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Effects of Various Lower Limb Ground States on Activation of the Shoulder and Trunk Muscles during Push-up Exercises

Myung-kwon Kim, MS[1)], Jae-min Jung, MS[2)], Sang-yeol Lee, PT, PhD[3)], Gak Hwangbo, PT, PhD[4)], Yun-seop Lee, PT, PhD[5)]

[1)] Department of Physical Therapy, Youngsan University
[2)] Graduated school of Physical Therapy, Daegu University: Naeri-ri, Jinlyang, Gyeongsan-si, Kyeongsangbuk-do, Republic of Korea, 15.
TEL: +82 51-624-0394, FAX: +82 51-624-1394, E-mail:6240394@hanmail.net
[3)] Department of Physical Therapy, Kyungsung University
[4)] Department of Physical Therapy, Daegu University
[5)] Department of Physical Therapy, Youngsan University

Abstract. [Purpose] The purpose of this study was to determine the effect of the moment arm length on the muscle activation of the upper limbs and the trunk. Subjects performed push-up exercises on a stable surface and on an unstable surface placing their feet at a higher level than the hands. [Subjects] The subjects of this study were 33 normal adults in their 20s who had normal range of motion and who were without disorders of the shoulder complex, musculoskeletal disease in the upper limbs or low back pain. [Methods] The experiment was performed using the following four positions: on an unstable surface created by placing a 65 cm diameter exercise ball under the ankle or knee joints of the subjects, and on a stable surface created by placing a bench with a height of a 65 cm under the ankle or knee joints of the subjects. To prevent the effect of muscle fatigue, all exercises were randomly performed. To measure muscle activation in the trunk, electrodes were attached to the erector spinae, rectus abdominis, and external oblique abdominal muscle. The serratus anterior, deltoid middle fiber, pectoralis major, and triceps brachii muscle were chosen as scapular stabilizers. [Results] The muscle activations of the four different positions were compared and the results show that there were significant difference among the erector spinae, rectus abdominis, external oblique abdominal, serratus anterior, deltoid middle fiber and pectoralis major. [Conclusion] The push-up exercise with the lower limbs on unstable ground increased trunk and shoulder muscle activation more than those on stable ground. We assume that muscle activation of the distal parts might have affected the muscle activation of the shoulder stabilizers that are proximal part muscles.
Key words: Push-up, Unstable surface, Muscle activation

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INTRODUCTION

Open kinetic chain exercise is widely applied as an exercise program because it enables the distal parts of the body to be freely moved while allowing the proximal parts to remain fixed, so that acceleration may be increased and functional actions can be promoted while engaging in the exercise[1)]. However, open kinetic chain exercise is not suitable for treatment programs that require complex exercises since it provides little proprioceptive stimulation. Thus, closed kinetic chain exercise is generally considered to be an appropriate approach for treatment plans that require complex exercises. Closed kinetic chain exercise is an exercise program for the dynamic stability of articulation and posture maintenance because it strengthens the muscles and promotes endurance and also reduces the shear force of the mechanical compression on the articular surface[2)].

The push-up exercise, a type of a closed kinetic chain exercise, is often used to strengthen the muscles of the upper limbs. The push-up is widely known as a therapeutic exercise for people who have shoulder problems because it helps improve shoulder function. Various studies have been conducted on this exercise[3)].

With regard to push-up exercises on a stable surface[4)], it has been reported that the position of the palms in relation to the shoulder joint, the moment surface of the arms, the position of the feet, and the push-up rate in relation to gravity all affect the intra-articular pressure on the limbs. Recently, push-ups are frequently being performed on unstable surfaces rather than stable surfaces in order to improve exercise performance. Many researchers have found that the activities of specific muscles are increased by performing squatting movements[5)], bridging exercises[6)], and traditional upper body strength exercises[5)] on unstable surfaces. Many previous studies have examined the results of engaging in push-up exercises on various unstable surface states to determine if it is possible to create motion in distal body parts and generate anticipatory control in the proximal parts of the body[7, 8]. However, studies have shown that engaging in push-up exercises on unstable surfaces primarily affects the upper limbs. In the study by Marshall[6], subjects performed push-up exercises by placing their upper limbs on a Swiss ball (unstable surface) and this exercise increased the muscular activation of their upper limbs and trunk. Naughton[9] conducted rehabilitation on an unstable surface with patients with shoulder instability and reported that this approach improved the proprioception of the shoulder joint.

Despite these studies, insufficient research has been conducted on the muscle activation of the shoulder and the trunk under conditions of lower limb instability and the moment arm length in relation to the lower limb fixed axis during push-up exercises. Therefore, in this study, we conducted push-up exercises on a stable surface and on an unstable surface with the feet placed at a higher level than the hands and analyzed the effect of the moment arm length on the muscle activation of the upper limbs and the trunk. This study will provide the data needed to develop a rehabilitation program for patients with shoulder injury.

