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The recruitment order of scapular muscles depends on the characteristics of the postural task

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ABSTRACT

Previous studies show that the scapular muscle recruitment order could possibly change according to the characteristics of the postural task. We aimed to compare the activation latencies of serratus anterior (SA), upper, middle, and lower trapezius (UT, MT and LT, respectively) between an unpredictable perturbation (sudden arm destabilization) and a predictable task (voluntary arm raise) and, to determine the differences in the muscle recruitment order in each task. The electromyographic signals of 23 participants were recorded while the tasks were performed. All scapular muscles showed earlier onset latency in the voluntary arm raise than in the sudden arm destabilization. No significant differences were observed in the muscle recruitment order for the sudden arm destabilization ($p > 0.05$). Conversely, for voluntary arm raise the MT, LT SA and anterior deltoid (AD) were activated significantly earlier than the UT ($p < 0.001$). Scapular muscles present a specific recruitment order during a predictable task: SA was activated prior to the AD and the UT after the AD, in a recruitment order of SA, AD, UT, MT, and LT. While in an unpredictable motor task, all muscles were activated after the destabilization without a specific recruitment order, but rather a simultaneous activation.

1. Introduction

It is widely known that the trapezius and serratus anterior (SA) muscles act in couple to provide dynamic stability to the scapula during arm movement (Kibler et al., 2007; Larsen et al., 2013; Ludewig et al., 2004). Furthermore, these muscles connect the upper limb to the spine, maintaining the posture of the cervicothoracic region, as well as postural balance (Alexander et al., 2007). These functions depend on muscle strength and suitable motor control, i.e., appropriate onset latency (timing) and amplitude (Cools et al., 2003; Phadke and Ludewig, 2013; Struyf et al., 2014).

Distinct onset latencies and scapular muscle recruitment order have been reported for both unpredictable (Brindle et al., 2007; Cools et al., 2002, 2003) and predictable tasks (De Mey et al., 2009; Larsen et al., 2013; Moraes et al., 2008; Phadke and Ludewig, 2013; Seitz and Uhl, 2012; Wadsworth and Bullock-Saxton, 1997). For instance, Wadsworth and Bullock-Saxton (1997) indicated that in a voluntary arm raise (predictable task), the upper trapezius (UT) was activated prior to the anterior deltoid (AD) and the SA after the AD. However, a more updated report observed an inverse recruitment order (Kibler et al., 2007). Their results indicated that the SA was activated prior to the AD, whereas the UT was recruited after the AD.

There are few studies specifically investigating sudden arm destabilization tasks (unpredictable task). Cools et al. (2003) indicated that the three portions of the trapezius are activated after a sudden arm destabilization, with different onset latencies between lower trapezius (LT) and middle trapezius (MT). Brindle et al. (2007) observed that SA, UT and MT were activated after a sudden arm destabilization. However, these authors did not compare the differences in onset latencies between scapular muscles, since those studies mainly focused on comparing each of the scapular muscles activation latencies between trained and untrained individuals. The aforementioned findings indicate that there is still no consensus about the recruitment order of the scapular muscles during predictable and unpredictable tasks.

In the abdominal, trunk and lower limb muscles, a specific recruitment order has been attributed to the demands of the postural task and to the presence of anticipatory postural adjustments (APAs) and compensatory postural adjustments (CPAs) (Allison and

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Morris, 2008; Tokuno et al., 2013). The CPAs are initiated by an "unpredictable" external sensorial input. They serve as a mechanism to restore the position of the center of mass following a perturbation (Aruin, 2002; Alexandrov et al., 2005; Aruin et al., 2015). In contrast, the APAs are generated prior to a "predictable" perturbation, irrespective of its internal or external origin (Kanekar and Aruin, 2015). They control the position of the center of mass prior to a perturbation, reducing the risk of losing balance (Aruin, 2002; Aruin et al., 2001, 2015; Cresswell et al., 1994; Santos et al., 2010). To our knowledge, Shiratori and Latash (2001) are the only authors who have identified APAs in arm muscles. These authors indicate that APAs can be seen in the arm, trunk and leg muscles prior to catching a load released either by the subject or by the experimenter (Shiratori and Latash, 2001).

At present, it is not possible to confirm whether the scapular muscle recruitment order varies according to the characteristics of the motor task, given that the few studies available are contradictory and have low statistical power (Larsen et al., 2013), and use a wide variety of electromyographic (EMG) signal analysis methods (Seitz and Uhl, 2012; Tokuno et al., 2013).

The aims of this study were to compare the onset latencies of the UT, MT, LT, and SA muscles between an unpredictable perturbation task (sudden arm destabilization) and a predictable task (voluntary arm raise), and to determine the differences in the muscle recruitment order in each of these tasks. According to these aims, two hypotheses were proposed. First, scapular muscles would present shorter onset latencies in the predictable task than in the unpredictable perturbation task. Second, the AD and scapular muscles would be activated after the unpredictable perturbation (Cools et al., 2003) in a recruitment order of SA, MT, UT, LT and AD. While the SA would be activated before the AD, and the UT after the AD (Kibler et al., 2007), in a recruitment order of SA, AD, UT, MT, and LT during the predictable task.

