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The Effects of Hip Position on Scapular Kinematics and Muscle Activation in the Oblique Sling: A Simulated Study

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The Effects of Hip Position on Scapular Kinematics and Muscle Activation in the Oblique Sling: A Simulated Study

By

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Accepted in Partial Completion

of the Requirements for the Degree

Master of Science

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Master's Thesis

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The Effects of Hip Position on Scapular Kinematics and Muscle Activation in the Oblique Sling: A Simulated Study

A Thesis
Presented to
The Faculty of
Western Washington University

In Partial Fulfilment
Of the Requirements for the Degree
Master of Science

By
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Abstract

The purpose of this study was to measure differences in scapular kinematics and muscular activation, associated with shoulder stabilization and the oblique sling, as a result of changes in hip position. Scapular kinematics and muscular activation of the latissimus dorsi, infraspinatus, upper trapezius, lower trapezius, serratus anterior, and the contralateral gluteus maximus were measured during scapular plane humeral elevation. Subjects (*n=25* male and female) were required to elevate the dominant arm up to 120º while remaining in the scapular plane and performed the following conditions in randomized order: standing bilateral hip extension, seated bilateral hip flexion, and seated unilateral hip flexion of the contralateral leg. A 3-way ANOVA was conducted to assess the interaction between degree of humeral elevation, condition, and muscle. Results I: Acute enhancement of scapular kinematics and muscle activation was not of statistical significance. The findings of this study do not support the involvement of the thoracolumbar fascia in force transmission between the gluteus maximus and the contralateral shoulder. Results II: Enhancement of scapular kinematics and muscle activation was of statistical significance. Since hip position affects shoulder motion practitioners might consider this in the rehabilitation of generalized shoulder injuries.

Acknowledgments

I would like to thank the faculty, staff, and students of the Kinesiology program and the Department of Health and Human Development for all of their support and assistance in the completion of this thesis project. I would also like to thank my family and friends for believing in my research and supporting me in this endeavor. Additionally, I would like to thank all of these individuals for pushing me and helping me see what I am truly capable of.

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Introduction

Function of the glenohumeral joint is dependent upon coordinated muscle activation, scapulothoracic articulation, and spinal alignment (Finley, & Lee, 2003; Kanlayanaphotporn, 2014; Kebaetse, McClure, & Pratt, 1999). The anatomy of the shoulder provides essential muscular attachment points that aid in the motion capabilities of the joint. For example, in healthy persons, superior-inferior humeral translation during arm elevation (at the glenohumeral joint) is 0.30 to 0.35millimeters and anterior translation measured 3.8mm (Halder, Itoi, & AN, 2000). Currently, it is understood that glenohumeral joint dysfunction, as a result of excessive humeral translation, can occur due to impaired myofascial force transmission (Joseph, et al., 2014). The oblique sling, a myofascial sling capable of force transmission from lower to upper body, connects the anterior and posterior portions of the body (Kim, et al., 2014). The posterior portion of the oblique sling connects the gluteus maximus and thoracolumbar fascia to the contralateral latissimus dorsi and lower trapezius (do Carmo Carvalhais et al., 2013; Joseph et al., 2014; Schleip, Klingler, & Lehmann-Horn, 2005). It is unknown how or if humeral translation is affected, via the myofascial connections within the oblique sling, by changing the position of the hips. Humeral elevation prompts increased activation of the rotator cuff muscles (Antony, & Keir, 2010; Nakamura, Tsuruike, & Ellenbecker, 2016). When considering humeral elevation, it is important to note that motion, in the frontal plane, increases the activation of the trapezius muscles (Thigpen et al., 2010). Activation of the serratus anterior serves as a critical stabilization force necessary for healthy scapular movement as well as positioning (Goldstein, 2004; Moraes, Faria, & Teixeira-Salmela, 2008). For this reason, activation of the upper and lower trapezius, in conjunction with the serratus anterior, will be considered during humeral elevation in this study.

Current research indicates that extensive connections exist between the thoracolumbar fascia, latissimus dorsi, and gluteus maximus. This suggests two things: that myofascial force transmission occurs between the structures and the possibility of a force coupling mechanism existing between the two muscles and fascial connection. Additionally, in a study conducted by do Carmo Carvalhais and colleagues (2013), tension of the latissimus dorsi or the gluteus maximus displaces the thoracolumbar fascia; however, this has yet to be reproduced in living humans. Although do Carmo Carvalhais and colleagues theorized the transduction occurred via the connective tissue overlaps between the muscles, this study did not assess the effect of changing joint angles. Due to the findings of this study, it may be possible to investigate force, stiffness, and tension production in the thoracolumbar fascia by assessing the effect of changing joint position of the hip on contralateral scapular kinematics (do Carmo Carvalhais et al., 2013).

Greater contralateral latissimus dorsi activation was found in women with chronic low back pain. It was theorized the individual adapted to lumbopelvic dysfunction (induced by impaired function of the gluteus maximus) by increasing activation of the contralateral trunk muscle to provide stability during movement (Kim, Kang, & Oh, 2014). Similar findings were reported by Barker, Briggs, and Bogeski (2004) where force was transmitted from one muscle in the lower body to a contralateral muscle in the upper body via fascial attachments. This study specifically examined transmission of force through the lumbar fascia (Barker, Briggs, & Bogeski, 2004). Lumbar fascia has been described similarly to crural fascia; therefore, it is theorized that it has similar innervation and contractile properties (Schleip, Klingler, & Lehmann-Horn, 2005). In a study conducted by Joseph and colleagues (2014), excessive anterior translation of the humeral head was seen in individuals with sacroiliac joint dysfunction. The main implications of this study were such that lumbopelvic dysfunction may cause contralateral shoulder dysfunction or, the opposite may be true. The researchers concluded the answer to understanding the connection between the two was in understanding mechanotransduction within the oblique sling (Joseph et al., 2014). Due to the findings of this study, it is important to establish an understanding of contralateral force transmission through fascial connections and whether or not posture affects it.

