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A Comparison of Scapulothoracic and Trunk Muscle Activities among Three Variations of Knee Push-up-plus Exercises

JUNG-BIN KIM[1)], IM-RAK CHOI[1)], WON-GYU YOO[2)]

[1)]*Department of Physical Therapy, The Graduate School, Inje University*
[2)]*Department of Physical Therapy, College of Biomedical Science and Engineering, Inje University: 607 Obangdong, Gimhae, Gyeongsangnam-do, 621-749 Republic of Korea. TEL: +82 55-320-3994, FAX: +82 55-329-1678, E-mail: won7y@inje.ac.kr*

Abstract. [Purpose] This study compared the activations of the shoulder and trunk muscles during dominant-leg-extended knee push-up-plus (KPP) exercises on a mat, on an unstable surface, and with loading. [Subjects] Fourteen healthy subjects, all right-side dominant and with no history of injury or surgery to the shoulder or neck were the subjects. [Methods] The subjects performed dominant-leg-extended knee push-up-plus using three variations. Electromyography activities of the serratus anterior (SA), upper trapezius (UT), external oblique (EO), and internal oblique (IO) muscles were recorded. [Results] We observed significant differences in SA activity among the exercise conditions. Dominant-leg-extended KPP on a stable surface produced the highest SA muscle activity. Dominant-leg-extended KPP using a wobble board produced the highest EO and IO muscle activity. [Conclusion] To apply the proper resistance to enhance selective SA muscle activity in KPP, the best technique is to raise the ipsilateral leg. Furthermore, KPP on an unstable surface can facilitate lumbar stabilization.
Key words: Electromyography, Knee push-up-plus, Serratus anterior

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INTRODUCTION

The scapula performs functions contributing to the stability and mobility of the shoulder complex[1)]. The loss of this stability mechanism typically influences scapular alignment. Poor scapular stability and alignment are often associated with neuromusculoskeletal dysfunction of the neck and shoulder region. Because the scapula plays a critical role in controlling the position of the glenoid, relative changes in the action of the thoracoscapular muscles can affect the alignment and forces involved in movement around the glenohumeral joint[2)]. The upper trapezius and the serratus anterior are the stabilizing muscles of the scapulothoracic joint[3,4)]. In cooperation with the lower trapezius, these muscles are optimally positioned to keep the scapula aligned with the thorax and ensure dynamic stabilization. Shoulder disorders are observed to be associated with an abnormal activation pattern of these muscles, termed scapular muscle imbalance[5)]. Specifically, patients with neck and shoulder disorders frequently show excessive activity of the upper trapezius combined with reduced activity of the lower trapezius and serratus anterior muscles[5)]. Scapular setting exercises are used to stabilize the shoulder and are of two types: open kinetic-chain (OKC) and closed kinetic-chain (CKC) exercises. Like standard push-up and standard push-up-plus (SPP), CKC exercises have been shown to stimulate mechanoreceptors that contribute to shoulder joint stabilization[6–8)]. Usually, push-up exercise is initiated from a prone position, and knee push-up-plus (KPP) is more effective for shoulder resistance[9)]. An unstable surface causes increased muscle activation. Some studies have been carried out to evaluate the effects of push-up exercises performed on unstable surfaces. Vera Gracia et al. (2002) found that curl-ups performed on an unstable surface increased abdominal muscle activation compared with more stable surfaces[10)], and Arokoski et al. (2001) also reported that an unstable surface caused greater activation in trunk muscles[11)]. Maenhout et al. (2009) reported scapular EMG activity during knee push-up-plus (KPP) and six commonly used variations[9)]. When using a kinetic-chain approach during KPP, ipsilateral leg extension increased SA activity because the stress of the thoracolumbar fascia was transmitted to the contralateral scapula.

The purpose of this study was to investigate the influence on SA, UT, EO and IO of KPP with leg extension using a wobble board under the supporting knee and with a load applied to the extended leg. We especially wanted to determine the appropriate exercises for selective strengthening of SA and the abdominal muscles.

SUBJECTS AND METHODS

Fourteen healthy subjects (eight men, six women) volunteered to participate in this study. The subjects were aged 23.7 ± 2.32 years, with average height of 170.7 ± 8.45 cm and average body weight of 62.5 ± 10.3 kg. All subjects were right-side dominant and met the requirements for muscle power, range of motion, and balance ability for the study. Subjects were excluded if they had a history of injury or surgery to the shoulder or neck. Ethical approval for this study was obtained from the Inje University Faculty of Health Sciences Human Ethics Committee. The subjects provided informed consent prior to their participation.

