COMPENSATORY MUSCLE ACTIVATION DURING UNSTABLE OVERHEAD SQUAT USING A WATER-FILLED TRAINING TUBE

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ABSTRACT

Glass, SC, and Albert, RW. Compensatory muscle activation during unstable overhead squat using a water-filled training tube. J Strength Cond Res 32(5): 1230–1237, 2018—The purpose of this study was to assess compensatory muscle activation of core and support muscle during an overhead squat using a water-filled training tube. Eleven experienced weightlifting (age = 20.10 ± 0.99, mass 89.17 ± 6.88 kg) men completed 3, 30-second trials of an overhead squat using an 11.4 kg tube that was partially filled with water. A central valve allowed 3 conditions of water movement: 50% open, 100% open, and a stable(S), closed valve condition. Subjects completed 8–10 repetitions within each condition. Electromyographic (EMG) electrodes were placed over the belly of the vastus lateralis, deltoid, rectus abdominus, and paraspinal muscles and recorded during concentric and eccentric (ECC) phases. Integrated EMG were computed and converted to percent maximal voluntary contraction (%MVC). Compensatory activation was assessed using the natural log of the coefficient of variation of %MVC across repetitions. A 1-way repeated-measures analysis of variance across (phase, condition) was used. Significant compensatory muscle activation was seen in the deltoid muscle during ECC (100% open = 3.60 ± 0.50 > stable LogCV = 3.06 ± 0.45). In addition, paraspinal muscle activity was also more variable during the ECC phase (50% open LogCv = 3.28 ± 0.26 > stable = 2.77 ± 0.67). We conclude that the water-filled training tube induces compensatory muscle activation in the deltoid and paraspinal muscles during the ECC phase of the overhead squat.

KEY WORDS instability training, slosh tube training, electromyography, neuromuscular training

INTRODUCTION

Training for stability and balance involves presenting the neuromuscular system with perturbations designed to induce compensatory adjustments in posture and muscle activation. Stable posture and balance is not reliant on adequate strength alone, but rather the rapid and continual minor compensatory adjustments in muscle activation to avoid large translations in posture, which could lead to strain and injury. Research has shown that limitations or delays in compensatory activation of muscle is a precipitating cause of lower back injury (9,26,28) and is also more common in older adults (10). Neuromuscular training induced by way of agility and instability training seems to enhance performance by improving core stability (27), compensatory posture adjustments (29), spinal reflex times (34), and speed of step initiation in athletes (35).

Research has examined the effect of neuromuscular training on the magnitude of muscle activation using instability training. These studies have focused on the magnitude of activation differences in core and support muscles during exercises that create unstable conditions by varying the base of support surface, such as Swiss ball or BOSU. These devices create conditions requiring stability adjustments of the lower body and core muscles to maintain balance and stability during lifts (2,19,21,22,33). Some studies have shown decreased force output, no change, or inconsistent results in primary muscle activation during unstable exercises (3,20,32) presumably due to accessory muscles working to stabilize the load and limit the amount of weight that can be safely managed (23). Research shows that if the goal is to simply increase core muscle activation, lifting heavy loads on a stable base of support will suffice (1). Others have shown that movements such as a push-up (8,31) or plank (30) on suspension straps or Swiss balls may not only cause additional activation of triceps muscles as well as core muscles but also create added lumbar compressive stress (5) Muscle adaptations during instability training are similar to improvements in strength seen on traditional stable resistance training, indicating that benefits of instability training can indeed contribute to increased strength as well as neuromuscular coordination (13).
Another approach to creating unstable conditions is to use a weight lifting implement that is unstable. A novel exercise device that is used by individuals for instability training is a training tube partially filled with water. This “slosh tube” is not typically heavy, but rather is used to generate minor, yet rapid perturbations because of the inertial changes in water movement within the tube. The movement is unpredictable and exacerbated by unstable lifting technique; thus the internal load redistribution within the device creates conditions where compensatory muscle activation is required to hold the device steady while lifting. In the practical setting, these devices are carried by an exerciser while they complete agility-type maneuvers or resistance training movements. The inertial movement caused by the water forces the exerciser to make continual adjustments in balance. The amount of water within the device both adds weight and inertial movement. However, as the tube fills, there is less room for water movement, and a balance between load and desired movement is required. Nairn et al. (25) examined the magnitude of trunk and prime movers during a bench press performed on a stable bench, stability ball, and a stable bench with a water-filled tube. They found reduced activation of the pectoralis but increased trunk muscle activation during the tube lift. In a similar study, Nairn et al. (24) examined the same tube during a standard squat and found that the size of the tube reduced trunk flexion and increased abdominal activation while reducing erector spinae activation. It seems that both the movement of the water forces added activation in muscles involved with stabilizing the implement while reducing activation in other muscles.

