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Tactile cues change trunk and scapular muscle activity, scapular winging, and thoracic kyphosis during knee push-up plus in subjects with scapular winging

The cross-sectional study

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Abstract

Serratus anterior muscle weakness causes scapular winging, characterized by scapular downward rotation and scapular anterior tipping in the resting position. Knee push-up plus (KPP), a modified push-up plus that is generally used in early rehabilitation programs, is performed to elicit SA activation. However, excessive thoracic kyphosis can easily occur as a compensatory movement during KPP. Therefore, the aim of this study was to examine the effect of tactile cues during KPP on activities of the thoracic erector spinae, rectus abdominis, lower trapezius, serratus anterior, and upper trapezius; scapular winging; and thoracic kyphosis in subjects with scapular winging.

Thirteen men with scapular winging performed KPP exercises under 3 different tactile cue conditions (no cue, to the thoracic spinous process [TSP], and to the interscapular region [ISR]). Electromyography was used to collect the muscle activity; in addition, a scapulometer and ImageJ software were used to measure the amount of scapular winging and thoracic kyphosis, respectively. One-way repeated-measures analysis of variance and Bonferroni correction were used to assess for statistical significance.

The activity of the thoracic erector spinae, rectus abdominis, serratus anterior, and upper trapezius had significant difference among three conditions ($P < .05$). Lower trapezius activity was no significantly different among 3 conditions. Degrees of scapular winging and thoracic kyphosis had also significant difference among 3 conditions ($P < .05$).

These results suggest that the tactile cue to the TSP and ISR in KPP exercise can be an effective method for decreasing scapular winging as well as correcting compensatory thoracic kyphosis during the KPP in subjects with scapular winging.

Abbreviations: ISR = interscapular region, KPP = knee push-up plus, TSP = thoracic spinous process.

Keywords: knee push-up plus, scapular winging, thoracic kyphosis

1. Introduction

The serratus anterior (SA) muscle is one of the most important muscles to stabilize the scapular medial border and inferior angle to the thoracic wall.[1] SA muscle weakness causes scapular winging, characterized by scapular downward rotation and scapular anterior tipping in the resting position.[2] Scapular winging and tipping are abnormal scapular kinematics caused by imbalances of the scapulothoracic musculature such as the upper trapezius (UT) and SA muscles.[3] Many previous studies reported that the UT muscle may be overly activated to compensate for SA weakness, so UT overactivity can result in middle and lower trapezius (LT) muscle weakness.

Open and closed kinetic chain exercises to strengthen the SA muscle have been investigated by many researchers.[4,5] Of these various exercises, the push-up plus is frequently used to strengthen the SA muscle.[6] Knee push-up plus (KPP), a modified push-up plus, is defined as maximal scapular protraction (the "plus") after full elbow extension at the end of the knee push-up maintaining the knees shoulder-width apart as the point of contact with the ground. KPP is generally used in early rehabilitation programs.[7]

Scapular protraction results from posterior translation of the thoracic wall on a fixed scapula in the plus phase of the push-up plus.[8] However, excessive thoracic kyphosis can easily occur as a compensatory movement during push-up plus. This increased flexed thoracic spine makes the scapula more protract and creates anterior tilting.[9] Thus, this posture may cause scapular posterior tilting muscle weakness (LT and SA) and glenohumeral joint range of motion limitations during arm elevation, thoracic erector spinae (TES) weakness, and shoulder impingement pathology.[10,11] Postural taping with exercise and spinal orthoses is usually used to decrease thoracic kyphosis.[11] Tactile cues also have been used to modify muscle alignment and

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activity.[12] Thus, we stimulated the thoracic spinous process (TSP) to induce thoracic alignment and the interscapular region (ISR) to induce TES activity. Park et al[13] reported higher TES activity on tactile feedback that caused continual caution and reeducation about proper position on a visual display terminal in people with postural kyphosis. However, no previous studies have investigated the effect of tactile cue on muscle activity, scapular alignment, or thoracic kyphosis angle in the plus phase of KPP in subjects with scapular winging.