Muscle activity of the SA, UT, EO, and IO muscles were recorded using a MP150WSW electromyography system (BIOPAC Systems, Santa Barbara, CA, USA) and surface EMG bipolar electrodes 20 mm in diameter. All EMG signals were amplified, bandpass filtered (30–450 Hz), and sampled at 1,000 Hz using Acknowledge 3.9.1 software (BIOPAC Systems, Santa Barbara, CA, USA). Skin impedance to electrical signals was reduced by shaving body hair and cleaning the skin with alcohol prior to electrode placement. SA electrodes were placed on the muscle belly at the mid-axillary line of the right (dominant) side, over the fifth rib. UT electrodes were placed on the muscle belly midway between the C7 spinous process and the trapezius insertion, at the right acromioclavicular joint. EO electrodes were placed parallel to the muscle fibers approximately 15 cm lateral to the umbilicus. IO electrodes were placed midway between the anterior iliac spine and symphysis pubis, above the inguinal ligament. The root mean square values of the raw data were calculated, and the maximal EMG data were used to normalize the EMG signals acquired during each maximum voluntary contraction (MVC) maneuver. The mean value of the EMG data for all tasks was expressed as a percentage relative to MVC. SA MVC procedures were performed with the subjects in the supine position; the scapula was protracted at 90 degrees of shoulder flexion as resistance was applied over the hand and at the elbow. UT measurements were performed with the subjects sitting in an erect posture without back support; the shoulder was abducted to 90 degrees, and then resistance was applied above the elbow. The maximum activation of the abdominal obliques (IO and EO) was obtained by a combined flexion-rotation exertion from a supported, straight-knee sitting position, with the hands placed behind the head and the trunk held at a 45° angle. Manual resistance was applied to the contralateral shoulder. Three repetitions of 5 seconds were performed, with 5 seconds rest between contractions. All EMG data were calculated from the middle 3 seconds of 5 seconds of data. Two minutes rest were provided between MVC measurements of different muscles.

The three exercises were as follows: Exercise 1 – KPP with ipsilateral leg extension on a mat; Exercise 2 – KPP with ipsilateral leg extension on a wobble board; Exercise 3 – KPP with ipsilateral leg extension with a 5 kg weight attached to the ankle of the raised leg. Before testing, a primary investigator explained the experimental conditions to all subjects, who practiced for 10 minutes to become familiar with the exercise surface. The wobble board was a wooden balance board commonly used as a stability exercise tool, 16 inches in diameter and 3 inches high (Fitter International, Inc., Canada). In the knee prone position, the subject's arms were positioned shoulder width apart. To standardize the position of the subject and the equipment, markers were placed on the floor. At the beginning of each exercise, a neutral-spine position was assumed, and the subject was encouraged to hold this position throughout the exercise. The neutral-spine position was set about halfway between full extension and a flat position of the spine. Speed was controlled with a metronome at 60 beats per minute. All exercises were performed three times, with 2 minutes rest between trials. All experimental procedures were performed by the same investigator to reduce variability in marker and electrode placements. The order in which the base surfaces were used and in which the exercises were performed were selected randomly.

The SPSS 17.0 statistical package was used for statistical analysis. Differences in SA, UT, EO, and IO activities during KPP with the dominant right leg extended on the mat, with a wobble board under the opposite knee, and with a 5 kg weight on the extended leg were tested by repeated one-way ANOVA. The major effects were evaluated using Bonferroni's correction, and results were considered significant at $p < 0.05$.

RESULTS

Statistical analysis of the SA EMG activity showed significant differences among the different KPP exercises with ipsilateral leg extension ($p < 0.05$). SA EMG activity when using a 5 kg weight was significantly higher than when the mat or the wobble board was used ($p < 0.01$). Clinically relevant and statistically significant differences in mean EO and IO EMG activity were also found ($p < 0.05$). The EO and IO activities when using the wobble board were significantly higher than their respective values when the mat was used. The comparison of all three exercises revealed no significant differences in mean normalized EMG UT activity (Table 1).

