significant differences were observed in muscle ac-
dition (Figure 3, Table 1). Vastus lateralis and VM muscle
U condition (Figure 2, Table 1) \( p \leq 0.05 \). Peak force and
RF D = rate of force development; AvgIEMG = average integrated electromyography; VM = vastus medialis; VL = vastus lateralis; BF = biceps femoris; G = medial gastrocnemius.
† Significant \( p \leq 0.05 \) difference between stable and unstable conditions.

Statistical Analyses
A general linear model multivariate analysis with a Bonferroni post hoc test was used for data analyses. The criterion \( \alpha \) (alpha) level was set at \( p \leq 0.05 \). All statistical analyses were performed through the use of SPSS statistical software (version 11.0; SPSS, Inc., Chicago, IL).

RESULTS
Peak force and RFD were significantly higher in the S vs. U condition (Figure 2, Table 1) \( p \leq 0.05 \). Peak force and RFD were 45.6% and 40.5%, respectively, less in U in comparison to S. Average integrated EMG values for the VL and VM were significantly higher in the S vs. U condition (Figure 3, Table 1). Vastus lateralis and VM muscle activity was 37.3% and 34.4%, respectively, less in U than S. No significant differences were observed in muscle ac-

**TABLE 1.** Mean values \( \pm SDs \) of force and electromyography variables. *

<table>
<thead>
<tr>
<th>Variable</th>
<th>Stable</th>
<th>Unstable</th>
</tr>
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<tbody>
<tr>
<td>Force</td>
<td>2186.95 ± 377.34†</td>
<td>1189.68 ± 427.10†</td>
</tr>
<tr>
<td>PF (N)</td>
<td>2689.32 ± 804.80†</td>
<td>1599.11 ± 675.43†</td>
</tr>
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<td>RFD (N·s⁻¹)</td>
<td></td>
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<tr>
<td>AvgIEMG</td>
<td>VM (µV)</td>
<td>192.35 ± 63.28†</td>
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<tr>
<td></td>
<td>VL (µV)</td>
<td>206.72 ± 66.56†</td>
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<tr>
<td></td>
<td>BF (µV)</td>
<td>38.90 ± 23.71</td>
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<tr>
<td></td>
<td>G (µV)</td>
<td>29.07 ± 17.74</td>
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<tr>
<td></td>
<td></td>
<td>119.56 ± 54.53</td>
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<tr>
<td></td>
<td></td>
<td>129.65 ± 53.83</td>
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<tr>
<td></td>
<td></td>
<td>57.61 ± 33.19</td>
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<td></td>
<td></td>
<td>28.53 ± 18.56</td>
</tr>
</tbody>
</table>

* PF = peak force; RFD = rate of force development; AvgIEMG = average integrated electromyography; VM = vastus medialis; VL = vastus lateralis; BF = biceps femoris; G = medial gastrocnemius.
† Significant \( p \leq 0.05 \) difference between stable and unstable conditions.

The force output in the current study during the unstable condition was 54.4% of the stable condition. If the stable condition is taken as 100% of maximal strength, then the stimulus for strength gain (54.4%) in the unstable condition would not meet the intensity requirement set by Häkkinen et al. (7) for appreciable strength gain as a result of resistance training. Häkkinen et al. (7) reported that training with intensities less than 80% of maximal strength resulted in decreased muscle activity and subsequent loss of strength with training. Therefore, the effectiveness of resistance training in an unstable environment is questionable. A consideration must also be made regarding the level of muscle activity present during unstable training. If increased activation was a by-product of unstable training then a consideration for its usage could be made. However, in the current study instability resulted in a significant decrease in activity of the agonist muscles and no significant change in antagonist or synergist muscles. Therefore, the noted benefit of increased muscle activation with instability seems to be unfounded as well. One study investigating the effectiveness of strength training, balance training, and combined training found no increase in muscle strength after balance training (9). It is recognized that in the current investigation an isometric test was utilized and thus the relationship to dynamic test could be questioned. However, strong statistically significant correlations have been reported between structural isometric testing (mid-thigh isometric pull) and dynamic lifting performance (10).

No discernable benefit of performing a resistance exercise in an unstable condition could be surmised from the observation made during an isometric squat in the current study. Instability resulted in decreased force output, decreased rate of force development and a decrease in agonist muscle activity. No change in antagonist or synergist muscle activity was observed. It remains unclear as to what positive influence resistance training in an unstable condition would have.

**PRACTICAL APPLICATIONS**
Although the use of equipment to simulate unstable environments in resistance training has received much attention and consequent use in recent years, the efficacy of this mode of training has been undetermined. Performing exercises with instability does not appear to elicit a response intense enough to provide an adequate stimulus for strength gain. In addition, the mode may not be effective in stressing the neuromuscular system to a greater extent than traditional resistance training methods. As mentioned previously, the use of an isometric test in the current investigation brings into question the application
of this data to dynamic activities. However, data exist that significantly correlate structural isometric tests to dynamic resistance training performance (10). Therefore, the results of this investigation indicate no discernable benefit of performing a resistance exercise in an unstable condition.

REFERENCES


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