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Electromyographic analysis of trunk and lower extremity muscle activities during pulley-based shoulder exercises performed on stable and unstable surfaces

Doochul Shin, PT, MS[1)], Jaeyun Cha, PT, MS[1)], Changho Song, PT, PhD[1)*]

[1)] *Department of Physical Therapy, Sahmyook University: 26-21 Gongneung 2-dong, Nowon-gu, Seoul 139-742, Republic of Korea*

Abstract. [Purpose] The aim of the present study was to identify the effects of an unstable support surface (USS) on the activities of trunk and lower extremity muscles during pulley-based shoulder exercise (PBSE). [Subjects] Twenty healthy college students were included in this study. [Methods] Surface EMG was carried out in twenty healthy adult men. The activities of trunk and lower extremity muscles performed during PBSE using a resistance of 14 kg on a stable or unstable support surface were compared. The PBSE included shoulder abduction, adduction, flexion, extension, internal rotation, and external rotation. [Results] On the unstable surface, the rectus abdominis and erector spinae showed significantly less activation during shoulder external rotation, but the extent of activation was not significantly different during other shoulder exercises. The external oblique and rectus femoris showed no significant difference during any shoulder exercises. The tibialis anterior showed significantly greater activation during all shoulder exercises, except flexion and extension. The gastrocnemius showed significantly greater activation during shoulder abduction, extension, and internal rotation. However, during shoulder adduction, flexion, and external rotation, the gastrocnemius showed no significant difference. [Conclusion] The use of USS to increase core stability during PBSE is probably not effective owing to compensatory strategies of the ankle.
Key words: Electromyography, Core stability, Ankle strategy

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INTRODUCTION

In recent years, there have been many studies on core stability[1)]. Core stabilization exercises may prevent or improve symptoms of low back pain because it provides the basis for force production by the limbs[2)]. Broad benefits of core stabilization have been reported, including improvement of athletic performance and prevention of injuries[3)].

The core muscles include the abdominal muscles in the front, paraspinal and gluteal muscles in the back, the diaphragm as the roof, and the pelvic floor and hip girdle musculature at the bottom. This core is composed of 29 muscle pairs that help to stabilize the spine, pelvis, and kinetic chain during functional movements. Without these muscles, the spine would become mechanically unstable[3)].

Many recommendations have been made for core stability training. Traditional core exercises, core stability exercises, ball and device exercises, free-weight exercises, and noncore free-weight training have been studied as methods for core stability[1)]. Methods of increasing core stability also involve the use of an unstable support surface (USS), such as a ball or balance platform[4, 5)]. The use of USS that increases trunk muscle activity may also be effective during core stability training[6–9)]. In addition, movements of the limbs and body weight during core stabilization exercises can be used to provide resistance to trunk muscles[10, 11)]. Moreover, shoulder resistance exercises increase the endurance and strength of core stability muscles[12)].

Several studies have been performed using USS during core stability training[13–16)], but no study has addressed the effects of a USS on core muscle activities during a shoulder exercise. Therefore, the purpose of this study was to determine the effects of USS on trunk and lower extremity muscle activities during pulley-based shoulder exercises.

SUBJECTS AND METHODS

Healthy adult male subjects participated in this study. Subjects were volunteers recruited from a university in Seoul and were accepted for this study if they were in good health, had no current musculoskeletal, neuromuscular, or cardiovascular problems, and had a normal range of shoulder joint motion. Subjects were excluded if they had trauma or pain in the trunk or a shoulder joint or a history of surgery. In addition, those who had experienced core stabilization training or therapy within the last 3 months were

*Corresponding author. Changho Song (E-mail: chsong@syu.ac.kr)

excluded. Subjects signed an informed consent form prior to participation, and the study protocol was approved by the Institutional Review Board of the University of Sahmyook.

Forty-eight hours before starting the study, all subjects abstained from excessive exercise. A 5-min warm-up stretching exercise was conducted prior to the performing of the exercises. Prior to electrode placement, sites were prepared by abrading the skin with fine sandpaper and cleaning it with 70% isopropyl alcohol. Hair was shaved if necessary. Muscle activations of the trunk were measured during pulley-based shoulder exercise (PBSE) using 14-kg resistance on the USS. PBSE comprised shoulder abduction, adduction, flexion, extension, internal rotation, and external rotation. The orders of the six PBSE exercises were randomized, and each exercise was repeated five times. A metronome, set at 80 counts per minute, was used during the exercises to control speed. Subjects were given a 1-min rest between each exercise to minimize muscle fatigue[17]. All exercises were conducted with the feet apart (within shoulder width) and parallel to the shoulders. Abduction and flexion exercises were conducted from 0° to 90° of the shoulder range of motion with the elbow joint in extension. Adduction exercise involved 90° to 0° of the shoulder range of motion with the elbow joint in extension. Extension exercise involved 180° to 90° of the shoulder range of motion with the elbow joint in extension. External rotation exercise involved internal rotation 45° to external rotation 45° with the elbow joint in 90° of flexion. Internal rotation exercise was conducted from external rotation 45° to internal rotation 45° with the elbow joint in 90° of flexion[17]. A pulley machine (Pulley EX, SANIMED, Ibbenbüren, Germany) was used for all shoulder exercises. The flat floor of the laboratory was used as the stable support surface, and a Pedalo®-Vestimed® #50 (diameter 50 cm, height 19 cm) was used for the USS during shoulder exercises. The top and bottom of the Pedalo device were connected by four fixed springs, and the top of the Pedalo device was able to move up and down in all directions.