Table 1. Comparison of EMG data in 3 knee push-up-plus exercises

Muscles	Mean ± SD (%)		
	Exercise 1	Exercise 2	Exercise 3
UT	18.6 ± 16.7	20.1 ± 17.3	20.5 ± 17.7
SA	78.6 ± 11.9	83.5 ± 12.0	90.5 ± 6.2*
EO	35.1 ± 23.6	43.0 ± 23.5*	35.4 ± 22.2
IO	56.8 ± 21.8	71.7 ± 22.8*	60.8 ± 21.6

*p<0.05

DISCUSSION

We investigated the muscle activity of UT, SA, EO, and IO during KPP employing ipsilateral leg extension while maintaining a four-point position under three conditions: mat, wobble board, and 5 kg loading. The SA activity was most affected when the KPP exercise included a 5 kg weight on the ankle while maintaining a four-point position. This may be due to myofascial connections, through which the lower limb muscle activity might have influenced scapular muscle activity[12)]. Extension of the ipsilateral leg generates gluteus maximus activity, which tightens the thoracolumbar fascia. The stress of the thoracolumar fascia would increase, regulating tension of the overall lumbar extension, which would stimulate ipsilateral EO activity. EO activity, in turn, would be transmitted to the ipsilateral scapula, leading to higher SA muscle fiber recruitment. The addition of extra weight to the ipsilateral leg would be more effective if the KPP exercise were used to strengthen selective SA muscles on the stable mat surface. According to Beith et al. (2001), the four-point position in which the inferior fiber of IO contracts independently is a better position than others[13)].

To maintain a balance between internal moment and lateral shear force, the IO muscles mobilize and transfer forces to the contralateral EO, enabling the pelvis and spine to maintain a neutral position. Maintaining balance on an unstable surface increases muscle activation of the stabilizing muscles and also increases the proprioceptive balance demands[14, 15)]. In this study, muscle activation of the EO and IO was higher for exercises performed on the unstable surface than on the stable surface. Therefore, exercising on the unstable surface activated the shoulder muscles and strengthened the deep IO muscles, improving lumbar stabilization. This study has several limitations: all participants were right side dominant, the effect of these exercises were short-term, and the sample size was small. In future studies, we recommend measuring both the shoulder muscles and increasing the sample size as well as observing the changes over the long term.

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REFERENCES

1) Mottram SL: Dynamic stability of the scapula. Manual Ther, 1997, 2: 123–131.
2) Sahrmann SA: Diagnosis and treatment of movement impairment syndromes (1st ed). St. Louis: Mosby, 2002.
3) Lear LJ, Gross MT: An electromyographical analysis of the scapular stabilizing synergists during a push-up progression. J Orthop Sports Phys Ther, 1998, 28: 146–157.
4) Ludewing PM, Cook TM, Nawoczenski DA: Three dimentional scapular orientation and muscle activity at selected positions of humeral elevation. J Orthop Sports Phys Ther, 1996, 24: 57–65.
5) Ludewig PM, Hoff MS, Osowki EE, et al.: Relative balance of serratus anteior and upper trapezius muscle activity during push-up exercises. Am J Sports Med, 2004, 32: 484–493.
6) Liebenson C: Self-management of shoulder disorder-part 3: Treatment self help patient's advice. J Body Mov Ther, 2006, 10: 65–70.
7) Lephart SM, Henry TJ: The physiological basis for open and closed kinetic chain rehabilitation for the upper extremity. J Sport Rehabil, 1996, 5: 71–87.
8) Wilk KE, Arrigo CA, Andrews JR: Closed and open kinetic chain exercise for the upper extremity. J Sport Rehabil, 1996, 5: 88–102.
9) Maenhout A, Praet KV, Pizzi L, et al.: Electromyographic analysis of knee push up plus variations: what's the influence of the kinetic chain on scapular muscle activity? Br J Sports Med, 2010, 44: 1010–1015.
10) Vera Gracia FJ, Grenier SG, McGill SM, et al.: Abdominal muscle response during curl-ups on both stable and labile surfaces. Phys Ther, 2002, 80: 564–569.
11) Arokoski JP, Valta T, Airaksinen O, et al.: Back and abdominal muscle function during stabilization exercises. Arch Phys Med Rehabil, 2001, 82: 1089–1098.
12) Meyers TW, Chaitow L, Juhan D: Anatomy trains myofascial meridians for manual an movement therapists (1st ed). Churchill Livingstone: Elsevier, 2001.
13) Beith ID, Synnott E, Newman A: Abdominal muscle activity during the abdominal hollowing manoeuvere in the four point kneeling and prone positions. Man Ther, 2001, 6: 82–87.
14) Anderson K, Behm D: Maintenance of EMG activity and loss of force output with instability. J Strength Cond Res, 2001, 18: 637–640.
15) Lehman GJ: An unstable support surface is not a sufficient condition for increases in muscle activity during rehabilitation exercise. J Can Chiropr Assoc, 2007, 51: 139–143.