The purpose of this study was to determine the effect of tactile cues (no cue, to the TSP, and to the ISR) on the electromyographic (EMG) amplitude of the TES, rectus abdominis (RA), LT, SA, and UT, scapular winging, and thoracic kyphosis in the plus phase of KPP in subjects with scapular winging. We hypothesized that corrective tactile cues to the TSP and the ISR would increase TES, LT, and SA activity; reduce RA, UT, and scapular winging; and reduce thoracic kyphosis degree during the KPP.

2. Methods

2.1. Study design and setting

This study was a cross-sectional study. Subjects were recruited from Wonju in South Korea. The Applied Kinesiology and Ergonomic Technology laboratory at Yonsei University conducted all procedures in this study. Before the investigation, subjects read and signed an informed consent form. The study was approved by the Yonsei University Wonju Institutional Review Board (1041849-201702-BM-040-03).

2.2. Subjects

We used the G-power software package for power analysis (ver. 3.1.6; Franz Faul, Kiel University, Kiel, Germany). Consequently, a necessary sample size of eight was calculated to achieve a power of 0.80 and effect size of 0.52 (calculated with a partial η_2 of 0.214 from a pilot study with 4 subjects) with an α level of 0.05. A total of 13 men with scapular winging participated in this study (mean age, 22.7 ± 3.2 years; mean height, 174.3 ± 5.3 cm; mean weight, 71.5 ± 6.1 kg; mean scapular winging = 30.2 ± 2.9 mm). Scapular winging degree was measured using a scapulometer. If the medial border of the scapula protruded >2 cm from the posterior thoracic rib cage, scapular winging was diagnosed.[14] If bilateral scapular winging was identified, the side with the greater degree was used in the data collection process. Inclusion criterion was excessive compensatory thoracic kyphosis (mean, 42.0 ± 8.7°) during the KPP. Exclusion criteria were: scapular winging due to posterior shoulder tightness; pain, a history of shoulder injury or surgery, or discomfort in the upper extremity during the previous 6 months[7]; and inability to extend the thorax at least 5° due to excessive thoracic kyphosis.[15]

2.3. EMG recording and data processing

We used a Noraxon TeleMyo 2400 system (Noraxon, Inc., Scottsdale, AZ) to collect the surface EMG data and Noraxon MyoResearch 1.06 XP software to analyze the data. The EMG signals were being recorded at 1000 Hz, processed into the root mean square after being amplified (band-pass filter: 20 and 450 Hz, and notch filter: 60 Hz). The data were collected from the TES, RA, LT, SA, and UT muscles on the scapular winging side. Disposable Ag/AgCl surface electrodes were attached to each muscle at the frequently referenced site[16] (Table 1) after the skin was shaved and rubbed with alcohol. Two electrodes were located approximately 20 mm apart in the direction of the muscle fibers to inhibit cross-talk. Maximal voluntary isometric contractions (MVIC) were collected to normalize the EMG data of the TES, RA, LT, SA, and UT muscles through Table 2.[17–19] EMG signal quality was confirmed for each muscle during MVIC. Subjects performed each posture for 5 seconds, and a 1-minute rest was given between trials to minimize muscle fatigue.[18] We used the middle 3 seconds of the 5-second contraction in the data analysis. The EMG signals recorded during the 3 exercises are shown as a percentage of MVIC (% MVIC).

Table 1

Electrode placement on the observed muscles.

Muscle	Electrode placement
Thoracic erector spinae	5 cm lateral to the 9th thoracic spine
Rectus abdominis	3 cm lateral to the umbilicus
Lower trapezius	Next to the scapular medial border at a 55° oblique angle
Serratus anterior	Horizontally (2 cm apart) just below the underarm area at the level of the scapular inferior border and medial part of the latissimus dorsi
Upper trapezius	Medial third of the way between the 7th cervical spinous process and the scapular acromion process

2.4. Measurements

2.4.1. Scapular winging measurement.

To measure the scapular winging, the investigator used a vertical ruler combined with a horizontal 30-cm ruler. The lower end of the vertical ruler was placed on the spinous process of T5 and the investigator measured the vertical distance between the scapular medial border and the TSP (Fig. 1).[20] The test–retest reliability of the scapulometer for measuring scapular winging was calculated in this study using the interclass correlation coefficient ([ICC], 0.94). The 95% confidence interval (CI) was 0.82 to 0.98,

Table 2

Maximal voluntary muscle contraction muscle positions.

