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Real-time kinematic biofeedback improves scapulothoracic control and performance during scapular-focused exercises: A single-blind randomized controlled laboratory study

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ABSTRACT

Emerging evidence suggests that scapular-focused therapeutic exercises hold promise for shoulder dynamic stability retraining. While recent findings show that therapeutic exercises can alter scapular neuromuscular function measured with muscle electromyography, no study has yet addressed the effects of kinematic biofeedback for improving scapulothoracic control and performance. The aim of this study was to assess the effectiveness of kinematic biofeedback on motor relearning transfer during shoulder flexion and a daily activity, on the quality of scapular-focused exercise performance, and on execution time. Thirty healthy young adults were randomly distributed into two groups. Skin mounted electromagnetic sensors were used to collect kinematic data of the thorax, scapula and humerus while subjects performed a shoulder flexion and a daily activity, prior to and after scapular-focused exercises. For both groups, the exercise execution error and the execution time determined the scapulothoracic control and performance. Significant statistical differences were found in the exercise execution error results within the experimental group ($z = 5.313$; $p = 0.037$) and between groups ($u = 37.00$; $p = 0.001$; $u = 64.00$; $p = 0.024$). This study's results demonstrate that real-time kinematic biofeedback improves scapulothoracic control and performance during scapular-focused exercise execution.

1. Introduction

Shoulder pain and dysfunction are among the most frequent musculoskeletal disorders that lead patients to seek health care professionals (Cunha-Miranda, Carnide, & Lopes, 2010; Luime et al., 2004). Neuromuscular activity and control imbalances are frequently related with scapular dysfunction, which compromises the shoulder dynamic stability as well as scapular performance during rest and dynamic activities (Ludewig & Reynolds, 2009). Emerging evidence shows the benefits of therapeutic exercises, which reduce neuromuscular activity and motor control imbalances when addressing musculoskeletal disorders (Kibler et al., 2013; Ludewig & Reynolds, 2009). Two recent randomized controlled trials showed that scapular-focused exercises can help enhance shoulder dynamic stability in patients with shoulder pain and/or dysfunction

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(Başkurt, Başkurt, Gelecek, & Özkan, 2011; Struyf et al., 2013). In order to achieve a higher quality of scapular performance, patients should go through a motor relearning process encompassing the sequential cognitive, associative and autonomous phases (Fitts & Posner, 1967). This study model focuses on the first 2 motor relearning phases with scapular-focused exercises aimed at awareness of the scapulothoracic (ST) neutral position (NP), referred to as ST-NP, and normalization of the scapulohumeral rhythm (Mottram, 1997). In the cognitive phase (Fitts & Posner, 1967), subjects need to understand the relevant task instructions and how to execute them. According to difficulty levels and subjects' ability to improve the quality of their next task execution, frequent performance errors are normal. Subjects must be given constant feedback, and over time, some success in achieving the task is expectable. The following associative phase (Fitts & Posner, 1967) is identified by an emphasis of practice, which will improve the way the task is performed. Errors still occur, but are smaller and less frequent than in the cognitive phase. Feedback is again essential to improve the motor relearning and gradually not only the movement pattern is more efficient, as energy costs required to complete the task are smaller. Subjects may remain in this stage for a long period of time, perhaps years, and some may never progress to the next phase. However, given sufficient practice, most will reach an automatic task execution level, which nevertheless does not imply perfection, since the quality of autonomous level performance may vary.

Good scapular performance is highly dependent on the integrity of intrinsic feedback mechanisms and proprioceptive changes that are often impairing subjects' action planning and control (Sørensen & Jørgensen, 2000). An extrinsic three-dimensional (3D) kinematic feedback source can accurately assess scapular position and orientation, making correct exercise execution easier by retrieving real-time feedback during (knowledge of performance) or immediately after a task (knowledge of result) (Giggins, Persson, & Caulfield, 2013). This will help modify subject performance to achieve rehabilitation goals, allowing the improvement of the quality of exercise execution and of the accuracy of specific functional tasks, as well as the reacquisition, retention, and motor relearning transfer of repeated movements to daily activities (Giggins et al., 2013; Van Dijk, Jannink, & Hermens, 2005). Although previous studies may have indicated that scapular muscle balance and control measured with muscle electromyographic activity can be altered with therapeutic exercises (Seitz & Uhl, 2012), there is still lack of evidence supporting the use of 3D kinematics as an extrinsic source of feedback for better ST control and performance (De Mey et al., 2013; Sturmberg, Marquez, Heneghan, Snodgrass, & van Vliet, 2013). The purpose of this study was to ascertain how effective the extrinsic feedback of 3D kinematics is on motor relearning transfer during shoulder flexion and a daily activity, on the quality of scapular-focused exercise performance throughout the cognitive and associative phases of a shoulder motor relearning process and on the execution time.

2. Methods

2.1. Subjects

A non-probabilistic sample of 30 healthy subjects was randomly and blindly distributed (Fig. 1) using a developed computational code for block randomization (size = 2) into a control group and an experimental group. The sample included 10 males and 20 females, the mean age being 21.57 years' of age (±4.14 years' of age), with a mean weight of 63 kg (±10.37 kg), and a mean height of 1.68 m (±0.08 m). All subjects provided written informed consent prior to data collection and all their rights were protected.

The investigation was approved by the ethics committee of Setúbal Polytechnic Institute, Portugal and was conducted in the Human Movement Analysis Laboratory of the above-mentioned institution's School of Healthcare.

Based on 6° in scapula kinematic standard deviation results published recently (Haik, Alburquerque-Sendín, & Camargo, 2014) and the effect size of 0.50 for kinematic differences on repeated measures, 15 subjects per group were estimated to get greater then 80% power to detect statistically significant differences ($df = 3$ and alpha = 0.05) and an account for a drop-out of 20% (Cohen, 1988). This sample size is in agreement with previous power sample estimations based on scapula kinematics (e.g. Borstad & Szucs, 2012). Healthy young adults with no history of shoulder pain and/or dysfunction were included. The exclusion criteria's were: over 60 years' of age (Ludewig & Cook, 2000); history of physical therapy or any other treatment in the previous 12 months'; regular sports activity in the previous 6 months' (at least 3 times per week); cervical radiculopathy or neurological disorders and visceral or systemic pain diagnosis (Michener, Walsworth, & Burnet, 2004); history of rheumatic diseases (Ludewig & Cook, 2000); history of shoulder, neck or spine high surgery (Cools, Witvrouw, Declercq, Danneels, & Cambier, 2003); and history of rotator cuff tendon rupture or acute inflammation (McClure, Michener, & Karduna, 2006), dislocation, subluxation or shoulder fractures (Cools et al., 2003).

2.2. Instrumentation

Three-dimensional kinematic data collection was obtained from the electromagnetic system trakSTAR (Ascension Technology, Burlington, Vermont), which includes a wide-range transmitter that allowed simultaneous tracking of 4 miniaturized 6 degrees of freedom sensors (model 800) at a sampling rate of 120 Hz. This system revealed excellent intra and inter-observer reliability for ST rotation evaluation in the sagittal plane and during daily activities with intra-class correlation coefficients up to 0.95 (Roren et al., 2013).

TrakSTAR sensor static accuracy has been reported at 1.8 mm and 0.5° (Ascension Technology Corporation, Burlington, Vermont), with an optimal operational range for positional electromagnetic sensor device between 22.5 cm and 64.0 cm,