SUBJECT AND METHODS

The subjects of this study were 33 normal adults in their 20s who maintained normal range of motion (ROM) and who were without disorders of the shoulder complex, musculoskeletal disease in the upper limbs or low back pain. Subjects were given sufficient explanation about the experimental procedures and each signed a written consent from signifying voluntary participation. The general characteristics of the subjects were age, 21.61 ± 1.32; height, 174.48 ± 5.80 cm; and weight, 70.09 ± 9.87 kg. Cameras and a personal computer monitor were used to provide visual information regarding the scapular motion in the push-up position and all the subjects were asked to always observe their own motion through the computer monitors while performing the push-up exercise, so they could perform accurate scapula protraction. While engaging in the push-up exercise, the subjects were also asked to spread their hands at shoulder width and align the acromion, the middle finger, and the capitate bone.

The push-ups were performed using the following four positions: 1) Foot ball, on an unstable surface created by placing a 65 cm diameter exercise ball under the ankle joints of the subjects; 2) Knee ball, on an unstable surface created by placing a 65 cm diameter exercise ball under the knee joints of the subjects; 3) Foot table on a stable surface created by placing a bench (Adjustable bench S5A, KAYE, USA) with a height of 65 cm under the ankle joints of the subjects; and 4) Knee table, on a stable surface created by placing a bench with a height of 65 cm under the knee joints of the subjects.

Muscle activation was repeatedly measured three times and the mean value was used for analysis. To prevent muscular fatigue of the shoulder stabilizers, push-ups in the four experimental positions were randomly performed.

Electromyography (EMG) was performed after depilating the electrode placement areas with a razor, removing the horny layer of skin with sandpaper, and cleansing the area with an alcohol swab accurate data. To measure muscle activation in the trunk, electrodes were attached to the erector spinae muscle, rectus abdominis muscle, and external oblique abdominal muscle. The serratus anterior muscle, deltoid middle fiber muscle, pectoralis major muscle, and triceps brachii muscle were chosen as scapular stabilizers.

ProComp Infiniti^{TM} (Thought Technology Ltd., Canada) biofeedback software was used to measure the activation of each muscle. A surface electrode composed of three electrodes was used in the experiments. The EMG signal was band-pass filtered between 20 Hz and 500 Hz and the sampling frequency was 1024 Hz.

The root mean square values of each muscle were measured for five seconds in the anatomical position. The relative muscle contraction was calculated with respect to the mean EMG signal for three seconds in the middle portion of the EMG recording, excluding the measurements for the first second and the last second. The muscle activation resulting from one push-up was expressed as the relative muscle contraction in %RVC.

The measured data were analyzed by performing a one-way ANOVA test using SPSS for Windows (version 12.0) to compare the activation of the shoulder stabilizers depending upon the muscle activation of the distal body part. The significance level was chosen as $p<0.05$.

RESULTS

The erector spinae muscle activity was 293.31 ± 37.71 in the Foot ball position, 202.08 ± 25.80 in the Knee ball position, 238.29 ± 32.97 in the Foot table position, and 174.86 ± 20.86 in the Knee table position, showing significant differences. The post-hoc test showed a significant difference between the Foot ball and the Knee ball results and between the Foot ball and the Knee table results.

The rectus abdominis muscle activity was 1276.1 ± 236.6 in the Foot ball position, 419.8 ± 41.1 in the Knee ball position, 601.9 ± 109.5 in the Foot table position, and 280.2 ± 26.4 in the Knee table position, showing significant differences. The post-hoc test showed a significant difference between the Foot ball and the Knee ball results, between the Foot ball and the Foot table results, and between the Foot ball and the Knee table results.

The external oblique abdominal muscle activity was 1161.8 ± 401.8 in the Foot ball position, 405.8 ± 102.4 in the Knee ball position, 479.8 ± 101.7 in the Foot table position, and 256.0 ± 52.5 in the Knee table position, showing significant differences. The post-hoc test showed a significant difference between the Foot ball and the Knee ball results, between the Foot ball and the Foot table results, and between the Foot ball and the Knee table results.

The serratus anterior muscle activity was 527.5 ± 56.4 in the Foot ball position, 363.8 ± 40.2 in the Knee ball position, 414.6 ± 41.5 in the Foot table position, and 327.4 ± 35.8 in the Knee table position, showing significant differences. The post-hoc test showed a significant difference between the Foot ball and the Knee ball results and between the Foot ball and the Knee table results.

Table 1. Average muscle activities of the four push-up exercises unit: %RVC

Muscle	Foot ball	Knee ball	Foot table	Knee table
ES*	293.3 ± 37.7 [a]	202.0 ± 25.8 [b]	238.2 ± 32.9 [a]	174.8 ± 20.8 [b]
RA*	1276.1 ± 236.6 [a]	419.8 ± 41.1 [b]	601.9 ± 109.5 [b]	280.2 ± 26.4 [b]
EOA*	1161.8 ± 401.8 [a]	405.8 ± 102.4 [b]	479.8 ± 101.7 [b]	256.0 ± 52.5 [b]
SA*	527.5 ± 56.4 [a]	363.8 ± 40.2 [b]	414.6 ± 41.5 [a]	327.4 ± 35.8 [b]
TRI	26154.4 ± 2538.6	21211.3 ± 2223.3	22780.5 ± 2281.4	19184.9 ± 2005.4
DMF*	17573.2 ± 2501.5 [a]	11622.4 ± 1549.1 [b]	12577.3 ± 1852.1 [a]	10117.0 ± 1477.7 [b]
PM*	6968.7 ± 479.7 [a]	5077.1 ± 359.0 [b]	5979.6 ± 462.4 [a]	4278.8 ± 281.3 [b]

Foot ball: Push-up exercise performed on an unstable surface created by placing a 65 cm diameter exercise ball under the ankle joints of the subjects. Knee ball: Push-up exercise performed on an unstable surface created by placing a 65 cm diameter exercise ball under the knee joints of the subjects.

