Periscapular Muscle Activities and Kinematic Analysis of the Performed on Different Supporting Surfaces for the Lower Limbs Push-up Plus Exercise

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Abstract. [Purpose] This study examined periscapular muscle activities and performed a kinematic analysis of the push-up plus exercises with the lower limbs supported on a stable surface (bench) and an unstable surface (elastic ball). [Subjects and Method] The subjects were 15 college students. Surface electromyograms were recorded of the upper trapezius, serratus anterior, latissimus dorsi, and infraspinatus while the subjects performed the push-up plus exercises with their feet placed on a bench or an elastic gym ball. Markers for kinematic changes of elbow flexion, shoulder extension, shoulder retraction and scapular adduction were attached to the C7 and T7 spinous processes, both acromions, scapula superior and inferior angles, humeral lateral epicondyles, and ulnar styloid processes. The subjects completed three sets of push-up plus exercise. Three dimensional angles were calculated for the elbow, glenohumeral and scapulothoracic joint motions. The collected data were analyzed using the paired t-test and SPSS 18.0. [Result] There were statistically significant increase in the serratus anterior, infraspinatus, latissimus dorsi muscle activities during push-up plus exercise performed on the unstable surface, while the activity of upper trapezius increased during push up plus exercise performed on the stable surface. The angle of shoulder extension was significantly greater on the stable surface than on the unstable surface. The length of scapular adduction was significantly greater on the stable surface than on the unstable surface. [Conclusion] When the push-up plus exercise was performed on an unstable surface, recruitment of the periscapular muscles helped to stabilize the instable scapula. Key words: Push-up plus exercise, Surface characteristics, Kinematic analysis

INTRODUCTION

Movement of the scapulothoracic joint is a vital factor for stability and mobility of the upper body. The main functions of this particular joint include providing a supporting surface for the movement of the humerus in order to increase the range of motion of the arm, maintaining a proper length-tension relationship of the deltoid when lifting the arm, and providing stability for the upper arm1).

The scapulothoracic joint is a false joint formed by fascia. Most exercises for the shoulder aims to stabilize the scapula by activating the muscle groups around the shoulder which stabilize the upper extremity2). Rehabilitation and prevention programs for shoulder instability, impingement syndrome, rotator cuff rupture, etc., emphasize the importance of scapular stabilizer exercise3). The push-up plus is the exercise most commonly used for enhancing shoulder joint functions. It is a modification of the standard push-up exercise, and the subject performs maximal scapular protraction once the elbows are extended. The “plus” refers to the voluntary addition of scapular protraction once the elbow is extended in a standard push-up4). High activities of the muscles around the scapula during push-up deliver stability and mobility to the shoulder joints and allow the upper arm to execute proper functional motion5–7). Recent rehabilitation programs recommend the use of the push-up plus on an unstable surface in order to increase the activities of the muscles around the scapula, proprioception, and balance of shoulder movement. Also, various researches are being performed to investigate the differences in muscle activities evoked by different supporting surfaces8–11).

Marshall and Murphy12) used a ball as an unstable surface. Ball exercise is one of the helpful exercises that can increase dynamic stability by activating deep muscles of the trunk, which is helpful for improving the balance ability of the whole body12, 13). Ball exercise was first used to treat children with cerebral palsy, but after its usefulness in increasing mobility, stability and coordination was proved, it became widely used in the treatment of various disorders as well as in many rehabilitation programs for athletes. Several researchers have reported on push-ups using a ball. They report that the exercise helps increase the muscle activities of the triceps brachii and rectus abdominis9, 14, 15). Borstad et al.13) reported a high correlation between muscle activity and scapular movement. They also mentioned that more in-depth research into muscle activities and scapular movement is required. It is evident that research related to push-ups has focused on muscle activity and movement analysis of the
scapulothoracic joint. However, little research has been carried out into the correlation between the elbow joint movement and shoulder joint muscle activities used in push-ups.

The present study focused on the role and influence of different characteristics of the supporting surfaces during the push-up plus. We compared the activity of the muscles around the scapula while doing the push-up plus on a stable bench surface, and an unstable gym ball surface. We also used 3-dimensional movement analysis system to investigate the movement of the elbow joint, shoulder joint, and scapula during performance of the push-up plus.

**SUBJECTS AND METHODS**

Fifteen males in their 20’s voluntarily participated in this study. None of the subjects had problems their musculoskeletal, nervous, or cardiovascular systems, and they were able to complete the push-up plus exercise according to the instructions given by the researcher. Before participating in this research, all the subjects were given an explanation about the content and the procedures of the experiment. They voluntarily participated in the research, and signed an informed consent form.

The instruments used for the push-up plus were an adjustable bench (adjustable bench S5A, KAYE, USA) for the stable surface, and a gym ball, diameter of 65 cm, for the unstable surface (Gymnic ball, Redplastic, Italy). The height of the bench was adjusted to 65 cm, the same height as the gym ball.