Current literature lacks expression of the effects of hip position on scapular kinematics through the perspective of combined anatomy, fascial connection, and posture. Seated versus standing posture is known to affect scapular kinematics, activation of the rotator cuff muscles is known to affect the function of the glenohumeral joint, and fascia is known to affect force production (Kanlayanaphotporn, 2014; Terry, & Chopp, 2000; Thigpen et al., 2010; Schleip, Klingler, & Lehmann-Horn, 2005; Yucesoy, Koopman, Baan, Grootenboer, & Huijing, 2003). However, the pleotropic effects of these attributes have yet to be directly applied to shoulder function as a result of hip position. Therefore, the purpose of this study is to determine the effect of hip position on scapular kinematics and muscle activation of the oblique sling. As such, this study intends to address the hypotheses that there would be no difference in scapular kinematics and muscle activation during humeral elevation, under conditions of seated unilateral hip flexion, seated bilateral hip flexion, and standing bilateral hip extension.

Methods

Description of study population. The sample size required to achieve a power level of 0.8 at an alpha level of 0.05 was computed using G*Power software (version 3.9.1.4) based on effect size (partial eta^2) of 0.40. The partial eta^2 used was taken from a previously conducted study assessing three-dimensional scapular kinematics (Hotta, et al., 2018). Using this information yielded a sample size of 12 subjects, but 25 subjects were used as this is more in line with the literature. Individuals experiencing pain or who had a current or recent shoulder or hip injuries were not included in an attempt to mitigate any possible confounding effects. Individuals with tight hip flexors, indicated by hip extension angle of +5 to +15 ^{o} above the horizontal, were excluded from the study due to impaired biomechanics and possible anterior pelvic tilt. This was assessed using the modified Thomas test as previously outlined by Aslan and colleagues (2018).

Sampling method. The study sample included healthy college-aged males and females. Subjects were recruited via flyer and word of mouth for participation. Subjects were included in the study following an initial meeting to familiarize with the protocol and provide consent to be included in the research.

Instrumentation. Scapular kinematics, of the dominant arm, were measured using the Polhemus Liberty (Polhemus Inc., Colchester, VT, USA) electromagnetic tracking system collecting at 240 Hz, Motion Monitor software (Innovative Sports Training Inc, Chicago, Ill, USA) system. Polhemus sensors were placed on the thorax, both upper arms (deltoid tuberosity), and the left and right scapular spines. The Polhemus uses these locations to identify movements in flexion/extension, abduction/adduction, and internal/external rotation of the scapula. The sensors are used in conjunction with subject demographics, such as height, to set up a world axis specific to the individual being tested. This is done by setting up and calibrating an anatomical coordinate system (ACS). The ACS is set up following the World Axes. The World Axes for this experiment were set for a positive x- axis to the right and positive y-axis pointing up. The segment axes of the ACS are determined by manual digitization of each point. The points used to set up the coordinate system following the ISB recommendation include the C7 spinous process, T12 spinous process, lateral epicondyle, medial epicondyle, T8 spinous process, xiphoid process, jugular notch, the root of the Scapular spine, acromial angle, and the scapular inferior angle (Wu, et al., 2005). The Polhemus was integrated with the, Noraxon Telemyo DTS (Noraxon, Scottsdale, AZ, U.S.A.) electromyography (EMG) system was used to assess muscular activation of the rotator cuff muscles as well as the muscles associated with the oblique sling. Electrodes were placed on the serratus anterior, latissimus dorsi, upper and lower trapezius, infraspinatus, and gluteus maximus as recommended by Cram and colleagues (1998). The sampling frequency was collected at 1500Hz with a common-mode rejection ratio (CMRR) of 100dB, and an inter-electrode distance of 2cm. Figure 1 shows the subject set up for the first test condition. Gluteal electrodes were placed such that the signal was not affected in the seated position as indicated in figures 2 and 3 below which present the setup and positioning for the seated bilateral and unilateral conditions.