Muscle	Position
Thoracic erector spinae	Subject lay in the prone position with the trunk horizontally cantilevered over the end of the bed. Subject then tried to extend the upper trunk in the sagittal plane and retract the scapulae while resistance was applied on the shoulders by the primary investigator
Rectus abdominis	Subject lay in the supine position and resists trunk flexion
Lower trapezius	Subject lay in the prone position while performing shoulder extension horizontally and shoulder external rotation or raising the arm overhead in line with the muscle fibers of the lower trapezius
Serratus anterior	Subject was seated on a chair with no back support and rotated the shoulder internally and abducted the shoulder to 125° in the scapular plane under resistance to the proximal elbow
Upper trapezius	Subject sat on a chair without back support and performed 90° of shoulder abduction, bent the neck to the same side, rotated the neck to the opposite side, and extended the neck while the primary investigator provided resistance to the head

Figure 1. Scapular winging measurement using a scapulometer in the starting position of the push-up plus motion.

standard error of measurement (SEM) was 0.71 mm, and minimal detectable change (MDC) was 1.97 mm.

2.4.2. Thoracic kyphosis measurement during the KPP. To measure thoracic kyphosis, 4 reflective markers were placed over the T1, T3, T11, and L1 spinous processes and photographed using a camera placed 2 m from the lateral side of the trunk during the KPP. The ImageJ program was downloaded from the Internet and used to calculate the thoracic kyphosis angle (Fig. 2A and B).[21,22] A positive thoracic angle indicated thoracic spine

Figure 2. Thoracic kyphosis measurement using Image J software.

flexion (Fig. 2).[22] The ICC of the thoracic kyphosis measurement taken twice using ImageJ software in this study was 0.99 (95% CI, 0.98–0.99; SEM, 0.87°; and MDC with 95% CI, 2.4°).

2.5. Procedure

MVIC, scapular winging, and thoracic kyphosis were measured before the intervention. Each subject was instructed how to perform the KPP by a primary investigator until the proper position were achieved and the subject felt comfort performing the motion. A 10-minute rest was provided after the familiarization period. KPP with no cue was performed first to inhibit the learning effect, and the order of the other conditions was randomized using the random number generator in Microsoft Excel (Microsoft Corp., Redmond, WA). The KPP motion was maintained for 5 seconds and performed twice by each subject with a 1-minute rest between trials.[23] The mean value of the 2 trials for each exercise was used in the data analysis. A 10-min rest was given between the 3 conditions to minimize muscle fatigue.[24] Scapular winging was measured on the scapular winging side immediately following each exercise to compare the immediate change in scapular winging after the corrective exercise of the compensatory thoracic kyphosis. Thoracic kyphosis was measured during each exercise to measure the degree of compensatory thoracic kyphosis.

2.5.1. KPP with no cue. KPP is a modified push-up with the supplement of full protraction of the scapula (the "plus") after full elbow extension at the end of the knee push-up maintaining the knees shoulder-width apart as the point of contact with the ground (Fig. 3). The KPP was performed as follows; scapular protraction by translating the thorax maximally posteriorly, maintaining the position for 5 seconds, and returning to the starting position.

2.5.2. KPP with tactile cue to the TSP. KPP with a tactile cue to the TSP was performed the same way as the KPP except with the tactile cue (TSP at the apex of the compensatory thoracic kyphosis observed during the KPP). The primary investigator pushed the TSP of every subject at a consistent force and maintained the touch from the start phase to the end phase to retain the push pressure. The primary investigator also gave the following verbal instruction: "During this exercise, try to focus on my hand and maintain a neutral trunk position."