An 8 channel electromyograph (8-EMG) (Pocket EMG, BTS, Italy) was used to measure muscle activities around the scapula during performance of the push-up plus. The sampling rate of electromyography was set to 1,000 Hz (1,000 samples/second) and the amplified wave was band-pass filtered between 20~500 Hz. We attached EMG surface electrodes (Ag/AgCl Monitoring Electrode 2225, 3M, Korea) to the muscles around the scapula. The 8-EMG system was used to collect raw surface EMG data from the serratus anterior, upper trapezius, infraspinatus, and latissimus dorsi muscles. The serratus anterior electrode was placed approximately 1 cm above the level of the inferior angle of the scapula, anterior to latissimus dorsi on the lateral thorax at the level of the fifth rib. The upper trapezius electrode was placed at the midpoint of the line between the acromioclavicular joint and the seventh cervical spinous process. The infraspinatus electrode was placed medial to the posterior deltoid approximately 1 cm below the spine of the scapula. The latissimus dorsi electrode was placed 3 fingerbreadths distal to and along the posterior axillary fold, parallel to the lateral border of the scapula.

Surface electrodes were attached along the direction of the muscle fibers of each muscle group, and ground electrodes were placed around the C6 spinous process. The activity of each muscle was normalized to the EMG activity of maximal voluntary isometric contraction (MVIC), which was measured in manual muscle tests after linear filtering of the data for 5 seconds. The first and the last 1 seconds of data were discarded, and the average EMG signal of the middle 3 seconds was used as 100% MVIC. The average root mean square (RMS) value was used to exhibit the activity of each muscle group while conducting push-ups on the stable and unstable surfaces.

A three-dimensional motion analyzer (SMART-E, BTS, Italy) was used to measure the distance between both scapulae and joint angles. The motion analyzer has 6 infrared cameras and 2 video cameras (vixta 2 TVC, BTS, Italy). Circular passive markers are used for motion analysis. The kinematic data were sampled at a frequency of 120 Hz and processed using the data analysis program, SMART Analyzer (SMART-E, BTS, Italy). The markers were attached to the C7 spinous process, acromions, scapular superior angles, scapular inferior angles, T7 spinous process, humeral lateral epicondyles, ulnar styloid processes. For the flexion value of the elbow joint, the angle between the acromion and the ulnar styloid process was measured using the humeral lateral epicondyle as the axis. For the extension angle of the shoulders, the angle between the scapular inferior angle and the humeral lateral epicondyle was measured with the acromion as the axis. We also measured the retraction angle of the shoulders between the T7 spinous process and the scapular superior angle, with the acromion as the axis. The value of the changes in the length of scapular adduction were measured as the distance between both the scapular superior angles.

The starting position of the push-up plus for the subjects was with their hands shoulder width apart, placed on the floor with fully flexed elbows and the lower limbs placed on the bench, the stable surface. Subjects then extended their elbows to the standard push-up position and continued to rise up by retracting the scapulae. The subjects then returned to the starting position by retracting the scapulae and flexing the elbows. While they executed the push-up plus, subjects were told to keep their bodies straight and not to abduct their shoulders. After practicing 3 times, measurements began. Within 1 minute of measurement, the subjects had executed 3 push-ups at a speed of their own comfort, and after each set of 3 push-ups 2 minutes were given for rest. Measurements were done 3 times. After completing push-ups on the stable surface, the subjects were given 30 minutes of rest to prevent carry-over effects. The measurements on the unstable gym ball surface were done in the same way, except with the lower limbs placed on a gym ball.

SPSS Version 18.0 for Windows was used for the data analysis of the present research. The characteristics of the data used in the analysis were confirmed to have a normal distribution with the K-S test (Kolmogorov-Smirnov test). The paired t-test was used in order to compare the values of muscle activities, angles, and the distance between the scapulae between the stable and unstable surfaces during performance of the push-up plus. Statistical significance was accepted for values of $\alpha \leq 0.05$.

**RESULTS**

The general characteristics of the subjects are presented in Table 1.

The muscle activities of the left serratus anterior, right latissimus dorsi, and right infraspinatus were significantly different between the stable and unstable surfaces. The muscle activities of the left serratus anterior, right latissimus dorsi, and right infraspinatus were significantly different between the stable and unstable surfaces. The muscle activities of the left serratus anterior, right latissimus dorsi, and right infraspinatus were significantly different between the stable and unstable surfaces.
higher on the unstable surface than on the stable surface (p<0.05), whereas the muscle activity of the left upper trapezius on the stable surface was significantly higher than that on the unstable surface (p<0.05) (Table 2).

The extension angle of the right shoulder on the stable surface was $55.48 \pm 12.89^\circ$ (Mean ± SD), which was significantly higher than that on the unstable surface, $52.04 \pm 15.35^\circ$ (p<0.05). The extension angle of the left shoulder on the stable surface was $57.87 \pm 14.47^\circ$, which was significantly higher than that on the unstable surface, $52.34 \pm 14.03^\circ$ (p<0.05). There were no significant differences in the flexion angle of the elbow joints or the retraction angle of the shoulder (p>0.05).

Changes in the length of scapulae adduction were more apparent on the stable surface ($80.74 \pm 20.74$ mm) than on the unstable surface ($75.00 \pm 22.20$ mm) (p<0.05).

