Selective activation of the latissimus dorsi and the inferior fibers of trapezius at various shoulder angles during isometric pull-down exertion

Se-yeon Parka, Won-gyu Yooa,⇑

aDepartment of Physical Therapy, The Graduate School, Inje University, Republic of Korea
bDepartment of Physical Therapy, College of Biomedical Science and Engineering, Inje University, 607 Obangdong, Gimhae, Gyeongsangnam-do 621-749, Republic of Korea

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A B S T R A C T

The aim of this study was to determine the effect of isometric pull down exercise on muscle activity with shoulder elevation angles of 60°, 90°, and 120° and sagittal, scapular, and frontal movement planes, by electromyography (EMG) of the latissimus dorsi, inferior fibers of trapezius, and latissimus dorsi/inferior fibers of trapezius activity ratio. Fourteen men performed nine conditions of isometric pull down exercise (three conditions of shoulder elevation × three conditions of movement planes). Surface EMG was used to collect data from the latissimus dorsi and inferior fibers of trapezius during exercise. Two-way repeated analysis of variance with two within-subject factors (shoulder elevation angles and planes of movement) was used to determine the significance of the latissimus dorsi and inferior fibers of trapezius activity and latissimus dorsi/inferior fibers of trapezius activity ratio. The latissimus dorsi activity and ratio between the latissimus dorsi and the inferior fibers of trapezius were significantly decreased as shoulder elevation angle increased from 60° to 120°. The inferior fibers of trapezius activity was significantly increased with shoulder elevation angle. The EMG activity and the ratios were not affected by changes in movement planes. This study suggests that selective activation of the latissimus dorsi is accomplished with a low shoulder elevation angle, while the inferior fibers of the trapezius are activated with high shoulder elevation angles.

1. Introduction

Selecting a proper strengthening exercise is essential for patients with shoulder injury and dysfunction to regain their muscle performance and functional movement (Holmgren et al., 2012; Marinko et al., 2011). Clinical literature have emphasized the exercise for activating rotator cuff or scapulothoracic musculature, whose muscle components contribute to functional arm elevation (Holmgren et al., 2012; Neumann, 2002). However, some surgery is needed to rehabilitate other muscles such as the latissimus dorsi. The latissimus dorsi is a broad muscle with many vascular branches and innervations; therefore, it has been used as a donor site for reconstructive surgery (Spear and Hess, 2005). According to previous studies, loss of the latissimus dorsi could result in functional impairment after this kind of surgery (Forthomme et al., 2010; Koh and Morrison, 2009; Fraulin et al., 1995). Forthomme et al. (2010) have reported muscle weakness after latissimus dorsi transfer; mainly in the shoulder adductor and internal rotator muscles. In addition, Fraulin et al. (1995) have investigated muscle power after reconstructive surgery, and have concluded that power deficit in the shoulder extension and adduction remains.

In the rehabilitation setting, some recent findings implied the increasing importance of surgery, such as the capsular shift for patients with shoulder instability, to restore normative kinematics. However, the findings also demonstrated that proper postoperative rehabilitation treatment is necessary to regain control of the scapulothoracic and glenohumeral musculature (Kiss et al., 2010; Illyés and Kiss, 2007). Compared with controls, patients with shoulder instability showed greater displacement between the rotation center of the scapula and humerus as well as increased glenohumeral motion and decreased scapulothoracic motion during arm elevation (Illyés and Kiss, 2006). For patients with shoulder instability, strengthening the inferior fibers of the trapezius might be more adequate than strengthening the inferior fibers of the latissimus dorsi. This is because activation of the inferior fibers of the trapezius is directly associated with the scapulothoracic joint, especially the upward rotation of the scapula during arm elevation.
Representative exercises for strengthening the latissimus dorsi and inferior fibers of trapezius are pull down, pull ups, and rowing exercises. Among these, pull down exertion has been mostly investigated in kinematic and electromyography studies. Several studies have demonstrated that muscle activation depends on grip width, expert instruction, and forearm orientation (Lusk et al., 2010; Snyder and Leech, 2009; Signorile et al., 2002). Signorile et al. (2002) have reported that wide grip hand position produces greater muscle activation than other hand positions. Lusk et al. (2010) have recommended anterior pull down with pronated grip for maximally activating the latissimus dorsi. In a recent study, pull down was suggested as an exercise for independently activating the inferior fibers of trapezius (Arliotta et al., 2011). The inferior fibers of trapezius and latissimus dorsi have similar obliquity of muscle’s pull, but the inferior fibers of trapezius could be activated with the high arm elevation angle because the most pronounced scapular motion occurs between 80 and 120° of arm elevation (Ebaugh et al., 2005; Bagg and Forrest, 1988). In addition, the inferior fibers of the trapezius are arranged within the frontal plane, while the arrangement of the latissimus dorsi has components of both the sagittal and frontal planes. However, there were no study investigated the effect of movement planes and arm elevation angles of the pull down exertion on muscular activation, both of the inferior fibers of trapezius and latissimus dorsi.