2.5.3. KPP with tactile cue to the ISR. KPP with tactile cue to ISR was performed in the same way as the KPP except tactile cues to ISR, which is middle position between spinous process of T4 and scapular medial border. The primary investigator gave verbal instruction to maintain subjects thoracic posture neutrally as well as tactile instruction same as KPP with tactile cue to TSP.

2.6. Statistical analysis

One sample Kolmogorov–Smirnov test was used to confirm normality of distribution. Test–retest reliability of scapular winging and thoracic kyphosis was assessed by ICC, 95% CI, SEM, and MDC. SEM was used to assess absolute consistency ($SEM = SD\sqrt{(1 - ICC)}$). MDC (95% CI) was calculated as $SEM \times 1.96 \times \sqrt{2}$. One-way repeated analysis of variance of the within-subject factors (no cue, tactile cue to TSP, and tactile cue to ISR) was used to assess the statistical significance of TES, RA, LT, SA, and UT EMG activities; scapular winging; and thoracic kyphosis using PASW Statistics 18 (SPSS, Chicago, IL).[25] The level of significance was set at $\alpha = 0.05$. We used Bonferroni correction for the pairwise comparisons when significant differences were detected ($\alpha = 0.05/3$).

3. Results

3.1. EMG activities of the TES, RA, LT, SA, and UT muscles

The activities during the 3 different conditions are shown in Table 3. There were significant differences in the TES, RA, SA, and UT activities in the 3 different conditions (F = 5.071, $P = .015$; F = 5.087, $P = .027$; F = 9.395, $P < .001$; and F = 5.400, $P = .023$, respectively). TES activity was significantly greater in the TSP cue condition compared with the no cue condition ($P = .014$). RA activity was significantly lower in the TSP ($P = .015$) and ISR ($P = .007$) cue conditions than in the no cue condition. LT activity was not significantly different in the 3 conditions (F = 0.454, $P = .641$). SA and UT activities were significantly lower in the TSP ($P = .003$ and $P = .005$, respectively) and ISR ($P = .015$ and $P = .009$, respectively) cue conditions than in the no cue condition.

3.2. Scapular winging and thoracic kyphosis

There were significant differences in scapular winging and thoracic kyphosis (F = 7.695, $P = .003$; and F = 59.476, $P < .001$, respectively) (Table 4). Scapular winging was significantly lower in the TSP ($P = .016$) and ISR ($P = .003$) cue conditions than in the no cue condition. Thoracic kyphosis was also significantly lower in the TSP ($P < .001$) and ISR ($P < .001$) cue conditions than in the no cue condition.

4. Discussion

The purpose of this study was to determine the effect of tactile cues (no cue, to the TSP, and to the ISR) on the activities of the TES, RA, LT, SA, and UT muscles; thoracic kyphosis during the KPP; and scapular winging immediately after each exercise in subjects with scapular winging. TES activity was significantly greater in the TSP cue condition than in the no cue condition. RA activity was significantly lower in the TSP and ISR cue conditions than in the no cue condition. LT activities were not significantly different among the 3 conditions. SA and UT activities, scapular winging, and thoracic kyphosis were significantly lower in the TSP and ISR cue conditions than in the no cue condition. These results partially supported our research hypothesis. To our knowledge, this is the first study to compare muscle activity and kinematics under different tactile cue conditions during the KPP in subjects with scapular winging.

TES activity was significantly greater (by 60%) in the TSP cue condition than in the no cue condition. TES activity was greater in the ISR condition than in the no cue condition by 54%; however, this increment was not statistically significant. Thoracic kyphosis was also significantly lower in the TSP (by 56%) and ISR (by 51%) cue conditions than in the no cue condition. Sinaki et al[26] reported that back extensor strength and degree of thoracic kyphosis had a negative moderate correlation. Increased thoracic kyphosis is associated with back extensor muscle weakness.[11] The finding of the beneficial effects of tactile cues in this study can be explained by mechanical surface stimulation to the TES region. Mechanical surface stimulation such as pressure or vibration enhances target muscle activation by stimulating