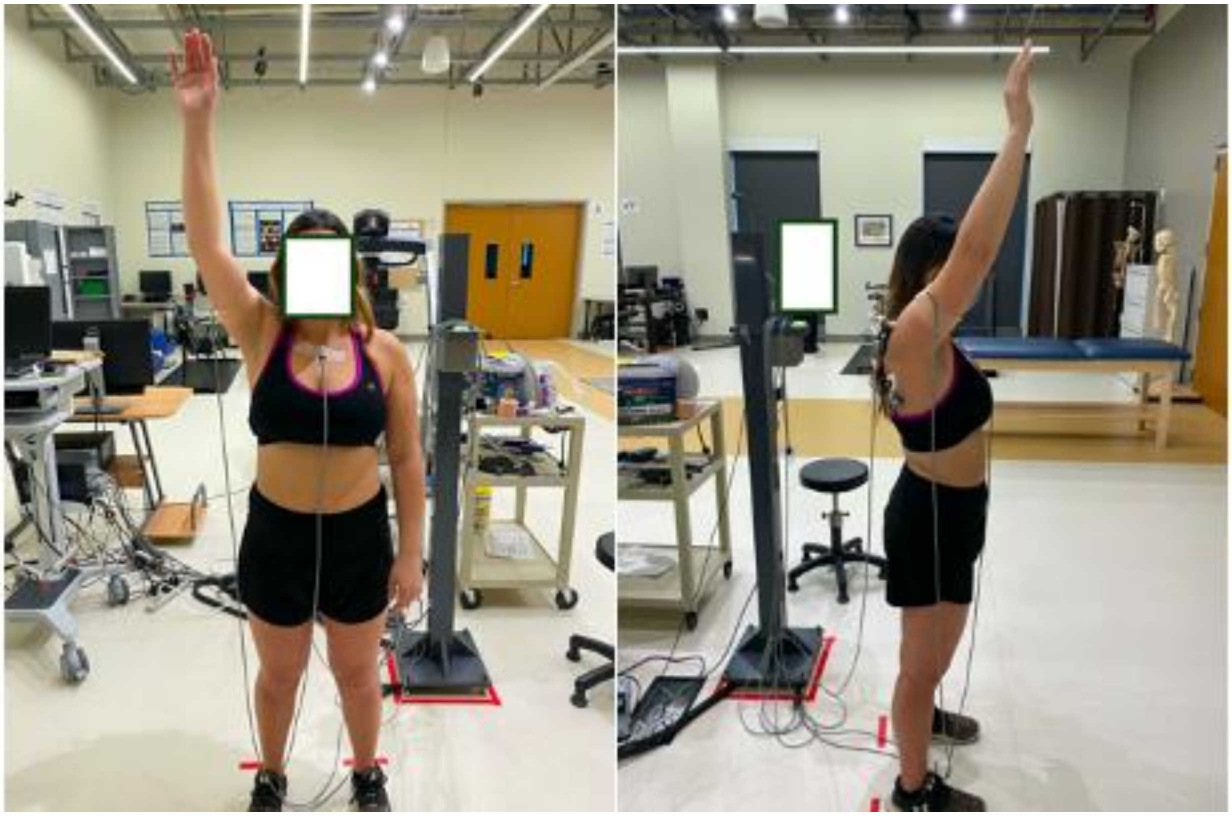

Figure 1: Right hand dominant subject is in the standing, condition 1, position with arm raised following subject set up with electrodes, EMG signal amplifiers, and Polhemus attachments.

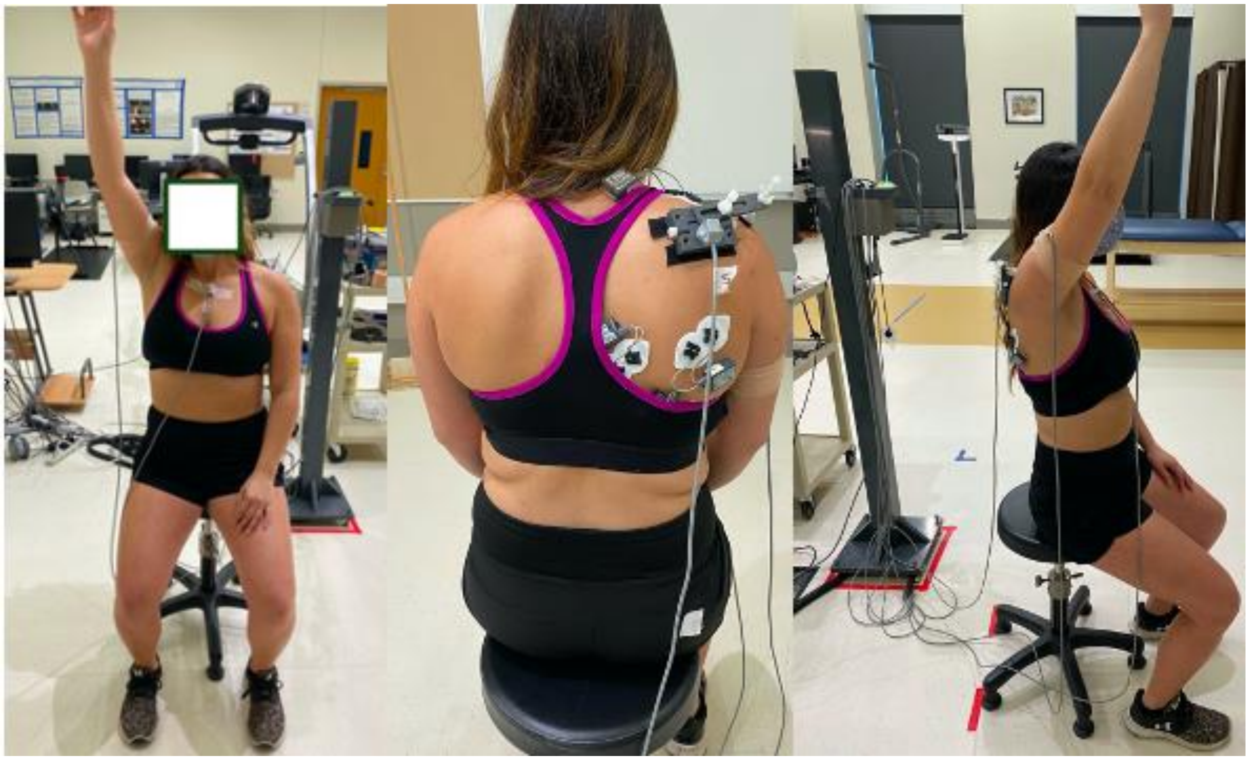

Figure 2: Right hand dominant subject is in the seated bilateral, condition 2, position with arm raised.