Some previous studies have performed pull down as an isotonic exercise, which is the general form. However, difficulty remains in adjusting the exercise to patients who need rehabilitation exercises at an early stage. It is considered that isotonic exercise for shoulder rehabilitation is a more stable way of initiating muscular activation without increasing load at the glenohumeral joint, especially in patients with limitations in shoulder mobility (Ellenbecker and Cools, 2010; Millett et al., 2006). Although one previous study has suggested activation of the shoulder muscle, including latissimus dorsi, under isometric conditions and various angles and planes, there remains a lack of evidence about which shoulder angle and movement plane are effective for activating the latissimus dorsi and the inferior fibers of trapezius during the pull down exercise (Anders et al., 2004). This previous study did not statistically compare the muscular difference according to shoulder angle and movement plane but compared sex differences.

Therefore, the present study is to investigate the activation of the latissimus dorsi and the inferior fibers of trapezius under conditions of various shoulder angles (60°, 90° and 120°), and three planes of movement (sagittal, scapular, and frontal plane) during pull down exercise. The purpose was to find out effective means of isometric pull down exercise for activating the musculatures. We hypothesized that the inferior fibers of the trapezius might be activated with increased shoulder elevation angles and closer proximity to the frontal plane, while the latissimus dorsi might be activated with decreased shoulder elevation angles and closer proximity to the sagittal plane.

2. Methods

2.1. Population

This study was performed on 14 asymptomatic men aged 20–22 years (mean ± SD: 21.8 ± 1.4 years), whose height and weight were 175.4 ± 5.2 cm and 68.1 ± 2.1 kg, respectively. Subjects with a history of upper extremity pain or discomfort in the past 6 months were excluded. For consistency, all subjects were right-hand dominant, which the dominance was defined as the one used for writing. Ethical approval for this study was obtained from the Inje University Faculty of Health Sciences Human Ethics Committee. The participants provided informed consent.

2.2. Instrumentation

A Trigno wireless system (Delsys, Boston, MA, USA) was used for obtaining electromyography (EMG) signals; the Trigno electrodes (Delsys, Boston, MA, USA) was set as band pass of 20–450 Hz and a common mode rejection ratio of 80 dB. The sensor (27 mm × 37 mm × 15 mm) included four skin contacts (5 × 1 mm) made of pure silver (99.9%), which contain two patient-pending stabilizing references and distance between skin contacts is 1 cm. The EMG data were corrected with EMG-Works-Acquisition (Delsys) at 2000 Hz, which simultaneously showed data display. Two surface electrodes were placed on the following muscules of the right side: latissimus dorsi, ~4 cm below the inferior tip of the scapula, half the distance between the spine and lateral edge of the torso. The electrode was placed at an oblique angle of ~25°; and the inferior fibers of trapezius, at 1.5 cm lateral and oblique to the T6 spinal process (Cram et al., 1998). Because there were differences between size of the participants, muscle belly of the latissimus dorsi and the inferior fibers trapezius were identified with the manual muscle testing (Kendall et al., 2005). To exclude any influence of electrical noise, the skin was prepared for EMG measurement by cleaning the electrode site with alcohol, and lightly abrading the skin with fine sandpaper.

2.3. Exercise procedure

Prior to the pull-down exercises, maximal voluntary isometric contractions (MVCs) for each muscle were performed to normalize the individual differences. The following EMG normalizing procedure was suggested previously (Cram et al., 1998; Kendall et al., 2005). A 5-s MVC was done for each muscle using three trials. The first and last second of each trial was excluded and the mean value of the middle 3 s was used for normalization.