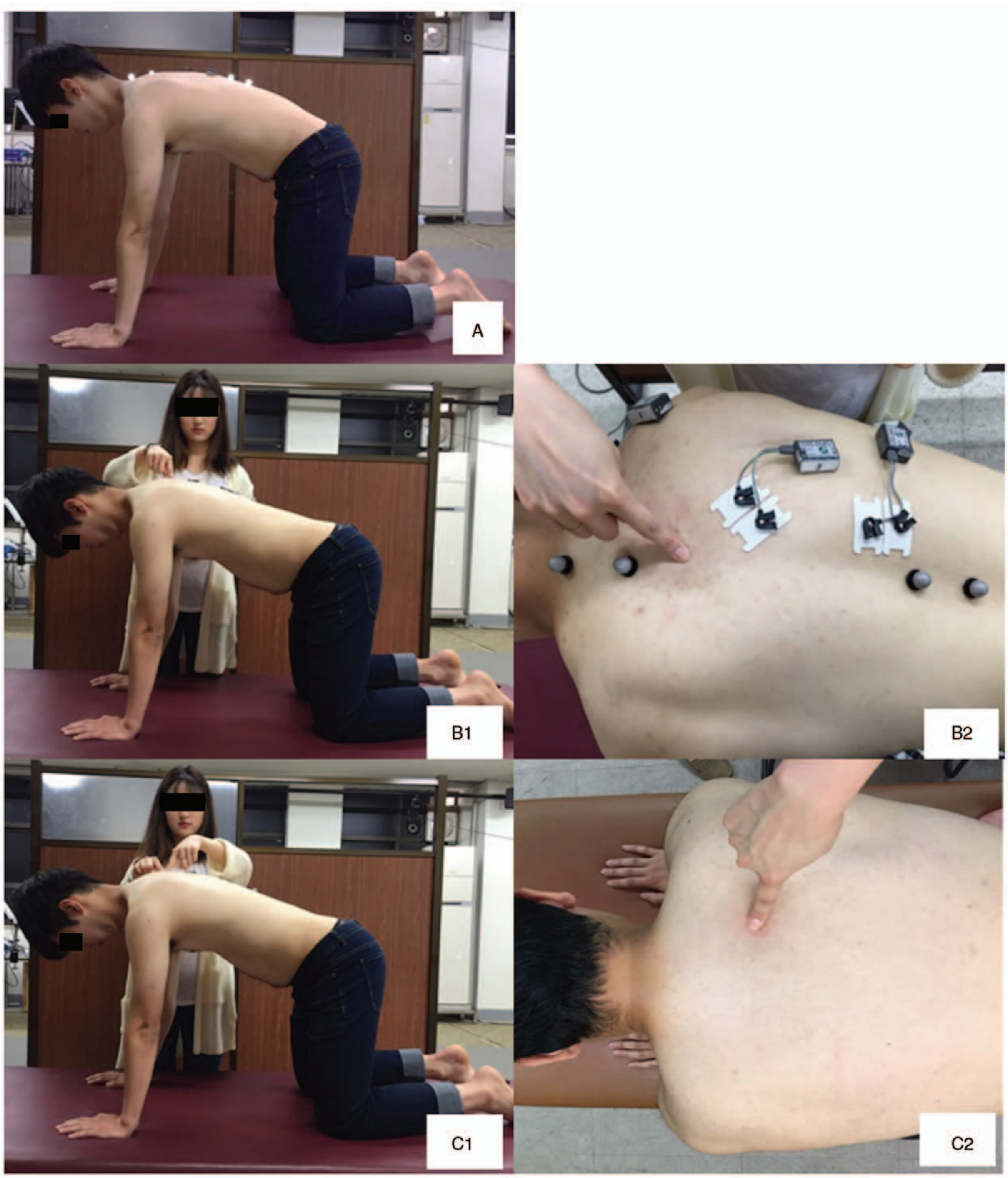

Figure 3. Tactile cue conditions during knee push-up plus. (A) No cue, (B) thoracic spinous process, (C) interscapular region. (1) Ending position, (2) cueing region.