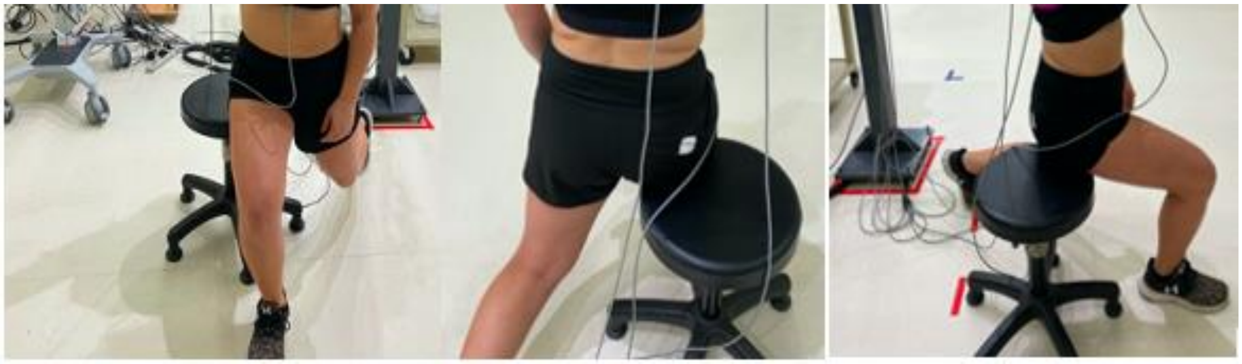

Figure 3: Left hand dominant subject is in the seated unilateral (condition 3). A white sticker indicated the placement of the gluteal electrodes the signal of which was unimpeded.

Experimental procedures. This study utilized a within-subjects observation design. Subjects came in for one session where they were set up on the magnetic tracking device (MTD) and EMG system. For the MTD the two single sensors were positioned on the deltoid process and thorax while the tracker was placed on the scapular spine with an attachment to the Acromion process. This was done following the collection of subject demographics and the collection of maximal voluntary isometric contractions (MVIC) for each muscle tested. MVICs were collected for later comparison of muscular activation. For EMG, the sensors were placed on the latissimus dorsi, gluteus maximus, upper and lower trapezius, and serratus anterior, and infraspinatus. The subject was allowed three practice trials for each position required to elicit maximal contractions prior to collecting MVIC data. To induce MVIC for the gluteus maximus the methods created by the Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles (SENIAM) project were used. This included instructing the subject to lay prone on a table and lift the entire leg against manual resistance applied by the researcher on the distal part of the thigh near the popliteal space (Merletti et al., 2016). To induce MVIC for the infraspinatus the subject was instructed to attempt external rotation of the shoulder with the arm at 90º of humeral elevation in the scapular plane and the elbow fixed at 90º with 30º of internal rotation. The subject was asked to resist manual resistance applied downward on the wrist as the subject attempted to externally rotate the shoulder (McCully, et al., 2007). For the latissimus dorsi MVIC, the subject was asked to lay prone on a table with arms by the sides and the shoulders internally rotated such that the subject was palm-up. Manual resistance in the, downward direction, was applied to the forearm as pressure was applied to the contralateral pelvis and the subject attempted to extend the shoulder toward the ceiling (Park & Yoo, 2013). For the upper trapezius, the subject was instructed to flex the elbow at 90º with the forearm positioned semi-prone and the arm at 90º of abduction. The subject was to resist forceful arm abduction while resistance was applied at the elbow (San Juan, et al., 2015; San Juan, et al., 2016). For the lower trapezius, the subject was instructed to flex the elbow at 90 º with the forearm positioned semi-prone and the arm elevated 20º in the scapular plane. The subject then resisted a combination of adduction and arm extension while resistance was applied at the elbow (San Juan, et al., 2015; San Juan, et al., 2016). For the serratus anterior, the subject was instructed to flex the elbow at 90º with the forearm positioned semi-prone and the arm flexed and internally rotated at 90º. The subject resisted horizontal adduction of the arm as resistance was applied at the fist (San Juan, et al., 2015; San Juan, et al., 2016).

Collected demographics included age, biological sex, physical activity, height, and mass. Measurements of height and mass (in cm and kg, respectively) were done using a DETECTO Scale (Webb City, MO, USA). MVIC data was collected using the myoMuscle version MR 3.112 (Noraxon, Scottsdale, AZ, U.S.A.) that was integrated with the Noraxon Telemyo DTS. MVICs were collected within the MR3 window prior to opening the Polhemus software to reduce impeded muscle activation as a result of the scapular spine sensor. Subjects were prepped for marker placement using CURAD Alcohol prep wipes (CURAD, Mundelein, IL, USA). The skin was shaved beforehand if necessary. Alcohol remaining on the skin was monitored to ensure evaporation, so the skin was dry prior to applying electrodes. To prepare the TeleMyo Direct Transmission System (DTS) EMG Sensor pre-amplifiers (Noraxon, Scottsdale, AZ, USA), TD-20 11 mm electrode collars (Discount Disposables, St. Albans, VT, USA) were applied. Dual EMG electrodes with an inter-electrode distance of 2cm were used (Noraxon, Scottsdale, AZ, USA). Adherence of the markers was aided by putting 3M transpore (3M, St. Paul, MN, USA) tape over the sensor. Once subjects were prepped and sensors for both the EMG and Polhemus were attached, further instructions within the software were followed.

