



Original article

Biomechanical measures in participants with shoulder pain: Intra-rater reliability

Lori A. Michener^{a,*}, Kevin A. Elmore^b, Benjamin J. Darter^b, Mark K. Timmons^c^a Division of Biokinesiology and Physical Therapy, University of Southern California, Los Angeles, CA 90089, USA^b Department of Physical Therapy, Virginia Commonwealth University, Richmond, VA 23298, USA^c School of Kinesiology, Marshall University, Huntington, WV 25755, USA

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ABSTRACT

Biomechanical measures are used to characterize the mechanisms of treatment for shoulder pain. The objective was to characterize test-retest reliability and measurement error of shoulder surface electromyographic (sEMG) and kinematic measures. Individuals ($n = 12$) with subacromial pain syndrome were tested at 2 visits. Five repetitions of shoulder scapular plane elevation were performed while collecting sEMG of the upper trapezius (UT), middle trapezius (MT), lower trapezius (LT), serratus anterior (SA), middle-deltoid, and infraspinatus muscles during ascending and descending phases. Simultaneously, electromagnetic sensors measured 3-dimensional kinematics of scapular internal/external rotation, upward/downward rotation, posterior/anterior tilt, and clavicular elevation/depression and clavicular protraction/retraction. Kinematic and sEMG variables were reduced for the total phase of ascending and descending elevation ($30^\circ - 120^\circ$, $120^\circ - 30^\circ$), at 30° intervals for sEMG, and at every 30° discrete kinematic angle. The intraclass correlation coefficients (ICC) ranged from 0.08 to 0.99 for sEMG and 0.23–0.95 for kinematics. Correspondingly, the standard error of the measurement (SEM) and minimal detectable change (MDC) for sEMG measures varied from 2.3% to 103.8% of a reference contraction (REF-contraction). For kinematics, the SEM and MDC varied from 1.4° to 5.9° . Between-day reliability was good to very good, except for scapular internal/external rotation kinematics, and sEMG for the LT, UT, and SA. sEMG error values were highest ($>25\%$ REF-contraction) for most of the LT, UT, and SA variables. Kinematic error values indicate changes or differences of $2^\circ - 3^\circ$ are meaningful, except for upward/downward rotation and internal/external rotation with MDCs of $4^\circ - 6^\circ$. Generally, data from the total phase of movement had better reliability and lower error than the data from sEMG interval or kinematic discrete angles.

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1. Introduction

The shoulder is a common site for musculoskeletal injury. Subacromial pain syndrome which includes rotator cuff disease is a shoulder disorder with multi-faceted biomechanical mechanisms. Manual therapy interventions are often used to address the biomechanical shoulder impairments and restore shoulder function. Evidence indicates that manual therapy can be effective for some patients, but it is not clear why manual therapy is not helpful for all patients with shoulder pain (Ho et al., 2009; Kromer et al., 2009; Gebremariam et al., 2014). To enable treatment decision-

making, a better understanding of how manual therapy works is needed (Bialosky et al., 2008). Specifically, identification of those impairments that improve with manual therapy and are associated with improved functional outcomes. Biomechanical impairments can be studied by using kinematics and surface electromyography (sEMG) techniques to elucidate the mechanisms of the effects of the manual therapy.

Biomechanical mechanisms of the effects of manual therapy can be studied with kinematic analysis and surface electromyography (sEMG), to characterize shoulder motion and muscle activity. A meta-analysis (Timmons et al., 2012) reported altered kinematics of decreased scapular upward rotation, external rotation and posterior tilt, and decreased clavicular elevation and retraction during active arm elevation in the scapular plane in those with subacromial pain syndrome. These altered scapular motions may be caused by or lead to dysfunctional scapular and rotator cuff muscle

* Corresponding author. Division of Biokinesiology and Physical Therapy, University of Southern California, 1540 E. Alcazar Street, CHP 155, Los Angeles, CA 90089, USA. Tel.: +1 323 442 0247; fax: +1 323 442 1515.

E-mail address: lmichene@usc.edu (L.A. Michener).

activity. A systematic review (Chester et al., 2010) described abnormal scapular muscle activity of increased upper trapezius, along with decreased middle trapezius, serratus anterior, deltoid and infraspinatus activity in individuals with subacromial pain syndrome. Improvements in shoulder muscle activity and kinematics have been demonstrated after exercise (DeMey et al., 2012) and spinal manipulation in patients with shoulder pain (Muth et al., 2012; Haik et al., 2014b).

Kinematic and sEMG methods used to measure the mechanistic effects of manual therapy should demonstrate acceptable measurement properties which include reliability and error metrics. Reliability studies are needed of shoulder kinematic and sEMG techniques used to assess the biomechanical impairments targeted with manual therapy. Prior reliability studies of dynamic shoulder kinematics have largely used healthy individuals or in participants with cerebral palsy, (Thigpen et al., 2005; Myers et al., 2006; Roren et al., 2013; Scibek and Garcia, 2013; Lempereur et al., 2014) thus limiting the application of these findings to patients with shoulder pain. One study has reported reliability for shoulder kinematics in patients with shoulder pain, however reliability was limited to 3 of the 5 scapular kinematic variables (Haik et al., 2014a). The reliability of sEMG shoulder muscle activity has only been studied in healthy individuals (Seitz and Uhl, 2012). Because reliability estimates can vary between healthy and impaired individuals (Harris et al., 2005; Wagner et al., 2008), studies are needed to characterize the measurement properties for sEMG and to extend the understanding for kinematics in individuals with shoulder pain. Estimates of inter-session reliability can extend our understanding of the reliability and error when measures are taken longitudinally over time in patients with shoulder pain. The purpose of this study was to characterize the test-retest inter-session reliability and measurement error of shoulder kinematics and sEMG in individuals with subacromial pain syndrome related shoulder pain.