skin mechanoreceptors.[27] The semispinalis thoracis passes the spinous process and transverse process of thoracic vertebrae. This muscle is connected with the longissimus thoracis, iliocostalis thoracis, and spinalis thoracis which passes between scapulae.[28] Therefore, tactile cues to both TSP and ISR during the KPP might have activated the semispinalis thoracis and iliocostalis thoracis, so they might have reduced the excessive compensatory thoracic kyphosis. Thus, the findings of this study suggest that the tactile cues effectively facilitate TES activity and reduce compensatory thoracic kyphosis during the KPP in subjects with scapular winging.

Our results demonstrated significantly lower RA activity in the TSP cue condition (by 61%) and ISR cue condition (by 57%) than in the no cue condition. Greater RA activity was reported in sway standing than in erect standing.[29] In addition, increased muscle activity or RA shortness can lead to thoracic kyphosis.[17] Our result of reduced RA activity with tactile cues can be attributed to the reciprocal inhibition mechanism. Providing

Table 3

Outcomes of the EMG activities of the thoracic erector spinae, rectus abdominis, lower trapezius, serratus anterior, and upper trapezius.

	No cue	To TSP	To ISR	F	*P*
TES	3.72±1.49	9.68±9.77*	8.99±9.10	5.071	.015†
RA	14.19±11.13	5.56±4.50*	6.05±5.28*	5.087	.027†
LT	7.63±9.37	9.42±7.88	7.56±7.55	0.454	.641
SA	41.21±22.84	17.76±10.07*	22.62±12.73*	9.395	.001†
UT	4.56±2.65	2.82±1.02*	3.01±1.37*	5.400	.023†

ISR=interscapular region, LT=lower trapezius, RA=rectus abdominis, SA=serratus anterior, TES=thoracic erector spinae, TSP=thoracic spinous process, UT=upper trapezius.
* Significant difference in comparison with the no cue condition after Bonferroni correction ($P<.017$).
† Significant difference among 3 conditions ($P<0.05$).

Table 4

Outcomes of scapular winging and thoracic kyphosis.

	No cue	To TSP	To ISR	F	*P*
Scapular winging	2.74±0.44	2.45±0.66	2.40±0.53*	7.695	.003†
Thoracic kyphosis	43.74±8.47	23.36±6.92*	24.99±8.86*	59.476	.000†

ISR=interscapular region, TSP=thoracic spinous process.
* Significant difference in comparison with the no cue condition after Bonferroni correction ($P<0.017$).
† Significant difference among 3 conditions ($P<.05$).

tactile cues to the TSP and ISR may have induced TES contraction (agonist muscle facilitation) while simultaneously inhibiting RA contraction (antagonist muscle inhibition). Thus, tactile cues to the TSP and ISR during the KPP can be used to decrease RA activity during the KPP in subjects with scapular winging.