Data collection time was set at 15 seconds to allow for collection of the entire motion from neutral to shoulder flexion. This experiment collected data from the dominant arm to assess differences in contralateral and ipsilateral hip positioning. Posture, while seated, was controlled by ensuring the individual was seated as upright as possible. This was done by reminding the subject to maintain an upright posture at beginning of each trial. Additionally, the seat used during data collection included back support which assisted the subject in assessing and correcting posture as needed. The researchers also ensured trunk lean did not occur during arm elevation in the scapular plane. Using real time biofeedback provided by the Polhemus, the subject was asked to elevate the arm, up to 180º, until approximately 35º of humeral elevation was achieved. The subject was then asked to practice raising the arm to this position three times at which point the subject was considered familiarized. This procedure allowed the subject and researcher to ensure the experimental procedure would be conducted in the scapular plane. Standing posture was controlled by reminding the subject to maintain an upright posture. For each condition, the subject was asked to perform the task and then return to neutral (arm at the side for this experiment) to enable the collection of all three conditions without the need to re-setup the participant between trials. The collection included a movement from neutral to humeral elevation up to 180º and then back to neutral where data collection ended. Capture began again once the subject was successfully positioned for the next condition. The three study conditions were randomized: (1) bilateral hip extension- the subject was asked to stand and raise the arm above the head (2) seated bilateral hip flexion-the subject was asked to sit down and raise the arm above the head; and (3) seated unilateral hip flexion- the subject performed a lunge (such that the ischial tuberosity of the contralateral hip was on the chair) and raise the arm above the head. These conditions were used to assess hip flexion of approximately 90º. The subjects were asked to raise the arm above the head to mitigate activation of the upper trapezius (UT). The UT was activated throughout the elevation, which occurs at 90º, in hopes of capturing activation of the lower trapezius which occurs most significantly at 120º of humeral elevation (Nakamura, Tsuruike, & Ellenbecker, 2016; Thigpen et al., 2010). EMG sensors were placed on the upper trapezius muscle to capture the degree of humeral elevation.

Data analysis. Data from the Polhemus was filtered using a 4th order Butterworth filter. EMG was full-wave rectified (the absolute value of all signals was used) so no information was eliminated, smoothed with a low pass filter set at 500, and normalized to the MVIC collected pre-trial through Noraxon software myoMuscle version MR 3.112 (Noraxon, Scottsdale, AZ, U.S.A.). Following this procedure, all EMG and scapular kinematics data were exported and uploaded into an Excel (Microsoft, Redmond, WA) spread sheet. Scapular kinematic data was run through a MatLab script (MATLAB 9.4 and Statistics Toolbox 8.1, The MathWorks, Inc., Natick, Massachusetts, USA) that was customized to extract data every 5 degrees of humeral elevation up to a maximum of 120º as this is the elevation angle raise within which the Polhemus is the most accurate. Data for scapular upward/downward rotation, internal/external rotation, and anterior/posterior tilt were collected for each condition. EMG data were analyzed by using the MVIC and calculating the activation of muscles for comparison to the MVIC expressed as a percentage of the MVIC.

Statistical analysis. Statistical analysis was conducted using IBM SPSS Version 26.0 for Windows (IBM Corporation, Armonk, New York, U.S.A.). A 3-way ANOVA was conducted to assess the interaction between degree of humeral elevation, condition, and muscle.

Results I

It was hypothesized that hip position would not cause changes in scapular kinematics or activation of muscles in the oblique sling and shoulder stabilizers during scapular plane humeral elevation. This was hypothesized to be the case during both seated and standing conditions. The dominant limb of each subject was used to assess the ipsilateral or contralateral hip extension and flexion. It was noted that scapular kinematics and muscular activation were greater in the standing position in comparison to the seated positions. This finding was not of statistical significance. There were also increases in measurements of scapular kinematics and muscular activation in the seated unilateral hip extension condition compared to the seated bilateral hip extension condition. These differences were not of statistical significance. The infraspinatus, upper and lower trapezius, and the latissimus dorsi evidenced greater activation during arm elevation in all conditions. Since scapular kinematic and muscular activation measurements were the same under conditions of standing bilateral hip extension, seated unilateral hip flexion and seated bilateral hip flexion the hypotheses were supported.

Discussion I

The purpose of this study was to determine the effect of hip position on scapular kinematics and muscle activation of the oblique sling. It was hypothesized there would be no differences in scapular kinematics and muscle activation during humeral elevation, under conditions of standing bilateral hip extension, seated unilateral ipsilateral hip flexion and seated bilateral hip flexion. These hypotheses were supported following the collection and analysis of the data, the results of which confirmed each hypothesis.