Subjects performed three trials of pull down exercise for each of nine conditions in randomized order: three planes (sagittal, scapular, and frontal plane) * three shoulder angles (60°, 90°, and 120°). The load for pull down was not controlled, but determined as maximal isometric exertion against a fixed pull down bar. From a standing position, subjects grasped the bar as pronaed and with a wide grip. Shoulder angle and planes for each condition were determined by measuring with a goniometer and inclinometer, and stacking wooden plates under the participant’s feet (Fig. 1). One researcher fixed the participant’s pelvis so as not to be rotated or translated in an upward direction. Each isometric exertion was maintained for 5 s, and the middle 3 s were used for further analysis. Three seconds of EMG data during the pull down were averaged, and the data were expressed as %MVC value against normalized data. The 5 s of isometric contraction was controlled by a 60-Hz metronome. Prior to measurement, each participant was instructed verbally and visually about how to perform a pull down, and given a 5-min practice time for each condition for familiarization of exertion. Three minutes of rest time was given to each participant between trials and conditions.

2.4. Data analysis

PASW Statistics (version 18.0; SPSS, Chicago, IL, USA) was used to analyze significant differences in the %MVC of each muscle. A two-way repeated measures analysis of variance was used to determine the effect of planes (frontal, scapular, and sagittal) and shoulder angles (60°, 90°, and 120°) on the EMG data. Preliminary analysis revealed there was no interaction between planes of exertion and shoulder angles. Specific pair-wise comparison between conditions of shoulder angles and between those of planes were done through Bonferroni correction, and a significant difference was revealed (p = 0.05).
3. Results

3.1. Latissimus dorsi

The average of normalized EMG values of the latissimus dorsi differed significantly \( (F_{2,12} = 12.674, p < 0.05) \) according to shoulder angle (Table 1). The activity levels of the latissimus dorsi during pull down exertions are shown in Fig. 2. There was no interaction \( (F_{4,10} = 0.427, p = 0.786) \) between shoulder angles and planes of movement. The pull down within 60° and 90° shoulder elevation showed a significantly \( (p < 0.05) \) higher normalized EMG of the latissimus dorsi than the same exertion within 120° (Fig. 2). However, there were no significant \( (F_{2,12} = 2.195, p = 0.154) \) difference between the conditions of the planes (Table 1).

3.2. Inferior fibers of trapezius

The normalized EMGs of the inferior fibers of trapezius during isometric pull down conditions are shown in Table 1. There were significant effects \( (F_{2,12} = 39.29, p < 0.05) \) for shoulder elevation angles in latissimus dorsi activation (Table 1). The result of pair-wise comparison revealed that the normalized EMG of the latissimus dorsi was significantly \( (p < 0.05) \) higher within 120° shoulder elevation than 60° and 90° elevation (Fig. 3). The pull down within 90° of shoulder elevation also showed a significantly \( (p < 0.05) \) higher normalized EMG of the latissimus dorsi than pull down within 60° shoulder elevation (Fig. 3). There were no major effects \( (F_{2,12} = 1.687, p = 0.226) \) for planes of movement in latissimus dorsi activation (Table 1). Interaction between planes of movement and shoulder angles was not indentified \( (F_{4,10} = 0.320, p = 0.858) \).

3.3. Ratio between latissimus dorsi and inferior fibers of trapezius (LD/IT ratio)

The ratios between the latissimus dorsi and inferior fibers of trapezius during isometric conditions are shown in Table 1. The LD/IT ratio differed significantly \( (F_{2,12} = 19.86, p < 0.05) \) according to shoulder angle (Table 1). The LD/IT ratio was significantly \( (p < 0.05) \) higher for 60° shoulder elevation than for 90° and 120° shoulder elevation (Fig. 4). The pull down with 90° shoulder elevation also had a significantly \( (p < 0.05) \) higher LD/IT ratio than for pull down with 120° shoulder elevation (Fig. 4). For LD/IT ratio, there

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Table 1

Descriptive statistics of normalized EMG and ratio values during isometric pull down exertions.