While muscles involved with stabilizing a movement are indeed activated to a differing degree during water tube training, balance is not simply a function of the magnitude of muscle activation. Instead, balance depends on the rapid, continuous adjustment in activation to counteract continual perturbations. These compensatory adjustments are not identified by measuring a magnitude response. Glass et al. (15) examined the compensatory activation of paraspinal and deltoid muscles using a water-filled tube during a bicep curl in men and women. They showed significant variability in muscle activation in the paraspinal and deltoid muscles during both concentric (CON) and eccentric (ECC) phases, indicating rapid, compensatory adjustments in muscle activation independent of any magnitude increases (15). These adjustments were observed using a load that was less than 50% of 1 repetition maximum (1RM), suggesting that even a light load provides a stimulus of unstable loading. Using an unstable implement may be able to induce compensatory activation in a variety of muscles, depending on how the implement is lifted or carried.

The overhead squat is a training movement that requires both trunk and shoulder support muscles to attenuate unstable movement. The novel device used in the present study allows for alterations in the nature of the water instability, and thus provides a means to examine changes in compensatory muscle activation depending on changes in water movement. Therefore, the purpose of this study was to examine the compensatory muscle activation patterns of selected core muscles and prime movers using a novel, water-filled training tube during the execution of an overhead squat in healthy, trained men. The device has the ability to induce both lateral water motion as well as a more turbulent flow that creates anterior-posterior movement.

**METHODS**

**Experimental Approach to the Problem**

This study was designed to examine the degree of compensatory activation of 2 core muscles (rectus abdominus [AB] and paraspinous) and 2 limb muscles (anterior deltoid and vastus lateralis [VLAT]) using a lift common to strength training (overhead squat). This exercise requires both stability and strength in the core and shoulder stabilizers, as well as the legs. In order to use an implement capable of creating random movement, a specially designed, water-filled tube (“slosh tube”) with a central control valve to modify the degree of water movement inside the lifting implement was used. This novel tube was created using a specially designed, water-filled tube. A control valve was added to the tube to modify the amount of water within the device. The device was constructed using a water-filled tube (“slosh tube”) with a central control valve to modify the degree of water movement inside the lifting implement. The novel device was created using a specially designed, water-filled tube. A control valve was added to the tube to modify the amount of water within the device.

**Subjects**

Eleven men (mean age = 20.10 ± 0.99; age range = 19–22 year) who were active and consistently lifting for the past year were recruited from weightlifting clubs and local CrossFit gyms. Before initiating the study, the proposed research
was approved by the Grand Valley State University Institutional Review Board (IRB) and all subjects provided written, informed consent in accordance with the Declaration of Helsinki. A review by Behm and Colado (6) of recent research examining EMG activation patterns during instability training showed a mean effect size of 2.48 across 12 studies. However, since this study was based on training using an unstable device, rather than unstable surfaces it was decided to use an effect size based on Swiss Ball-related studies. For these studies, effect sizes ranged between 0.40 and 0.50. Based on a power of 0.80, significance of $p = 0.05$, and effect size of 0.40 a minimum sample size of 10 was estimated necessary to establish adequate statistical power to reject the null hypothesis. Subjects were provided written and verbal instructions regarding their participation in the study, including the risks and benefits of their involvement. Subjects reported to the laboratory on 2 occasions. Day 1 testing involved baseline assessment of health history, height, mass, resting blood pressure, and assessment of shoulder press 1RM. Subjects with any contraindicated orthopedic condition, current injury, or blood pressure exceeding 140/90 were excluded from the study to minimize any cardiovascular and musculoskeletal risk factors related to the lift. Following resting measures, subjects completed an overhead press 1RM test using a standard barbell. Maximum was achieved within 5 trials of increasing loads (3–5 minutes rest between trials). Subject who were unable to press at least 23 kg were excluded, as we wanted the load to be well under 50% 1RM for the muscles involved in the overhead squat. Since the load was very light for squatting, we only tested the deltoid strength. Mean implement load was 14.64 ± 2.23% of shoulder press 1RM across subjects. Subjects were also provided a familiarization trial with the instability device, during which they practiced squat at each instability setting at the selected cadence. Baseline subject characteristics are shown in Table 1.