Muscular Activation. Activation of the infraspinatus increased as the angle of arm elevation increased. Additionally, the infraspinatus evidenced greater activation at elevations above 90º.This is similar to the findings of Hawkes and colleagues (2012) whose research indicated increased activation of the infraspinatus as the subject increasingly elevated the arm. This study produced evidence of statistical significance, unlike the current one, which could be due to the use of an applied external load and a difference in the tasks asked of the subjects. The current study results also concurs with the findings of Antony and Keir (2010) whose research indicated greater infraspinatus activation at humeral elevations greater than 90º. The activation of upper and lower trapezius increased as the subject raised the arm higher. The greatest activation of these muscle occurred from 90º to 120º of humeral elevation. Antony and Keir also utilized an external load, in two of their conditions, which may have resulted in the statistical significance of their study in comparison to the current one. The findings of Nakamura and colleagues (2016) were similar to this finding though they produced effects of statistical significance. The researchers applied loads of 0, 3, and 7% of the subjects bodyweight. These researchers found lower trapezius activation to be greatest at elevations up to 120º and the greatest upper trapezius activation at elevations up to 90º (Nakamura, Tsuruike, & Ellenbecker, 2016). A similar study conducted by Thigpen and colleagues (2010) also produced evidence of greater upper and lower trapezius activation as humeral elevation angle was increased. The latissimus dorsi was significantly more active when the arm was elevated. As the angle of elevation increased the activation of the latissimus dorsi increased as well. This was similar to the findings of both Hawkes and colleagues (2012) and Antony and Keir (2010). Both studies produced similar evidence of increased latissimus dorsi activation as a result of increasing the angle of humeral elevation (Antony & Keir, 2010; Hawkes et al., 2012). The results of Thigpen and colleagues may have produced similar significant activation patterns due to the application of an external load of 3% of the subjects bodyweight. In this way, these studies differed from the current study which did not use an external load and did not produce results of statistical significance. This being said, the current study did produce evidence of increased activation, however the hypotheses were confirmed since they were not of statistical significance.

Net Torque in the Oblique Sling. The posterior oblique sling connects the upper and lower body via muscular and myofascial insertions (Kim, et al., 2014). It is comprised of connections between the gluteus maximus, thoracolumbar fascia, and the contralateral latissimus dorsi and lower trapezius (do Carmo Carvalhais et al., 2013; Joseph et al., 2014; Schleip, Klingler, & Lehmann-Horn, 2005). Joseph and colleagues (2014) described the sling as an elastic cable, the anterior portion of the sling being one cable and the posterior portion of the sling being the other. It was described that the net force, if compromised, results in force balance shifts such that force transmission may become impaired (Joseph et al., 2014). This theory could explain the differences in both scapular kinematics and muscular activation between experimental study conditions. For example, in both the seated bilateral and standing bilateral hip extension conditions, there was no change in activation of shoulder stabilizers or muscles of the oblique sling. It could be that since the subject was not experiencing any sort of asymmetry, at the pelvis, the oblique sling did not have to compensate for changes in pelvic position. This theory is further augmented by the findings of increased shoulder stabilizer and oblique sling activation during the seated unilateral hip extension condition. For example, it could be that the fascia increased in stiffness because the net torque of the system was no longer zero as evidenced by increased activation of the gluteus maximus and contralateral lower trapezius and latissimus dorsi. Since the subject was performing a lunge, the gluteus maximus showed increased activation causing a shift in myofascial force transmission such that the contralateral shoulder was affected to compensate for the pelvic asymmetry. Though these differences were not of statistical significance, there may be merit to further studying them. A possible explanation for the statistical significance of the studies conducted by Kim and colleagues (2014) and Joseph and colleagues (2014) is the comparison of a healthy population to individuals with chronic low back pain or sacroiliac joint dysfunction, respectively. Additionally, the study by Kim and colleagues (2014) was able to directly measure activation in the oblique sling which is something the current study lacked. This was conducted during prone hip extension which is different from the current study’s protocol which included seated and standing hip extension. The study conducted by Joseph and colleagues (2014) compared resting position of the humeral head, anterior translation of the humeral head, and posttranslational distance of the humeral head of individuals with sacroiliac joint dysfunction in comparison to healthy controls. This is a different protocol in comparison to the current study. These differences could account for the lack of statistical significance in the results of the current study.

Effect of Posture. Similar muscle activation patterns were seen in the gluteus maximus, latissimus dorsi, upper and lower trapezius, serratus anterior, and infraspinatus during all three experimental conditions. This is similar to the findings of Al-Eisa and colleagues (2006) who demonstrated similar effects in muscular activation of the pelvis and trunk under both seated and standing conditions. This study also produced evidence that asymmetry of the pelvis contributes changes in lumbar and trunk kinematics. It was theorized these changes in kinematics further up the kinetic chain were the result of some sort of compensatory mechanism produced as a result of changing pelvic position (Al-Eisa, Egan, Deluzio, & Wassersug, 2006). This study differs in comparison to the current one in that the researchers investigated both twisting and lateral bending to the extreme (as much as the subject was capable) in individuals with low back pain and healthy controls. It could be that the inclusion of extreme postures and comparison to healthy controls were able to elicit the results reported with statistical significance which the current study lacked.

The current study evidenced increased scapular kinematics, activation of shoulder stabilizers, and muscles of the oblique sling when the subject was in the seated unilateral position in comparison to the seated bilateral position. This difference in activation pattern could be the result of the compensatory mechanism described by Al-Eisa and colleagues (2016). It could be further theorized that the change in activation due hip position could be representative of the force coupling mechanism described by Joseph and colleagues (2014) in reference to the net torque of the oblique sling. Since the sling connects the upper and lower body and a change in one leads to a change in the other, the sling itself could be the compensatory mechanism described by the research conducted by Al-Eisa and colleagues (2016). At 120º of humeral elevation there were no differences of statistical significance in the scapular kinematic measurements of elevation, upward rotation, posterior tilt, and lateral translation between seating and standing positions. This agrees with the findings of McKenna and colleagues (2017) who found the same results when assessing scapular kinematics as a result of humeral elevation under both seated and standing conditions. This study looked specifically at individuals with shoulder pain and measured lumbar lordosis and thoracis kyphosis as covariates when assessing seated versus standing posture with both the arm by the side and at 120º of glenohumeral scaption. The use of the special population and different conditions could have possibly aided in the production of significant results since the individuals were experiencing shoulder pain during the study. This theory is compounded by the conclusions of the researchers who suggested this is why posture may have affected scapular orientation in this population.

