Temporal Sequence of Muscle Recruitment during Scapular Plane Elevation: A Pilot Study

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Introduction

Overload and overuse injuries and disorders are the leading causes of compensable lost-time cases in developed societies (Keyserling, 2000), with the incidence of upper extremity injuries second only to disorders of the lower back (Muggleton et al, 1999).

Overload of an anatomical structure can occur when there is a deficiency of function in any segment of a kinetic chain (Nichols, 1994). In the upper limb, a problem with scapular motion may manifest as changed loads on more distal elements (Kibler, 1998). The scapula provides a link to transfer kinetic energy and force from the legs and trunk to the upper limb (Kibler, 1998), a function dependent on the scapular rotator muscles that attach the scapula to the vertebral column and ribs (Culham and Peat, 1993). In view of the importance of this muscle group and the frequency of upper limb pathology, the current study was designed to investigate the function of the upward scapular rotator muscles and important representative shoulder muscles during scapular plane elevation - a common activity in daily life. The aspect of muscle function investigated was the temporal pattern of muscle recruitment. Due to the paucity of information available (only one study was found: Wadsworth and Bullock-Saxton, 1997), the temporal pattern of recruitment of these muscles was investigated.

Before investigating patient populations, which was the investigators’ ultimate aim, the temporal sequence of muscle recruitment had to be established in subjects without any muscle or joint dysfunction or pain. The research questions asked were:

Is there a recognisable pattern in the timing of muscle recruitment in normals and if there is, how stable is it?

Subjects

After gaining approval from the University Human Research Ethics Committee, nine pain-free subjects (4 females, 5 males), with a mean age of 36.78 years (range 27-55 years), were assessed for joint and muscle dysfunction of the upper back, neck and shoulders. Subjects were volunteers that responded to advertisements on the university campus and were all students or staff members. Subjects were excluded from the study if they did not have 180° of arm elevation, had latent myofascial trigger points (LTrPs) in the scapular rotator muscles, had a positive apprehension test (glenohumeral instability), upper limb tension test (neurological dysfunction) or significantly increased thoracic kyphosis. Subjects were also excluded if they reported any pain in the upper back, neck or either upper limb in the previous week or if they were under 18 or over 60 years of age.

Methods

Surface electromyography (sEMG) was used to measure time of onset of muscle activity of five muscles on the dominant arm. The upper and lower trapezius and serratus anterior represented upward scapular rotators, the infraspinatus was selected to represent the rotator cuff muscle group and the middle deltoid as a prime mover during elevation of the arm in the scapular plane.

Bipolar Ag/AgCl electrodes (3M Red Dot) were used and were positioned according to Cram and Kasman (1998). The raw EMG signal from each muscle was collected using an eight channel data recording system (Powerlab, ADInstruments, Castle Hill, NSW). The EMG signal was amplified, filtered (low pass=500Hz, high pass 10Hz) and then rectified and smoothed using a root mean squared (RMS) calculation. The sampling speed was 2000 samples/sec. A custom built microswitch was placed on the subject’s thigh to align with the subject’s ventral forearm, immediately proximal to the wrist creases. When the forearm moved away from the
body a voltage change was recorded, signifying the start of the movement. This enabled time at the onset of muscle activity to be normalised to the start of the movement.

An inclinometer (Applied Measurement, Melbourne, Australia) was strapped to the postero-lateral aspect of the subject’s upper arm to measure the limb angle relative to the vertical plane during the test movement. This was also displayed on one of the channels of the Powerlab system and will allow the relationship between the onset of muscle activity and limb angle to be explored (data not yet available).

Recordings were carried out according to the procedures reported by Wadsworth and Bullock-Saxton (1997). Plane of motion, standing posture, postural sway and the velocity of movement were controlled. Two vertical movement guides were used to ensure that movement of the arms occurred in the correct plane of motion. Standardising stance width and external fixation of the pelvis regulated standing posture. Each subject was asked to focus on a point three meters in front of the eyes in order to restrict postural sway. The velocity of movement of the limbs was standardised using a metronome set at 60 beats per minute. See figure 1.

**Figure 1: Starting position of the test movement.**

Elevation of the arms in the scapular plane was performed without allowing the subject to externally rotate at the end of the range (figure 2). This restricted subjects to 160° of movement and allowed the infraspinatus to act as a glenohumeral stabiliser rather than a prime mover in external rotation. Subjects practised the velocity of movement (40°/sec) with the metronome prior to the EMG evaluation until they could reliably reproduce the required movement velocity. After adequate rest, the subject performed three trials of the movement with a four second rest between trials.