<table>
<thead>
<tr>
<th>Plane</th>
<th>Shoulder angles</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>60°</td>
<td>90°</td>
</tr>
<tr>
<td>Latissimus dorsi (LD)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frontal plane</td>
<td>90.46 ± 34.77</td>
<td>72.44 ± 28.13</td>
</tr>
<tr>
<td>Scaption plane</td>
<td>80 ± 40.74</td>
<td>66.53 ± 31.25</td>
</tr>
<tr>
<td>Sagittal plane</td>
<td>78.68 ± 33.17</td>
<td>67.47 ± 32.89</td>
</tr>
<tr>
<td>Inferior fibers of trapezius (IT)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frontal plane</td>
<td>34.14 ± 18.88</td>
<td>46.77 ± 21.58</td>
</tr>
<tr>
<td>Scaption plane</td>
<td>29.12 ± 19.13</td>
<td>40 ± 22.8</td>
</tr>
<tr>
<td>Sagittal plane</td>
<td>36.68 ± 20.77</td>
<td>47.55 ± 20.44</td>
</tr>
<tr>
<td>Ratio(LD/IT)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frontal plane</td>
<td>3.28 ± 1.87</td>
<td>1.79 ± 0.86</td>
</tr>
<tr>
<td>Scaption plane</td>
<td>4.19 ± 3.95</td>
<td>2.03 ± 1.21</td>
</tr>
<tr>
<td>Sagittal plane</td>
<td>2.6 ± 1.5</td>
<td>1.57 ± 0.85</td>
</tr>
</tbody>
</table>

* Significant difference between conditions.
were no interactions ($F_{4,10} = 1.033, p = 0.437$) between planes of movement and shoulder angles, as well as no significant difference ($F_{2,12} = 2.709, p = 0.107$) between planes of movement (Table 1).

4. Discussion

This study examined the influence of shoulder elevation angles and planes of exercise on muscular activation during isometric pull down exertion. The normalized EMG of the latissimus dorsi differed according to shoulder angle, which was significantly greater for a relatively lower elevation angle. Although we could not confirm the causes, due to the absence of measuring three dimensional shoulder positions, the reduced active tension of the latissimus dorsi could have resulted from increased internal rotation of the shoulder, followed by arm elevation. Recent research has shown the kinematics of shoulder elevation, and has reported that the average amount of external rotation of the humerus was 14° from the starting position to 60°, but the humerus then rotated internally by an average 9° by the time the shoulder reached maximum elevation (Matsuki et al., 2012). Another previous study has compared the normalized EMG of the latissimus dorsi during different types of exercise, and has reported that seated row exercise (performed with a low shoulder elevation angle) induces greater activation of the latissimus dorsi than other types of pull down exercise (Lehman et al., 2004). Both the previous and present results indicate that a high level of shoulder elevation for pull down exercise is not required for activating the latissimus dorsi.

In contrast to the latissimus dorsi, the mean normalized EMG in the inferior fibers of trapezius showed gradual increases with increases in shoulder elevation angle. Both the latissimus dorsi and inferior fibers of trapezius contribute to depression of the shoulder girdle, but the insertion was different that the inferior fibers of trapezius for the apex of the scapular spine, and latissimus dorsi for the intertubercular groove of humerus (Kendall et al., 2005). Recent findings have suggested that the most pronounced scapular upward rotation occurs in the mid-range (90–120°) of arm elevation (Ebaugh et al., 2005). Additionally, Bagg and Forrest (1988) have reported a mean glenohumeral to scapular rotation ratio of 3.29:1 below 90° of abduction, and 0.71–1 between 82° and 139° (Bagg and Forrest, 1988). In terms of the active length–tension relationship, production of muscular activation can be accomplished by adopting an appropriate position above the resting length. Although the length of the latissimus dorsi receded from the appropriate length of exertion with increased shoulder elevation angles, we estimated that the length of the inferior fibers of trapezius approached the appropriate length for exertion with increased scapular upward rotation.

Another explanation for these contrast results between the latissimus dorsi and inferior fibers of trapezius is the difference in angle of pull of the muscles. A clinical literature demonstrated that the latissimus dorsi has lower obliquity of muscle’s pull for the humerus than do the inferior fibers of trapezius for the scapulae (Neumann et al, 2002). The greater the obliquity of the muscle’s attachment, the less the force of the muscle contraction contributes to the motion at the joint (Muscolino, 2011). Arwert et al. (1997) investigated the EMG of shoulder muscle relation to force direction, and demonstrated controversial directional of muscle’s force production between the latissimus dorsi and the inferior fibers of trapezius. We speculated that the inferior fibers of the trapezius and latissimus dorsi have close to appropriate leverage of a muscle at 120° and 60° of arm elevation, respectively.