Another observed difference was the lack of upper and lower trapezius activation at 120 º compared to that found below 120º. Nakamura and colleagues (2016) found the activation of the upper and lower trapezius muscles were greater at elevations of 120º to 150º. One theory for this increased activation could be that the researchers tested the muscles in the prone position as opposed to the current study which assessed them in both seated and standing positions. Additionally, the researchers applied an external load to the subjects. This could have caused additional motor unit recruitment which would cause increased activation of the trapezius muscles (Nakamura, Tsuruike, & Ellenbecker, 2016).

Results II

It was hypothesized that hip position would not cause changes in scapular kinematics or activation of muscles in the oblique sling and shoulder stabilizers during scapular plane humeral elevation. This was hypothesized to be the case during both seated and standing conditions. The dominant limb of each subject was used to assess the ipsilateral or contralateral hip extension and flexion. It was noted that scapular kinematics and muscular activation were greater in the standing position in comparison to the seated positions. This finding was of statistical significance. There were also increases in measurements of scapular kinematics and muscular activation in the seated unilateral hip extension condition compared to the seated bilateral hip extension condition. These differences were of statistical significance. The infraspinatus, upper and lower trapezius, and the latissimus dorsi evidenced greater activation during arm elevation in all conditions. Since scapular kinematic and muscular activation measurements were dissimilar under conditions of standing bilateral hip extension, seated unilateral hip flexion and seated bilateral hip flexion the hypotheses were not supported.

Discussion II

The purpose of this study was to determine the effect of hip position on scapular kinematics and muscle activation of the oblique sling. It was hypothesized there would be no differences in scapular kinematics and muscle activation during humeral elevation, under conditions of standing bilateral hip extension, seated unilateral ipsilateral hip flexion and seated bilateral hip flexion. These hypotheses were not supported following the collection and analysis of the data, the results of which did not confirm each hypothesis.

Muscular Activation. Activation of the infraspinatus increased as the angle of arm elevation increased. Additionally, the infraspinatus evidenced greater activation at elevations above 90º.This is similar to the findings of Hawkes and colleagues (2012) whose research indicated increased activation of the infraspinatus as the subject increasingly elevated the arm. It also concurs with the findings of Antony and Keir (2010) whose research indicated greater infraspinatus activation at humeral elevations greater than 90º. The activation of upper and lower trapezius increased as the subject raised the arm higher. The greatest activation of these muscle occurred from 90º to 120º of humeral elevation. The findings of Nakamura and colleagues (2016) were similar to this finding. These researchers found lower trapezius activation was greatest at elevations up to 120º and the greatest upper trapezius activation at elevations up to 90º (Nakamura, Tsuruike, & Ellenbecker, 2016). A similar study conducted by Thigpen and colleagues (2010) also produced evidence of greater upper and lower trapezius activation as humeral elevation angle was increased. The latissimus dorsi was significantly more active when the arm was elevated. As the angle of elevation increased the activation of the latissimus dorsi increased as well. This was similar to the findings of both Hawkes and colleagues (2012) and Antony and Keir (2010). Both studies produced similar evidence of increased latissimus dorsi activation as a result of increasing the angle of humeral elevation (Antony & Keir, 2010; Hawkes et al., 2012).

Net Torque in the Oblique Sling. The posterior oblique sling connects the upper and lower body via muscular and myofascial insertions (Kim, et al., 2014). It is comprised of connections between the gluteus maximus, thoracolumbar fascia, and the contralateral latissimus dorsi and lower trapezius (do Carmo Carvalhais et al., 2013; Joseph et al., 2014; Schleip, Klingler, & Lehmann-Horn, 2005). Joseph and colleagues (2014) described the sling as an elastic cable, the anterior portion of the sling being one cable and the posterior portion of the sling being the other. It was described that the net force, if compromised, results in force balance shifts such that force transmission may become impaired (Joseph et al., 2014). This theory could explain the differences in both scapular kinematics and muscular activation between experimental study conditions. For example, in both the seated bilateral and standing bilateral hip extension conditions, there was no change in activation of shoulder stabilizers or muscles of the oblique sling. It could be that since the subject was not experiencing any sort of asymmetry, at the pelvis, the oblique sling did not have to compensate for changes in pelvic position. This theory is further augmented by the findings of increased shoulder stabilizer and oblique sling activation during the seated unilateral hip extension condition. For example, it could be that the fascia increased in stiffness because the net torque of the system was no longer zero as evidenced by increased activation of the gluteus maximus and contralateral lower trapezius and latissimus dorsi. Since the subject was performing a lunge the gluteus maximus showed increased activation causing a shift in myofascial force transmission such that the contralateral shoulder was affected to compensate for the pelvic asymmetry. Since these differences were found to be of statistical significance, there is merit to further studying them.