Foot table: Push-up exercise performed on a stable surface created by placing a bench with a height of 65 cm under the ankle joints of the subjects. Knee table: Push-up exercise performed on a stable surface created by placing a bench with a height of 65 cm under the knee joints of the subjects ES: erector spinae muscle, RA: rectus abdominis muscle, EOA: external oblique abdominal muscle SA: serratus anterior muscle, DMF: deltoid middle fiber muscle, PM: pectoralis major muscle. TB: triceps brachii muscle

NOTE. Each value represents the mean ± SE. The values with different superscripts in the same column are significantly different ($p<0.05$) by Tukey's test.

The deltoid middle fiber muscle activity was 17573.2 ± 2501.5 in the Foot ball position, 11622.4 ± 1549.1 in the Knee ball position, 12577.3 ± 1852.1 in the Foot table position, and 10117.0 ± 1477.7 in the Knee table position, showing significant differences. The post-hoc test showed a significant difference between the Foot ball and the Knee ball results and between the Foot ball and the Knee table results.

The pectoralis major muscle activity was 6968.7 ± 479.7 in the Foot ball position, 5077.1 ± 359.0 in the Knee ball position, 5979.6 ± 462.4 in the Foot table position, and 4278.8 ± 281.3 in the Knee table position, showing significant differences. The post-hoc test showed significant differences between the Foot ball and the Knee ball results and between the Foot ball and the Knee table results (Table 1).

DISCUSSION

In this study, subjects performed push-up exercises on a stable surface and on an unstable surface while placing their feet at a higher level than their hands. We then analyzed the effect of the moment arm length on the muscle activation of the upper limbs and the trunk. The muscle activity analysis showed significant differences among the individual positions in the erector spinae muscle, rectus abdominis muscle, external oblique abdominal muscle, serratus anterior muscle, deltoid middle fiber muscle, and pectoralis major muscle.

The change in the erector spinae muscle, rectus abdominis muscle, and external oblique abdominal muscle activities in the trunk during the push-up exercises were significantly different among the individual positions. The push-up exercises were performed with the feet placed at a higher level than the hands and this might have increased the muscle activity of the trunk reducing the lordosis increase of the spine and pelvis caused by the increased moment and gravity between the arms and shoulders. Additionally, the rectus abdominis muscle, external oblique abdominal muscle, and erector spinae muscle muscle activities were higher in the Foot ball position than in the other positions in order to maintain the balance between the left and right sides, because these muscles contribute to trunk stability. This result is consistent with the result of Vera-Garcia[10)], who noted that the contraction and muscle activity of the trunk flexors and extensors were higher when a curl-up exercise was performed on an exercise ball.

No significant differences were found in the triceps brachii muscle activities during the push-up exercises among the different exercise position. The proximal part of the body should be under anticipatory control to insure the stable motion of the distal parts. Anticipatory control is known to free the distal part motion by increasing the stability of the proximal parts. In this study, the shoulder complex stabilizers might also have been contracted in advance under the unstable conditions to insure the stable balance of the lower limbs and the trunk, which were the unstable distal parts. This result is consistent with the result of Naughton[9)] who found that the muscle activation of the proximal parts is required in order for motion of the distal parts to occur. However, the reason why the muscle activity of the triceps brachii muscle was not significantly different in this study may be due to the fact that the muscle activity of the triceps brachii muscle, the agonist of the elbow extensor, remained constant since the height of the ball and the bench were the same; thus, the gravitational weight load on the hands remained constant. This result is in agreement with the findings of Gregory[7)], who noted that push-up exercises performed on a ball and a bench did not affect the muscle activity of the triceps brachii muscle. All the muscle activities except that of the triceps brachii muscle were higher in the Knee ball position than in the Knee table position, but the differences were not significant. This indicates that push-up exercises performed on a stable surface and on an unstable surface with shortened moment do not significantly affect the muscle activation of the upper limbs and the trunk.

The erector spinae muscle, serratus anterior muscle, deltoid middle fiber muscle, and pectoralis major muscle activities were higher in the Foot ball position than in the Foot table position, but the differences were not significant. This result contradicts previous results since no significant difference was found between the two positions.

The results of this study cannot be generalized to subjects in an older population or to subjects with shoulder pain. Also the increase in the muscle activity should be investigated in more varied motions than those included in the push-up exercise performed on an unstable surface.

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