The ratios between the muscle groups have been suggested for identifying relative and selective activation of target muscles during exercise (Park et al., 2013; Ludewig et al., 2004). With a similar pattern to normalized EMG of the latissimus dorsi, the ratios also differed significantly between angles of shoulder elevation. For 120° elevation during pull down exercise, the ratio was close to 1, regardless of movement planes, which meant that the latissimus dorsi and the inferior fibers of the trapezius were activated at a similar level. The 60° and 90° shoulder elevation conditions during pull down showed 2–4 times greater ratios than for 120° elevation, which indicated that selective activation of the latissimus dorsi can be accomplished with lower arm elevation during pull down exertion.
Although different pull down actions were applied in this study (e.g., pull down within the sagittal plane induced shoulder extension mainly, but frontal plane induced shoulder adduction), there were no significant differences in latissimus dorsi, inferior fibers of trapezius, and LD/IT ratio between the movement planes. The changes in movement plane were demonstrated as changes in grip width of the pull down exertion. In agreement with previous findings, the movement plane (grip width in previous study) did not significantly influence the latissimus dorsi activation, nor was there any interaction between grip width and shoulder orientation (Lusk et al., 2010). It was investigated that the three positions of pull down included front of neck (scapular plane), frontal plane using a V-shaped bar, and behind the neck (Sperandei et al., 2009). They also reported that there was no significant difference in normalized EMG of the latissimus dorsi between the types of pull down exertion. However, the previous and present results do not indicate that there is no necessity to consider movement planes during pull down exercise. The glenohumeral ligament could be tightened with increases of shoulder horizontal abduction. When the capsular ligament is over-tightened, it may increase joint contact pressure and lead to soft tissue damage (Itoi et al., 1996). Although the mean normalized EMG of the latissimus dorsi was higher during pull down with the frontal plane than the scapular or sagittal plane, exertion with the frontal plane is not recommended because of the risk of shoulder strain and absence of significant advantages for activating the latissimus dorsi or the inferior fibers of the trapezius.

The present study had some limitations. First, we examined EMG data normalized relative to MVCs, but some cases showed >100% of the MVC. A previous study demonstrated that the isometric pull-down exertion is used to induce MVC of the latissimus dorsi (Snyder and Leech, 2009; Signorile et al., 2002). Further study is needed to determine the proper MVC method for the latissimus dorsi. Second, the electrode placement did not include the pectoral or sagittal plane, exertion with the frontal plane is not recommended because of the risk of shoulder strain and absence of significant advantages for activating the latissimus dorsi or the inferior fibers of the trapezius.

5. Conclusions

The present study was performed to evaluate whether shoulder elevation angle and plane of movement affected the latissimus dorsi and inferior fibers of trapezius during isometric pull down exercise. Activation of the latissimus dorsi was gradually decreased with increases in arm elevation angle, but the inferior fibers of trapezius activity showed the opposite pattern. In addition, we confirmed that the both the latissimus dorsi and inferior fibers of trapezius activities were not related to planes of movement. During isometric pull down for activating the latissimus dorsi, we recommend that selective activation of the latissimus dorsi can be accomplished with low shoulder elevation angle and selecting less horizontally abducted posture, to reduce risk of injury.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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References


Se-yeon Park received his master of science in physical therapy at the Inje university in 2012 and now is a doctor of science student in physical therapy and rehabilitation sciences at Inje university. He is currently working as a researcher of National Research Foundation of Korea and a member of the Korean Physical Therapy Association. His research interests include musculoskeletal response in physical therapy interventions, and scapular dyskinesis.

Won-gyu Yoo received the Ph.D. in Physical Therapy Treatments for Musculoskeletal Disorders from the Yonsei University, the Republic of Korea, in 2008. He was the acting head of the Department of Physical Therapy at Inje University in Gimhea, Gyeongsangnam-do, Republic of Korea. He is working as the main researcher of National Research Foundation of Korea for posture correction research of computer users. His research interests include biological signal processing, chronic muscle pain and dysfunction due to overuse, and medical device development for physical therapy interventions.