**DISCUSSION**

The muscle groups around the scapula are vital for the mobility and stability of the scapula joint. The stabilizers around the scapula include the serratus anterior, trapezius, rhomboideus, and rotator cuff18). When any scapula stabilizer weakens or suffers fatigue, the scapulohumeral rhythm is damaged causing limitation of function in the shoulder joint.

Ludewig and Cook3), McClure et al. 19), and Tucker et al.20) reported that when patients with impingement syndrome raise their arms, a decrease of activity in the serratus anterior and an increase of activity in the upper trapezius is seen. Therefore, in rehabilitation and prevention programs for dysfunction of the shoulder joint, balanced reinforcement of the muscles around the scapula is necessary. The push-up plus seems to be the most appropriate form of exercise for improving shoulder movement during push-ups.

This study compared the activities of muscle groups around the shoulder, and movement of elbow joint, shoulder joint, and scapula during execution of the push-up plus on different supporting surfaces. Using this data, we investigated what is the most effective method of exercise for improving shoulder movement during push-ups.

The results of this study show the muscle activities of the left serratus anterior, right latissimus dorsi and right infraspinatus on the unstable surface were significantly higher than those on the stable surface (p<0.05). We also found that the muscle activity of the left upper trapezius on the stable surface was significantly higher than that on the unstable surface (p<0.05). These results empirically support the theory proposed by Shumway-Cook and Wollacott17), who reported that stabilizer muscle groups tend to co-contract in order to keep the balance of the body on an unstable surface. The increase in muscle activity when executing the push-up plus on the unstable surface, a gym ball, means that a large number of motor units were recruited in order to keep the shoulder properly balanced5). However, the left upper trapezius showed more activity on the stable surface, a result which calls for further research on differentiated muscle functions of muscles located above and below the scapula. Park et al.7) reported that there was an increase in muscle activity of the serratus anterior when executing push-ups on an unstable surface, a sling, compared to a stable surface. Our research confirms their result. The same result was also reported by Lee et al.22), who suggested that muscle activity increases to compensate for increased instability in maintaining the balance of the body.

The shoulder joint extension and elbow joint flexion changed in push-up plus performance on different surfaces. The extension angle on the stable surface was significantly higher than that on the unstable surface (p<0.05). We also found that the length of scapulae adduction was significantly longer on the stable surface compared to that on the unstable surface (p<0.05). These results suggest that the movement of the joints on the stable surface was greater than on the unstable surface, where the increase in muscle activity around scapula may have limited the movement of the joints. As previously stated, when exercising on an unstable

**Table 1. Subjects' characteristics**

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<tr>
<th>Age (yrs)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
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<td>Mean ± SD</td>
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| Experimental Group (N=15) | 22.5 ± 2.16 | 177.3 ± 5.57 | 67.0 ± 6.74 |

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<th>Table 2. Comparison of muscle activities on different surfaces during performance of the push-up plus</th>
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<tr>
<td>Measured Muscle</td>
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<td>-----------------</td>
</tr>
<tr>
<td>Right serratus anterior</td>
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<td>Right serratus anterior</td>
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<tr>
<td>Left serratus anterior*</td>
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<td>Left serratus anterior*</td>
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<tr>
<td>Right upper trapezius</td>
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<td>Right upper trapezius</td>
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<td>Left upper trapezius*</td>
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<tr>
<td>Left upper trapezius*</td>
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<td>Right latissimus dorsi*</td>
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<td>Left latissimus dorsi</td>
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<td>Left latissimus dorsi</td>
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<td>Right infraspinatus*</td>
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<td>Left infraspinatus</td>
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[Unit : mV/sec] * p<0.05
surface, muscle groups around the scapula are activated in order to maintain balance which may restrict motion of the scapula.

To summarize, our research result leads us to conclude that the push-up exercise can be more helpful for strengthening muscle groups around the scapula when it is performed on an unstable surface rather than on a stable surface. Also, the movement of the shoulder joint and the length of scapular adduction were larger on the stable surface than on the unstable surface. This result perhaps indicates that although strength training on the unstable surface is important, functional movements of the scapula in activities of daily living are greater on a stable surface.

A limitation of the present research is that this experiment was conducted using only a small number of adult males who were able to execute the push-up plus. Thus, we may not safely generalize our research results to any other age group. However, the main significance and contribution of the current research may lie in its focus on kinematic analysis of the movement of the shoulder joints during performance of push-ups on different surfaces using a motion analyzer. Therefore, the results of this research might provide kinematic evidence for the movement of shoulders that can be helpfully used in designing a rehabilitation program for damaged shoulders on stable and unstable surfaces. Further research needs to be done using patients with shoulder joint dysfunction and an organized training program for a sufficient amount of time. We also recommend that periodic kinematic analysis of shoulders be performed for patients with shoulder dysfunction according to the schedule of a rehabilitation program.

REFERENCES

1) Borstad JD, Scace K, Navalagund A: Scapula kinematic alterations following a modified push-up plus task. Hum Mov Sci, 2009, 28: 738–751. [Medline] [CrossRef]