To measure trunk muscle activities, EMG data were collected from the rectus abdominis (RA), external oblique (EO), and erector spinae (ES); to measure lower extremity muscle activities, EMG data were collected from the rectus femoris (RF), tibialis anterior (TA), and gastrocnemius (Ga). For the RA, electrodes were placed 2 cm lateral, 1 cm superior, and 1 cm inferior to the umbilicus. For the EO, the electrode was placed midway between the anterior superior iliac spine and the most inferior aspect of the rib cage. For the ES, the electrodes were placed 2 cm lateral to the 3rd lumbar vertebra and parallel to the lateral-most high iliac crest. For the RF, the electrode was placed midway between the knee and iliac crest on the front of the thigh. For the TA, the electrode was placed on the lateral side of the tibia three-fourths of the distance from the knee to the ankle. For the Ga, the electrode was placed medially midway to the posterior side of knee. The locations of all electrodes were determined using the method described by Cram and Kasman[18], and all electrodes were placed on the dominant sides. A DataLOG P3X8 data acquisition unit (Biometrics Ltd, Gwent, UK) was used to measure muscle activity. Surface EMG signals were extracted with the Biometrics Analysis Software (v7.50) in ASCII and were processed using a root mean square (RMS) algorithm in MyoResearch XP Master Edition 1.06 (Noraxon U.S.A. Inc., Scottsdale, AZ, USA). The sampling rate was set at 1,000 Hz per channel, EMG signals were band-pass filtered from 20 to 450 Hz, and a 60-Hz notch filter was used to reduce noise.

Table 1. Subject characteristics

Characteristics	
Age (years)	22.4 ± 2.7
Height (cm)	176.4 ± 5.1
Weight (kg)	69.8 ± 8.6
Dominant site	Right

Values are expressed as mean ± SD

SPSS ver. 19.0 was used for data analysis. All subjects had a normal distribution. Descriptive statistics were used to analyze general subject characteristics, and a one-way repeated-measures analysis of variance was used for each muscle. Statistical significance was accepted for p values < 0.05.

RESULTS

Twenty healthy adult male subjects (height, 176 ± 5 cm; weight, 70 ± 9 kg; age, 22 ± 3 years; values are presented as means ± SD) participated in this study (Table 1).

The RA and ES showed significantly less activation on the USS ($p < 0.05$) during shoulder external rotation, but they showed no significant difference on the USS during shoulder abduction, adduction, extension, flexion, and internal rotation. The EO and RF showed no significant difference on the USS during any shoulder exercises (Table 2). However, the TA showed significantly greater activation ($p < 0.05$) on the USS during shoulder abduction, adduction, external rotation, and internal rotation. On the other hand, the TA showed no significant difference during shoulder extension and flexion on the USS, whereas the Ga showed significantly greater activation ($p < 0.05$) on the USS during shoulder abduction, extension, and internal rotation. However, during shoulder adduction, flexion, and external rotation, the Ga showed no significant difference on either a stable surface or the USS (Table 3).

DISCUSSION

This study indicates that the use of USS during PBSE did not increase trunk muscle activity. On the contrary, the TA and Ga activities increased during some of the shoulder exercises. This is probably because of the compensation strategy of the ankle rather than because of that the trunk muscles. This ankle compensation is a postural control strategy that first appears when there is a slight instability in the support surface. Balance in the upright posture can be restored through muscle contraction near the ankle joint, and a close relationship exists between this ankle strategy and the activities of the TA and Ga. In the case of postural

Table 2. Mean (SD) of the EMG activity of trunk muscles on USS

Shoulder exercise	Stable support surface	Unstable support surface
Rectus Abdominis		
1. Abduction	48.4 ± 8.6	45.9 ± 9.8
2. Adduction	41.4 ± 9.9	43.7 ± 7.9
3. Extension	28.3 ± 6.5	27.0 ± 5.6
4. Flexion	50.1 ± 4.9	50.3 ± 8.0
5. External rotation	53.7 ± 5.2	47.9 ± 7.6*
6. Internal rotation	47.6 ± 10.4	47.1 ± 9.0
External Oblique		
1. Abduction	44.7 ± 7.9	43.2 ± 24.1
2. Adduction	36.4 ± 7.0	35.3 ± 20.3
3. Extension	35.1 ± 7.0	34.7 ± 19.5
4. Flexion	43.8 ± 7.5	46.1 ± 23.6
5. External rotation	43.8 ± 7.5	46.1 ± 23.6
6. Internal rotation	48.2 ± 5.9	45.4 ± 25.1
Erector Spinae		
1. Abduction	49.8 ± 7.4	45.1 ± 9.3
2. Adduction	44.4 ± 7.4	42.8 ± 10.4
3. Extension	31.2 ± 5.2	33.4 ± 8.1
4. Flexion	50.8 ± 8.1	51.1 ± 8.3
5. External rotation	57.5 ± 9.2	49.2 ± 10.6*
6. Internal rotation	47.8 ± 7.4	45.8 ± 8.8