Contrary to our research hypothesis, our results showed significantly less SA activity in the TSP and ISR cue conditions than in the no cue condition (by 57% and 45%, respectively). In addition, scapular winging was significantly lower in the TSP (by 10%) and ISR (by 12%) cue conditions compared with the no cue condition. Although previous researchers have recommended use of the plus phase to increase SA activity during push-ups,[7] here we found that the application of tactile cues can favorably alter scapular and thoracic alignment (i.e., decreased scapular winging and thoracic kyphosis) and reduce SA activity during the KPP. The reduced SA activity with improved scapular and thoracic alignment may be explained by the scapular medial stabilizer. In this study, tactile cues to the TSP (attachment site for the middle trapezius) and ISR (direct cue application to the middle trapezius) during the KPP and verbal instruction might have activated the middle trapezius muscle, a scapular medial stabilizer. It is possible that the activated middle trapezius efficiently stabilized the scapula as evidenced by the decreased amount of scapular winging, although middle trapezius activity was not measured in this study due to the application of the tactile cue to the ISR. Additionally, it is likely that the middle trapezius muscle activation reduced the SA activity. Cools et al[30] reported that middle trapezius activity was increased when SA activity was decreased, whereas middle trapezius activity was decreased when SA activity was decreased during protraction and retraction isokinetic movements in overhead athletes. Another mechanism that suggests improved scapular stability even with decreased SA activity can be explained by the established alignment in the thorax. Thoracic spine alignment was improved from both cue conditions. The increased TES in the TSP condition and decreased RA in the TSP and ISR conditions induced the decreased compensatory thoracic kyphosis during push-up plus in subjects with scapular winging. Given that the scapula is positioned on the posterior ribs, which are connected to the thoracic spine by the costovertebral and costotransverse joints, optimal alignment of the thoracic curve (i.e., reduced excessive thoracic kyphosis) can contribute to proper posterior rib and rib cage alignment, and eventually allowed scapular placement with less winging. Thus, we recommend the application of tactile cues to the TSP and ISR during the KPP to decrease scapular winging activity during the KPP in subjects with scapular winging.

UT activity was significantly lower in the TSP cue condition (by 38%) and ISR cue condition (by 34%) than in the no cue condition. Excessive UT activity was a substitution that occurred when SA activity was deficient.[31] When the UT is excessively activated, shoulder pathology such as subacromial impingement and subacromial bursitis as well as altered acromioclavicular joint forces would occur.[7] Therefore, studies have aimed to develop methods to decrease or minimize UT activity during push-up plus.[7,20] Tactile cues applied in this study also reduced UT activity, which may be explained in 2 ways. First, decreased thoracic kyphosis might affect UT activity. An increased thoracic kyphosis (slouched posture) induces greater medial rotation, downward rotation, and anterior tip of the resting scapula position.[32] Since the tactile cues to the TSP and ISR decreased thoracic kyphosis during the KPP (which involves a less slouched position), activity of the UT, one of the main elevators of the scapula in the scapulothoracic musculature,[33] might have been reduced because the scapula was no longer superiorly translated. Second, the decreased UT activity might be affected by increased middle trapezius activity. In our study, the possible middle trapezius activity increase from both cue conditions contributed to the lower UT activity because scapular stability was ensured by engagement of the medial stabilizer. Thus, this study's findings indicate that the TSP and ISR cue conditions during the KPP are recommended to decrease UT activity during the KPP in subjects with scapular winging.

There were some limitations in our study. First, age range of our subject population was restricted to 19 to 29 years of age that cannot generalize other age groups. Second, the limitation was crosstalk. Although the primary researcher attached electrodes carefully, crosstalk has happened between TES and LT. Third, this study was cross-sectional. Therefore, the long-term effects of the tactile cues to TSP and ISR in the plus phase of KPP exercise on scapular and trunk muscle activity, scapular winging, and thoracic kyphosis cannot be decided. Fourth, we cannot be convinced that middle trapezius decreases SA activity because we did not measure the medial scapula muscles. Further studies should investigate the long-term effects of tactile cues to TSP and ISR during the KPP in patients with scapular winging. Furthermore, muscles of scapular medial aspect must be measured for the effect on SA activity.

5. Conclusion

This study investigated the effect of tactile cues on the EMG amplitudes of the TES, RA, LT, SA, and UT muscles; thoracic kyphosis during the KPP; and scapular winging immediately after KPP in subjects with scapular winging. Our results showed that TES activity was significantly increased in the TSP cue condition; the RA, SA, and UT activities were significantly decreased; and the scapular winging and thoracic kyphosis were reduced in the TSP and ISR cue conditions. Therefore, the TSP and ISR tactile cues can be successfully applied to alter trunk and scapular muscle activities and prevent compensatory motions during the KPP.

Author contributions

Conceptualization: A-Reum Shin.
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Supervision: Heon-seock Cynn, Ji-Hyun Lee.
Writing—original draft: A-Reum Shin.
Writing—review & editing: Heon-seock Cynn, Ji-Hyun Lee.

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