### Procedures

Day 2 testing was performed 1 week after day 1 and at the same time of day. Subjects were prepared for surface electromyography over the muscle bellies of the rectus AB, paraspinal, VLAT, and anterior deltoid muscles according to the locations established by Cram (12). Skin was shaved and abraded, and a skin impedance of less than 2 kΩ was established for each site (4). Bipolar adhesive surface electrodes (Ag-AgCl) with a 2.0-cm interelectrode distance were placed over the muscle bellies of the target muscles, using the right side of the body (12). Ground electrodes were placed on the sternum. The Biopac Tel-100 EMG system (Biopac Systems, Inc. 2007, Goleta, CA) was used to measure muscle electrical activity and record the data during each CON and ECC contraction of each squat repetition. The raw EMG data were sampled at 1,000 Hz and analyzed using AcqKnowledge ver. 3.9 software.

Subjects then completed 3 trials of the overhead squat using the instability training tube. Trials were applied using a counterbalanced design, with 3-minute rest intervals. The control condition trial consisted of a valve closed, no water movement setting (stable). The 2 instability trials were performed using a 50% open valve position, which created turbulent flow throughout the tube during the lift (50%) and a 100% open valve, which allowed full water movement across the tube (100%). Spotters were used to place the tube in the hands of the subjects, starting in an elbow extended, standing position. After a metronome cadence of 20 repetitions per minute, subjects completed 7–9 overhead squats in each trial. Because of the unstable nature of the lifting, a manual marker using a keystroke was used to establish the boundaries between CON and ECC based on visual observation. Changes in valve settings between trials were made after the water within the tube had stabilized to prevent any uneven distribution of water during the closed valve setting.

After the lifting trials, a maximal voluntary contraction (MVC) was obtained for each muscle. Because of the light nature of the load and a desire to not influence the study data, MVC testing was performed after the trials. Maximal voluntary contraction was completed by having subjects fully contract against a nonmoving, bracing force applied by a researcher to obtain a maximal static contraction. For the anterior deltoid, the subject completed a static shoulder flexion against a bracing hold. Abdominal MVC was obtained with a supine, static abdominal crunch and paraspinal MVC was obtained using a prone, static back hyperextension. Vastus lateralis MVC was obtained using seated knee hyperextension at 45° knee flexion against a wall. Maximal voluntary contractions were held for 2 seconds, and the central 1.0 seconds of the contraction were integrated and used as the maximal signal. It should be noted that statistical analysis is unaffected by either integrated

### TABLE 1. Subject characteristics.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>20.10 ± 0.99</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>179.75 ± 1.88</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>89.19 ± 6.88</td>
</tr>
<tr>
<td>Resting systolic blood pressure (mm Hg)</td>
<td>129.14 ± 5.40</td>
</tr>
<tr>
<td>Resting diastolic blood pressure (mm Hg)</td>
<td>85.43 ± 3.41</td>
</tr>
<tr>
<td>Overhead press 1RM (kg)</td>
<td>79.26 ± 12.41</td>
</tr>
<tr>
<td>Implement as a percent of 1RM</td>
<td>14.64 ± 2.23</td>
</tr>
</tbody>
</table>
EMG data or %MVC transformed data, since no comparisons across days or muscles were performed.

All raw EMG data were filtered using a filter suggested by the manufacturer to assist with removal of ECG wave forms observed in the core muscles (Biopac-High pass, Blackman –67 db, 30 Hz cutoff, 255 coefficients). Data were then rectified and integrated for each CON and ECC as well as MVCs. This method of quantifying EMG magnitude has been identified (14) as an effective method of identifying the magnitude of muscle activation. Data were converted to a percent of MVC for each CON and ECC contraction to analyze data based on relative muscle activation.

Training Tube Specifications. The instability training tube was constructed from high-density plastic material, with screw caps on each end for access to add water. The tube dimensions (Length = 159.4 cm, Diameter 11.4 cm, circumference 36.2 cm) necessitated straps attached as a support to assist with securing hand holds (55 cm apart) during the overhead squat. The squat was completed with hands in a palm up position, under the tube, with the thumb and the fingers forming a secure hold. Dry weight of the tube was 5.0 kg, and for the study 6.0 L of water was added for an 11.0-kg load. Maximal volume of the tube was 11.0 L for a maximal load possible of 16.0 kg. However, as fill volume increases, water instability decreases, so a volume was chosen to both provide adequate load stimulus and maximize load instability (Figure 1).