*Statistical significance ($p < 0.05$)

Table 3. Mean (SD) of the EMG activity of lower extremity muscles on USS

Shoulder exercise	Stable support surface	Unstable support surface
Rectus Femoris		
1. Abduction	47.0 ± 15.4	45.8 ± 13.0
2. Adduction	48.8 ± 16.4	45.4 ± 15.0
3. Extension	43.4 ± 10.0	41.7 ± 12.2
4. Flexion	49.73 ± 9.89	49.5 ± 11.8
5. External rotation	47.9 ± 12.6	40.9 ± 14.8
6. Internal rotation	49.9 ± 17.4	47.3 ± 12.3
Tibialis Anterior		
1. Abduction	15.9 ± 3.9	22.6 ± 7.9*
2. Adduction	14.6 ± 4.3	18.9 ± 5.2*
3. Extension	23.4 ± 10.9	24.3 ± 12.1
4. Flexion	18.6 ± 5.5	21.7 ± 7.9
5. External rotation	15.5 ± 5.7	21.5 ± 11.6*
6. Internal rotation	15.7 ± 8.2	20.3 ± 4.8*
Gastrocnemius		
1. Abduction	20.4 ± 10.0	27.2 ± 9.2*
2. Adduction	23.7 ± 10.4	27.4 ± 8.8
3. Extension	16.8 ± 6.0	23.4 ± 7.6*
4. Flexion	27.1 ± 9.4	28.9 ± 9.8
5. External rotation	17.9 ± 9.4	19.8 ± 8.9
6. Internal rotation	23.4 ± 10.9	30.5 ± 8.2*

*Statistical significance ($p > 0.05$)

sway under unstable conditions, balance is recovered by an ankle strategy, a hip strategy, or both simultaneously[19]. In the case of rapid shaking of the support surface, balance recovery is achieved via an integrated ankle/hip joint strategy, and in the case of swaying of the support surface in an upright posture, balance can be maintained by ankle movement without hip joint extension[20]. In addition, to maintain postural control, normal adults mainly use an ankle strategy, whereas elderly individuals and children mainly use a hip strategy[21]. In this study, we compared muscle activities in young male subjects on stable and unstable support surfaces. Based on the results, it would appear that compensation for the USS involved an ankle strategy rather than trunk muscle activity. Shoulder abduction and adduction exercises involve movements in the frontal plane[17], and postural sway from the USS occurs in the medial/lateral direction. The results showed significantly increased TA and Ga activities ($p < 0.05$) during shoulder abduction when USS was used but only showed significantly increased TA activity during shoulder adduction. Although Ga activity did not significantly increase during shoulder adduction, muscle activity increased slightly. In this study, the use of USS significantly increased Ga muscle activity during shoulder extension ($p < 0.05$). The extension and flexion exercises involve movements in the sagittal plane[19]; thus, postural sway occurs as the center of gravity moves forward and backward on the support base. The maintenance of balance against such forward/backward sway is dependent on the alternating activities of the TA and Ga. Ga activity begins before the body collapses in the forward direction, whereas TA activity appears before collapse in the backward direction[23]. In the present study, shoulder flexion resulted in no significant differences in lower extremity or trunk muscle activity on the unstable surface. However, the most activity was seen in the TA compared with the other muscles. In the normal upright posture, the center of gravity is on the front side[22], and ankle dorsiflexor activity is low; on the other hand, ankle plantar flexor activity is high[21, 23, 24]. The ankle plantar flexor plays an important role in torque adjustment at the ankle joint and in the maintenance of upright posture[25]. Therefore, back sway occurs during shoulder flexion due to use of USS, but because of the influence of the center of gravity at the ankle joint, it appears to have no significant impact on TA activity due to the ankle dorsiflexors. Shoulder external and internal rotation exercises change the center of gravity with a complex form in the forward/backward direction as well as in the medial/lateral direction. During shoulder external rotation on USS, the body sways in the lateral backward direction, and an ankle strategy can be used to maintain balance. In this study, the TA activity increased significantly on the USS ($p < 0.05$), showing that the TA compensated for lateral backward sway via eccentric contraction. Shoulder internal rotation causes the body to sway in a forward medial direction, and the ankle strategy is used to maintain balance in a manner similar to that during shoulder external rotation ($p < 0.05$).

In this study, PBSE may have been able to increase core stability, but using a USS to enhance core stability may not be effective.

Further confirmation of these results is necessary in larger, more diverse populations, including females and older individuals, and there is a need to measure the deep muscles such as the transverse abdominis and internal oblique.

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