2. Methods

2.1. Participants

Participants (n = 12) seeking treatment for shoulder pain were recruited from local clinics (Table 1). Inclusion criteria for subacromial pain syndrome was 3 or more positive tests of painful arc, pain or weakness with resisted external rotation, Neer, Hawkins–Kennedy and Jobe/Empty Can tests (Michener et al., 2009; Hegedus et al., 2012). Exclusion criteria included adhesive capsulitis ($\geq 50\%$ loss of passive shoulder external rotation and $\geq 25\%$ loss of shoulder elevation), history of upper arm fracture, systemic musculoskeletal disease, shoulder surgery, cervical motion reproducing shoulder pain, or a full thickness rotator cuff tear (positive ultrasound or MRI imaging). The study was approved by Virginia Commonwealth University Internal Review Board, and all participants provided written informed consent. An *a priori* power analysis indicated a sample size of 10 participants was adequate; hypothesizing a relationship of 0.80 (95%CI = 0.55, 0.92), power >0.80 and significance level of 0.05, a sample size of 10 would be adequate (Weir, 2005; Hertzog, 2008).

2.2. Procedures

Participants completed 2 test sessions, separated by a mean of 5.2 (3–6) days based on participant availability to return for testing. The Pennsylvania Shoulder Scale (Penn) (Leggin et al., 2006) measured shoulder pain, satisfaction, and function with daily activities (0–100; 100 = full use). Scapular 3-dimensional kinematics and sEMG of shoulder muscle activity of the participants' symptomatic shoulder were assessed during arm elevation and lowering

Table 1

Participant demographics and characteristics (n = 12).

Variable	Distribution
Age (years); mean (sd)	49.2 (14.7)
Weight (kg); mean (sd)	90.3 (22.2)
Height (cm); mean (sd)	178.0 (7.2)
Body mass index (kg/m ²); mean (sd)	28.3 (5.7)
Male gender; n (%)	8 (66.7)
Dominant arm; n (%)	10 (83.3)
Initial visit	
Penn Shoulder Score (0–100; 100 = no disability)	78.9 (8.8)
Pain (0–30, 30 = no pain)	22.9 (4.3)
Satisfaction subscale (0–10, 10 = fully satisfied)	6.1 (2.4)
Function subscale (0–60, 60 = full function)	49.9 (8.8)
Re-test visit	
Penn Shoulder Score (0–100; 100 = no disability)	77.8 (8.2)
Pain (0–30, 30 = no pain)	24.9 (3.4)
Satisfaction subscale (0–10, 10 = fully satisfied)	6.0 (2.1)
Function subscale (0–60, 60 = full function)	46.9 (8.1)

in the scapular plane defined as 40° anterior to the frontal plane (Karduna et al., 2001). Starting with the arm at the side of the body, the participant raised their arm with their thumb pointing towards the ceiling, to maintain a position of mid-range humeral rotation. Elevation was standardized to a 3-s count during the ascending and descending phases to control for effects of velocity (Roy et al., 2008). Arm elevation in the scapular plane was monitored visually to ensure that the plane of elevation was maintained. Participants held weights during testing; 1.4 kg (3-lb) for those under 68.1 kg and a 2.3 kg (5-lb) weight for those over 68.1 kg (Tate et al., 2009). Five consecutive repetitions were completed with the middle 3 repetitions used for kinematic and EMG analysis. The same investigator performed all test sessions, while data analysis was performed by a second investigator blinded to test session. On the re-test visit, the Penn Shoulder Score was completed to ensure no change in pain, satisfaction, and shoulder function between test days (Table 1). Procedures were performed by a biomechanist with 8 years of experience collecting shoulder kinematics and sEMG data.

2.3. Measurements

Kinematics. The scapula, humerus, and thorax were instrumented with sensors and tracked using the Polhemus 3SPACE FASTRACK (Polhemus Inc, Colchester, VT) electromagnetic motion-tracking system (Fig. 1). The sensors received an electromagnetic signal emitted from a transmitter secured on a support platform 115 cm above the floor. One sensor was affixed with adhesive tape on the third thoracic vertebrae to capture upper trunk movement. A second was affixed with adhesive tape on the flat surface of the posterior-lateral acromion for tracking scapular motion. The third sensor was fixed with a rubber strap to the posterior aspect of the distal humerus midway between the medial and lateral epicondyles. Scapular motion was expressed relative to the thorax by humeral elevation angles, with humeral motion expressed with respect to thorax. A digitizing wand connected to a 4th sensor was used to digitize bony landmarks to create local coordinate systems. The trunk was defined by digitizing the seventh cervical spinous process, seventh thoracic spinous process, suprasternal notch, and the most caudal point of the xyphoid process. The scapula was defined by the root of the spine of the scapula, the inferior angle of the scapula, and the posterior-lateral acromion angle. The humerus was defined by the medial and lateral epicondyles, and the center of the humeral head; the center was approximated by the coincident point of the vectors using the least squares method recorded during multiple humeral positions.

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