**Figure 2: Performing elevation of the arm in the scapular plane. Note lateral aspect of the index finger remains in contact with the movement guide to prevent any external rotation of the shoulder.**

To identify the onset of muscle activity, the algorithm suggested by Hodges and Bui (1996) for a low-noise signal analysis (10ms windows, 1 standard deviation above the baseline and 500hz low pass filter) was employed. The process was as follows. A 50msec sample, representative of the baseline, was selected and the mean and standard deviation (SD) calculated. A macro was written to select a 10msec window and calculate the mean and SD of this selection, then to move the selection forward by one sample and repeat the process. This procedure was repeated for a 1.5sec period. The time of onset of muscle activity was defined as the time at the start of the first 10msec selection whose mean was more than one SD above the mean of the baseline. The accuracy of this process was confirmed by a visual inspection to ensure the time identified as the beginning of muscle activity was not associated with ECG or other artifact.

**Results**
The mean time at onset with the standard deviation for each muscle is shown in table 1 and depicted graphically in figure 3.

Table 1: Mean onset time relative to movement start (milliseconds (msecs)) and standard deviation for each muscle.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Mean (msecs)</th>
<th>Standard Deviation (msecs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper trapezius</td>
<td>-118</td>
<td>38</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>84</td>
<td>88</td>
</tr>
<tr>
<td>Middle deltoid</td>
<td>203</td>
<td>66</td>
</tr>
<tr>
<td>Serratus anterior</td>
<td>484</td>
<td>56</td>
</tr>
<tr>
<td>Lower trapezius</td>
<td>871</td>
<td>110</td>
</tr>
</tbody>
</table>

Figure 3: Mean time (msecs) at onset of muscle activity relative to movement start for each muscle. UT=upper trapezius, INF=infraspinatus, MD=middle deltoid, SA=serratus anterior, LT=lower trapezius.

Of 27 trials (nine subjects × three trials per subject), the order of recruitment listed above in table 1 occurred in 26 trials. In the one trial where the order was different, the middle deltoid activated 100 milliseconds before infraspinatus instead of after the infraspinatus. The spread of onset times was small for most muscles, with the lower trapezius being the least consistent in its time of muscle activation.

Discussion

In 1997, Wadsworth and Bullock-Saxton investigated the activation sequence of the upward scapular rotator muscles of nine freestyle swimmers with subacromial impingement and compared them to matched controls. These authors used the same method of data collection as the present study but identified the onset of muscle activity by finding the time at which the sEMG (smoothed and rectified) amplitude reached 5% of its maximal amplitude. Hodges and Bui (1996) suggested that this method of identifying activity onset could be inaccurate due to the sensitivity of this technique to the magnitude of the peak and the rate of increase in amplitude, which can vary between muscles. Therefore, in the current study, the Hodges and Bui protocol for identifying the onset of muscle activity was employed.

As the Wadsworth and Bullock-Saxton study did not investigate the infraspinatus or middle deltoid muscles, comparison can only be made between the three upward scapular rotator muscles: upper trapezius, serratus anterior and lower trapezius. Comparisons of the mean onset times between the control subjects of that study and the ‘normals’ of the current one are provided in table 2.

Table 2: Comparison of mean onset times (msecs) for the upward scapular rotator muscles between studies.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Lucas et al.</th>
<th>Wadsworth and Bullock-Saxton</th>
</tr>
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<td>Upper trapezius</td>
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<td>53</td>
</tr>
<tr>
<td>Lower trapezius</td>
<td>871</td>
<td>349</td>
</tr>
</tbody>
</table>

The onset time for the upper trapezius muscle appears to be similar in both studies with 100 milliseconds difference. This complies with an observation made by other authors (Wadsworth and Bullock-Saxton 1997, Perry et al. 1992, Scovazzo et al. 1991, Yamshon and Bierman 1948) that suggests the activity of the upper trapezius muscle is generally less variable than the other scapular rotator muscles.

Both the serratus anterior and lower trapezius onset times were delayed in the present study when compared to the previous study, which may be related to subject differences. The previous study used competitive freestyle swimmers training an average of 30.2km/week over 8.2 years with a mean age of 23.2 years, whereas the present study used students and academics as subjects with a mean age of 36.7 years.

In addition, the subjects from the present study were also examined for muscle pathology (latent myofascial trigger points (LTrPs)) in the scapular rotator muscles, which was not performed on the young swimmers. The effects of LTrPs in this muscle group have not been investigated previously.
Finally, as previously mentioned, Wadsworth and Bullock-Saxton used a different means of identifying the onset of muscle activity, making a direct comparison difficult.

**Conclusion**

A pilot study to investigate the temporal sequence of recruitment of key shoulder girdle muscles in normal subjects, with no shoulder joint or muscle dysfunction or pain, was performed to establish whether these subjects had a recognisable temporal pattern of muscle recruitment and to establish the variability of this recruitment pattern. A stable temporal sequence of recruitment during elevation of the arm in the scapular plane was found.

**References**