2. Methods

2.1. Participants

A sample of 23 voluntary subjects was calculated based on a 95% confidence interval, a power of 0.8, and 15% loss. A mean of 159.6 ms and a standard deviation of 56.4 ms for UT onset latency was obtained in a previous study (Cools et al., 2002) and considered for the sample size calculation. The Bioethics Committee of the Universidad de Talca (Chile) approved all procedures, and an informed consent form was read and signed by each subject before participating in the study.

Twenty-three young and healthy men were recruited. Exclusion criteria were: (1) BMI greater than 29.9 kg/m^2 as the extra subcutaneous tissue can compromise the quality of the EMG signal (Phadke and Ludewig, 2013), (2) incomplete range of motion of the shoulder, (3) a current or past history of shoulder pain, (4) participation in overhead sports, and (5) history of trauma, dislocation, rotator cuff tear, spinal deformities, radicular symptoms, and/or neurological diseases. The participants presented the following baseline characteristics: age 20.3 ± 1.5 years, height 1.73 ± 0.06 m, weight 73.9 ± 7.5 kg, BMI 24.8 ± 2.9 kg/m^2, and physical/sporting activity 3 ± 1.2 times a week.

2.2. Instrumentation

The surface EMG (sEMG) signal was acquired with a Delsys Trigno™ Wirless sEMG System and recorded with the Delsys EMGworks Acquisition 4.2.0 (Delsys Inc., Boston. MA, USA) software. The sEMG was sampled at 4000 Hz and stored on a computer using a 16-bit analog-digital converter. The electrodes were made of silver (99.9%) and had an inter-electrode distance of 10 mm. A band-pass filter was used (fourth-order, zero-delay butterworth filter with frequencies between 20 and 450 Hz) and the signal was digitally amplified with a gain of 300, common mode rejection ratio >80 dB, signal-to-noise ratio <0.75 mV RMS.

Prior to electrode placement, the hair was shaved and the skin was cleaned with dermoabrasive paper and 70% isopropyl alcohol solution to reduce the impedance (typically $\leqslant$10 kΩ). The sEMG signals were recorded from the dominant arm and the electrodes were located on the UT, MT, LT, SA and AD muscles. The electrodes were placed according to SENIAM recommendations (Hermens et al., 2000) [SA electrodes were placed according to a previous study (Lehman et al., 2008)], and positioned in parallel to the direction of the muscle fibers. Proper electrode placement was further verified by observing the EMG signal on a computer monitor during a maximal voluntary isometric contraction of the arm.

2.3. Procedures and data collection

The participants performed two randomized tasks in one session. These tasks consisted in an unpredictable perturbation (sudden arm destabilization) and a predictable task (voluntary arm raise). Both tasks were performed again in a second session to evaluate test-retest reliability. The evaluation on day two was undertaken 24 h following day one because this period has been considered appropriate to avoid the effects of learning new motor skills (Statton et al., 2015). At the beginning of each session, warm-up exercises of the scapular and rotator cuff muscles were performed.

The unpredictable perturbation task was performed on a platform involving sudden arm destabilization while in a standing position (Fig. 1a). Visual and proprioceptive signals that may provide information about the forthcoming arm perturbation were reduced in order to define the task as "unpredictable" (individual was blindfolded and wore headphones); this allowed us to identify CPAs (Aruin et al., 2001; Massion, 1992). The platform consisted of a movable trapdoor that supported the arm and forearm abducted at 90° with the glenohumeral joint at 30° of horizontal adduction. This position was chosen to optimize the function of the shoulder muscles within the "plane of the scapula" (Brindle et al., 2007). The trapdoor had a plastic surface covered with foam to reduce cutaneous information and provide a comfortable area of support for the arm. The trapdoor was attached to a hinge-spring device, which supported a column that allowed a sudden arm adduction. A triaxial accelerometer (Delsys Inc., Boston, MA, USA) was attached to the movable trapdoor to record the exact moment of unpredictable perturbation. At the beginning of the experiment, a researcher informed the participants that the moving trapdoor would fall suddenly but did not indicated the exact moment of destabilization. The EMGWorks 4.2.0 Acquisition software was used to confirm a signal-to-noise ratio of less than 20% (no pre-muscle activity) for all the signals. Three trials were completed in which the EMG signals of the AD and scapular muscles were recorded.

The predictable task consisted in a voluntary arm abduction of 180° in the scapular plane (described above) (Fig. 1b). This movement was executed voluntarily in the presence of visual and proprioceptive information in order to consider the task as "predictable" to allow the identification of APAs (Aruin et al., 2001; Kanekar and Aruin, 2015; Massion, 1992). The raise was executed at a velocity of four seconds per cycle of abduction-adduction in a range of motion of 180° with the objective of standardizing movement velocity in a normal scapular-humeral rhythm with a ratio of 2.4 (Sugamoto et al., 2002). A metronome was used with a frequency of 15 beats per minute to facilitate the learning of the abduction-adduction cycle at a velocity of four