Statistical Analyses
To determine a measure of compensatory muscle activation across each trial, the natural log of the percent coefficient of variation (Ln SD/mean) of %MVC was computed across each trial and each muscle. To complete an analysis of variance (ANOVA) analysis, 3 assumptions needed to be met: the CV values must be approximately normally distributed, the variances of the population must be equal, and the observations must be independent. Two assumptions were not met: the equal variance assumption and the normality assumption. The residuals tended to vary more as the predicted value of the CV increased, thereby violating the equal variance assumption. The natural log of the CV values (logCV) was taken and checked to see if the assumptions

![Figure 1](image1.png)  
*Figure 1. Example of overhead squat using the water-filled training tube.*

![Figure 2](image2.png)  
*Figure 2. Variability in muscle activation of the deltoid across 3 instability settings. ECC 100% open > stable. ECC = eccentric.*
were met, and they were. A 1-way repeated-measures ANOVA was used to examine CON and ECC contraction compensation individually for the abdominal, deltoid, VLAT, and paraspinal muscles. Post hoc Tukey tests were used for paired comparisons in the presence of main effects.

**RESULTS**

Significant compensatory muscle activation was seen in some muscles, and was dependent on the contraction type and the nature of the water movement. Figure 2 shows the compensatory muscle activation of the deltoid muscle across the 3 instability settings. Significant compensatory activation was seen during ECC contractions during the 100% open valve condition (LogCv = 3.60 ± 0.50) compared with the stable condition (3.06 ± 0.56), representing a 15% increase in compensatory activation in the deltoid during the 100% open valve setting.

Figure 3 shows the compensatory activation of the paraspinal muscles across 3 instability settings. Significant differences were seen during the ECC contractions during the 50% open valve condition (LogCv = 3.29 ± 0.26) compared with the stable condition (2.77 ± 0.67), representing a 16% increase in compensatory activation in the paraspinal muscles during the 50% open valve setting.

For the VLAT (Figure 4) and rectus AB (Figure 5) muscles, there were no significant differences in the compensatory muscle activation during any of the valve conditions or contraction type. Log CV values ranged from 2.8 to 3.1 for the VLAT and 2.95 to 3.38 for the rectus AB.

**DISCUSSION**

The results of this study show that compensatory activation was seen in the deltoid muscles during the 100% open condition, whereas paraspinal activation was significantly greater during the 50% open condition. By altering the nature of the water movement within the tube, we were able to see alterations in compensatory activation across muscle groups during the same overhead squat movement. Often training devices that induce stability affect only select muscles, and as the exercise becomes more skilled at the movement, the instability training effectiveness of the device may be limited. The device examined in this study offers random water movement sufficient to induce compensatory activation up to 15% greater than the control position. In addition, the central control valve allows modification in the water, movement that changes the muscles required to maintain stability.

Compensatory activation in this study represents the degree of variation in activation of the muscle, rather than the magnitude of activation, thereby providing information
about the continual activation adjustments made by the muscle to counter the load perturbations induced by water movement. These adjustments act to stabilize the load so that the squat can be performed without affecting the lower body. Training the neuromuscular system for stability during movement requires muscles to be presented with variations in load demands that invoke compensatory activation. Stability during movement is both a function of an increased magnitude of force output to perform an activity but also the degree of compensatory adjustments in muscle activation necessary to smoothly execute movement (7). The unique aspect of the tube used in this study was a central control valve, which allowed for some control over the nature of the water turbulence. This allowed for the specificity of compensatory activation to be in either the deltoid muscles (during the 100% open valve setting) or the paraspinal muscles (during the 50% open valve condition). Despite the load being only 15% of shoulder press 1RM, it was adequate to induce significant compensatory activation of the supporting muscles. Wojtys et al. (34) showed that spinal reflex times as well as cortical response times improved in leg muscles of agility trained subjects, with no changes in strength trained subjects. In addition, Kennedy et al. (18) showed that there was an earlier activation of postural muscles with small burst amplitudes following seated platform oscillation training. Therefore, activity that creates rapid load changes and demands on the muscle induces neuromuscular adaptations which allow for more rapid compensatory adjustment and therefore more stability control. Stability is not a function of large magnitude changes in force but rather many small adjustments to maintain control. Light loads that rapidly induce compensatory muscle activation are specific to this training need.

