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The Effect of Push-up Exercise with Different Lower Limb Heights on the Trunk and the Shoulder Stabilizing Muscles

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Abstract. [Purpose] In this study, to investigate the effect of various lower limb heights on the muscle stabilizers and the trunk muscles, we measured the muscle activation of the trunk muscles and the shoulder girdle muscles as different lower limb heights. [Subjects] The subjects of this study were 17 healthy adults in their 20s who had normal range of motion and who had no disorders of the shoulder complex, musculoskeletal disease in the upper limbs, or low back pain. [Methods] The lower limb height was controlled during the push-up plus exercise by placing the lower limbs on the ground (0 cm) or elevating them to 30 cm using a box. The height was increased to 60 cm using a Bobath table. 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 activities of the erector spinae, rectus abdominis, serratus anterior and that of the deltoid middle fiber increased as the lower limb height increased. In particular, the increase was significant at the level of 60 cm. [Conclusion] Our result that the muscle activation of the shoulder girdle muscles increases as the height of the lower limbs increases during push-up exercise is similar to those of the previous studies. The muscle activities of trunk muscles was also increased. The increase was significant at the lower limb height of 60 cm.
Key words: Push-up, Unstable surface, Muscle activation

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INTRODUCTION

Many researchers have studied the abnormality in the position and movement of the shoulder girdle. The major causes of the dysfunctions of the shoulder joint are considered to be the dysfunction in the surrounding muscles that induce the abnormal movement of the shoulder girdle[1)]. Many researchers have been interested in the role of the serratus anterior in the stabilization of shoulder joints, and have studied exercise methods that can selectively strengthen the serratus anterior[2)]. Appropriate activation of the serratus anterior is important for maintaining the normal scapulohumeral rhythm when raising the arms. The serratus anterior keeps the scapula attached to the thorax, during flexion of the humerus and the raising of it in the abduction, preventing the scapula from being webbed and helping it to turn in the posterior direction by rotating it upwards[3)]. The serratus anterior plays an important role in stabilizing the scapula as well as the entire shoulder joint[2)].

Open kinetic chain and closed kinetic chain exercises are often conducted as shoulder girdle rehabilitation exercises. In closed kinetic chain exercises resistance is simultaneously applied to the proximal and distal parts while the proximal part is fixed. In particular, push-up plus exercise is known as an exercise method that enhances the a positive effect on shoulder stabilizing muscle strengthening, since it elevates the muscle activities of the shoulder stabilizer muscles[4, 5)].

An unstable surface is often used in stabilization rehabilitation exercises to increase muscular strength and proprioceptive sense. A number of researchers have reported that the muscle activation of specific trunk and leg muscles is higher when performing squats, bridging exercises and upper limb strengthening exercises on an unstable surface than when perfirming them on a stable surface[6–8)]. To effect stable movement of the distal part during push-up exercise, many studies have examined exercises on unstable surfaces that allow anticipatory control of the proximal part[5, 9, 10)].

However, in most of the studies, the unstable conditions used in push-up exercises were unstable bases under the upper limbs. Gregory et al., conducted a study of various push-up exercise positions and reported that increased foot heighrs in push-up exercises enhanced the a positive effect on the shoulder complex stabilizer muscles such as the serratus anterior and the upper trapezius[11)]. Kim showed that the muscle activities of the shoulder and trunk muscles is dependent on the resistance directions of the leg of the

Table 1. Mean of average muscle activity during push up variations heights

Muscle	0 cm	30 cm	60 cm
ES*	122.1 ± 13.0 [a]	151.2 ± 21.9 [a]	219.2 ± 30.5 [b]
RA*	303.4 ± 47.1[a]	429.5 ± 82.9[a]	697.5 ± 147.8 [b]
EOA	282.0 ± 68.0	327.7 ± 69.9	544.1 ± 756.7
SA*	366.9 ± 53.1 [a]	470.9 ± 54.5 [a]	767.6 ± 97.9 [b]
TB	14955.6 ± 2824.6	17897.2 ± 3359.8	19341.1 ± 3925.1
DEF*	6441.2 ± 1438.7 [a]	8536.6 ± 936.4 [a]	11292.6 ± 1583.3 [b]
PM	5375.9 ± 722.9	5747.6 ± 882.7	5109.0 ± 718.9

(Unit: %RVC) ES: erector spinae muscle, RA: rectus abdominis muscle, EOA: external oblique abdominal muscle SA: serratus anterior muscle, TB: triceps brachii muscle, DMF: deltoid middle fiber muscle, PM: pectoralis major muscle
NOTE. Each value represents the mean ± SE. The values with different superscripts in the same row are different significantly ($p<0.05$) according to Tukey measure.

same side during the push-up plus exercise, and reported that performing push-up exercises while raising the leg on the same side was effective at selectively strengthen the serratus anterior[12].

However, the previous studies only showed that increased lower limb heights in push-up exercises increased the muscle activation of the serratus anterior, and there has been insufficient study of the effect of different lower limb heights on other shoulder stabilizers and the trunk muscles. Therefore, in this study, we investigated the effect of lower limb heights on the muscle activation of the trunk muscles and the shoulder girdle muscles.