The deltoid muscle, which provides stabilization to the shoulder joint during the overhead squat showed increased instability only during the ECC phase of the 100% open valve setting. An interesting aspect of the valve control of a water-filled tube is that when the valve is fully open, water movement is a laminar lateral flow, leading to large shifts in lateral forces. Our results show that the deltoid is a key muscle forced to actively compensate during these particular shifts in load during the 100% open valve setting while performing the overhead squat. The ECC phase of the squat movement also will bear the inertial disturbance created by the CON lift, because of unweighting during the lowering. This magnifies lateral water movement and creates a need for deltoid compensation to keep the load stable. At the 50% open valve setting, there was more water turbulence because of the valve restriction of flow but less dramatic lateral load shifts. As a result, the deltoid was not activated to any significant degree at the 50% open setting beyond that seen during the stable lift. Marshall and Murphy (22) studied muscle activation during bench press exercise with subjects either on a flat bench or a Swiss ball and found increased deltoid activation during bench press on the Swiss ball. The lateral sway in the bar was countered by the deltoid to maintain the frame needed through the plane of motion. In this study, the 100% open valve setting is more specific to train deltoid compensation than 50% open valve.

Paraspinal muscles showed results more specific to their functional control of trunk rotation. Paraspinal compensatory activation was significantly higher during the ECC phase of the 50% open valve setting compared with the stable setting, but not different during the 100% open valve. For functional movement, the inability to adjust to rapid changes in posture may result in injury, or may be a symptomology following injury. Jacobs et al. (17) determined that in people with low back pain there were delays in anticipatory activation of muscles during arm movements, suggesting that the core muscles lose rapid responsiveness to motor control, which can lead to a loss of postural control. Hedayati et al. (16) examined the responsiveness of the transverse AB and erector spinae muscles in patients with nonspecific low back pain and found decrements in the variability of postural responsiveness in men and women, indicating a loss of core control. The inability to make rapid, minor adjustments in core muscle tone during movements lead to increased torque that must be stabilized to a greater degree or lead to injury. Therefore neuromuscular training that helps to preserve or improve core muscle responsiveness can lead to better postural control. Our study shows that using the water-filled training tube in the 50% open valve setting provides a stimulus to the paraspinal muscles that forces rapid and random compensatory activation during the overhead squat. However, this is done using a load that is well below 50% 1RM, thus minimizing risk of injury.

A range of devices are currently available to train for functional performance, balance, and stability. Due to training specificity, often the best form of stability training is done by destabilizing the musculoskeletal system and forcing it to adjust to the perturbation. A number of past research studies have examined the magnitude of muscle activation during movements performed on an unstable base of support, such as unstable push-ups (1,5,8), weight lifting with a Swiss ball or BOSU as a base of support (19,20,22), or unstable squats (21,23). However in some cases, such as suspension push-ups, increased muscle activation is gained at the expense of increased lumbar forces, creating potential for injury (30). This study instead examined the degree of variability of muscle activation within a muscle across the repetitions, using an unstable implement. The advantage of this form of training is that the implement can be used in a variety of ways, and the movements can be executed on either a firm base of support or an unstable base, creating wide variations in the degree of training stimulus possible. The loads can be adjusted relative to the strength of the individual, or as a means of progression. In addition, water can be added or removed from the device, or valve position can be modified to vary the amount of inertial perturbation induced during a lift. Although the loads are light, our data
Compensatory Activation During Unstable Overhead Squat

support the use of water-filled devices to force compensatory muscle activation to maintain stability.

**Practical Applications**

Functional training is designed to provide real-time perturbations to the body, requiring instantaneous compensatory adjustments in core and joint support muscle activation. Much like driving a fast car on the freeway, minor light adjustments maintain stability better than large magnitude adjustments. Therefore, training for performance requires a varied approach to strength training. One may train for increased strength, speed, and power; however, training for postural control, however, may be enhanced by providing conditions where the muscles must rapidly activate to maintain postural control. This study demonstrates a form of training that may be used to improve the responsiveness of postural and joint support muscles with loads much less than those typically associated with strength training. Our study examined skilled resistance training men using a very light load; however, other populations often use light load training. For novice strength trainers, often beginning movements are done with a bar only, to learn smooth technique execution as well as balance. The water-filled device used in this study could be an adjunct to beginning training by providing lightweight balance challenges requiring compensatory activation of key muscles used for stabilization. As the athlete moves to heavier loads, the neuromuscular training resulting from the tube training may be beneficial in balance and coordination of added loads. A possible area of future research could examine more clinical settings, where very light strength training is used with stroke patients, Parkinson’s, and other musculoskeletal diseases, training devices could possibly help patients make an easier transition to more complex standing, walking, and lifting movements. This study shows utility in using a water-filled weight-training device to induce compensatory muscle activation.

**References**