SUBJECTS AND METHODS

The subjects of this study were 17 healthy in their 20s who had normal range of motion (ROM) and who had no 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 an informed consent form confirming their voluntary participation. The general characteristics of the subjects were age, 22.3 ± 4.1; height, 173.5 ± 5.0 cm; and weight, 71.3 ± 6.7 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 on a computer monitors while performing the push-up exercise, so that they could perform accurate scapula protraction. For 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 lower limb height was controlled during the push-up plus exercise by placing the lower limbs on the ground (0 cm), and elevating them to 30 cm using a box. The level was increased to 60 cm using a Bobath table (AKRON, AKRON Mat Table-4511). The muscle activities were measured three times while repeating the exercise, and the mean value was used for the analysis. To avoid the effect of muscular fatigue of the shoulder stabilizers, the three heights (0 cm, 30 cm and 60 cm) were randomly ordered for the exercise.

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. To measure muscle activities 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 InfinitiTM (Thought Technology Ltd., Canada) biofeedback software was used to measure the activity 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. Muscle contractions were calculated relative to the mean EMG signal for three seconds in the middle portion of the EMG recording, excluding the measurements of the first second and the last second. The muscle activities of resulting from one push-up were expressed as the relative muscle contraction in %RVC.

The measured data were analyzed by performing one-way ANOVA using SPSS for Windows (version 12.0) to compare the activities of the shoulder stabilizers depending upon the muscle activation of the distal body part. Significance was accepted for values of $p<0.05$.

RESULTS

The erector spinae muscle activity was 112.1 ± 13.0 as the lower limb height of 0 cm, 151.2 ± 21.9 at 30 cm, 219.2 ± 30.5 at 60 cm, showing significant differences. The post hoc test showed significant differences between the 0 cm and 60 cm, and between 30 cm and 60 cm ($p<0.05$). Rectus abdominis muscle activity was 303.4 ± 47.1 at 0 cm, 429.5 ± 82.9 at 30 cm, 697.5 ± 147.5 at 60 cm, showing significant differences. The post hoc test showed significant differences between 0 cm and 60 cm, and between 30 cm and 60 cm ($p<0.05$). Serratus anterior muscle activity was 366.9 ± 53.1 at 0 cm, 470.9 ± 54.5 at 30 cm, 767.6 ±

97.9 at 60 cm, showing significant differences. The post hoc test showed significant difference between 0 cm and 60 cm, and between 30 cm and 60 cm ($p<0.05$). Deltoid middle fiber muscle activity was 6441.2 ± 1438.7 at 0 cm, 8536.6 ± 936.4 at 30 cm, 11292.6 ± 1583.3 at 60 cm, showing significant differences. The post hoc test showed significant difference between 0 cm and 60 cm, and between 30 cm and 60 cm ($p<0.05$). (Table 1).

DISCUSSION

In this study, to investigate the effects of different lower limb heights on the shoulder muscle stabilizers and the trunk muscles, we measured the muscle activities of the trunk muscles and the shoulder girdle muscles.

Regarding the trunk muscles, the activation of the erector spinae and that of the rectus abdominis increased as the lower limb height was increased. In particular, the increase was significant at the height of 60 cm. A possible explanation for the sesults is that the eccentric contraction of the erector spinae and the concentric contraction of the rectus abdominis increased to neutralize the increase in pelvic lordosis, as the gravitational force was increased between the axis (foot) and the shoulders by the elevation of the feet. The muscle activation of the external oblique abdominal muscle was increased, but not significantly, possibly because the elevated foot height only the up-and-down stability, not left right stability.

Regarding the shoulder girdle muscles, the muscle activation of the serratus anterior and that of the deltoid middle fiber increased as the lower limb height was increased. In particular, the increase was significant at the elevation of 60 cm. Since anticipatory control of the proximal part needs to be performed for stable movement of the distal part, it is conceivable that pre-contraction of the shoulder complex stabilizers occurred in order to stabilize the trunk before the lower limb height increase. The shoulder girdle flexion angle was increased by the elevation of the lower limbs, which resulted in increased muscle activities due to by the upward rotation of the scapular and flexion of the glenohumeral joint. Other shoulder girdle muscles, the triceps brachii and the pectoralis major, also showed increased muscle activities, but the increases were not significant. It is possible that cocontraction of the other shoulder girdle muscles occurred when the gravitational load on the hands was increased by the increase of the lower limb height, causing the concentric and eccentric contraction of the elbow during its extension and flexion as well as the concentric and eccentric contraction of the glenohumeral joint during its internal and external rotation.

Our result that the muscle activities of the shoulder girdle muscles was increased by increase of lower limb height during push-up exercises is similar to those of previous studies. The muscle activities of the trunk muscles also increased. The increases were significant at the height of 60 cm. In light of the outcomes, one of the effective ways for athletes or ordinary people to employ rehabilitation would be to elevate the lower limbs when performing push-ups, which would strengthen their shoulder girdle muscles and trunk muscles. However, a limitation of this study is that the subjects were young healthy males having no history of shoulder pathology; therefore the results of this study should not be generalized to older populations or subjects with shoulder pain. Future studies need to be conducted to accurately measure the shoulder angle at higher elevations of the lower limbs during push-up exercise, and to investigate the muscle activities of other shoulder girdle muscles.

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