Effect of Posture. Similar muscle activation patterns were seen in the gluteus maximus, latissimus dorsi, upper and lower trapezius, serratus anterior, and infraspinatus during all three experimental conditions. This is similar to the findings of Al-Eisa and colleagues (2006) who demonstrated similar effects in muscular activation of the pelvis and trunk under both seated and standing conditions. This study also produced evidence that asymmetry of the pelvis contributes changes in lumbar and trunk kinematics. It was theorized these changes in kinematics further up the kinetic chain were the result of some sort of compensatory mechanism produced as a result of changing pelvic position (Al-Eisa, Egan, Deluzio, & Wassersug, 2006). The current study evidenced increased scapular kinematics, activation of shoulder stabilizers, and muscles of the oblique sling when the subject was in the seated unilateral position in comparison to the seated bilateral position. This difference in activation pattern could be the result of the compensatory mechanism described by Al-Eisa and colleagues (2016). It could be further theorized that the change in activation due hip position could be representative of the force coupling mechanism described by Joseph and colleagues (2014) in reference to the net torque of the oblique sling. Since the sling connects the upper and lower body and a change in one leads to a change in the other, the sling itself could be the compensatory mechanism described by the research conducted by Al-Eisa and colleagues (2016). At 120º of humeral elevation there were no statistical differences in the scapular kinematic measurements of elevation, upward rotation, posterior tilt, and lateral translation between seating and standing positions. This agrees with the findings of McKenna and colleagues (2017) who found the same results when assessing scapular kinematics as a result of humeral elevation under both seated and standing conditions.

One observed difference was the lack of upper and lower trapezius activation at 120 º compared to that found below 120º. Nakamura and colleagues (2016) found the activation of the upper and lower trapezius muscles were greater at elevations of 120º to 150º. One theory for this increased activation could be that the researchers tested the muscles in the prone position as opposed to the current study which assessed them in both seated and standing positions. Additionally, the researchers applied an external load to the subjects. This could have caused additional motor unit recruitment which would cause increased activation of the trapezius muscles (Nakamura, Tsuruike, & Ellenbecker, 2016).

Limitations

This study has several limitations. A major limitation to this study is the lack of collecting physical data. Due to the current pandemic, this was not a possibility therefore anything that may have occurred during collection could not be accounted for. One limitation is the lack of ability to measure fascial stiffness directly. To do this, data collected via Motion Monitor EMG analysis was used to discuss muscular activation and implicate fascial stiffness. The use of EMG could also be a limitation. Due to the nature of fastening EMG electrodes to skin, it is possible that skin artifacts may affect electrical stimulus. Skin artifacts are any noise or movement at the skin-electrode interface that may alter the reading (Amasay, & Karduna, 2009; Waite, Brookham, & Dickerson, 2010). In order to minimize the effect of skin artifacts, the skin was shaved if necessary, abraded, and cleaned with alcohol to ensure the markers could be adhered properly.

To ensure proper marker placement, SENIAM guidelines were used in conjunction with other studies when palpating (to locate muscle) and placing EMG electrodes. The use of maximal voluntary isometric contractions (MVIC) is a limitation due to the assumption the subject produced maximal effort during these trials. Individuals may not have contracted maximally which would have distorted values for comparison.

Subjects were sitting in a chair without a back support. Therefore, the subjects were not stabilized nor were they restricted in movement. This is a limitation considering the lack of ability to monitor posture throughout the collection process. In order to minimize this effect, we encouraged them to maintain an upright posture during collection. Another limitation is the lack of comparison between subjects. Additionally, the subjects were not assigned to any particular group. Future research should include comparisons such as trained versus untrained, the influence of sex, limb dominance, and possibly age.

The posture used during the seated trials, may not be familiar to the participants making it a possible limitation. In order to minimize possible effects, due to lack of familiarity, familiarization trials were used. Other limitations include threats to internal validity such as selection bias and instrumentation. The study does not include a randomized control, nor does it control for possible calibration error between uses of the Polhemus Liberty or possible observational drift of researchers.

Conclusion I

The findings of this study do not support the involvement of the thoracolumbar fascia in force transmission between the gluteus maximus and the contralateral shoulder. Since the results were not significant, future studies should include an external load applied at the shoulder to address the acute increases in muscular activation seen in the current study.

Conclusion II

The findings of this study suggest that the thoracolumbar fascia may be responsible for force transmission between the gluteus maximus and the contralateral shoulder. This has implications for the treatment of individuals with pelvic asymmetry, low back pain, and shoulder instability. Since hip position affects shoulder motion, practitioners might consider this in the rehabilitation of generalized shoulder injuries.

Declarations

The experiments conducted within this study comply with the current laws of the country in which they were performed. The authors declare no conflict of interest.

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Review of Pertinent Literature

The biomechanical and myofascial connections between the lumbopelvic region and the contralateral shoulder have recently become areas of exploration. A reason for this new exploration is the findings of several studies which suggest the sacroiliac joint influences structures further up or down the kinetic chain. For example, hamstring tightness and inflexibility as well as dysfunction of the atlanto-occipital-axial joints have been reported in individuals with sacroiliac joint dysfunction. Sacroiliac joint dysfunction (SJD) is defined as the altered or impaired function of the somatic framework of the sacroiliac joint due to variable anatomical positions of articular surfaces on either side. The sacroiliac joint is known to assist in force transmission across the body. It is thought that force transmission is occurring through the myofascial slings present in this region of the body (Joseph, et al., 2014). Additionally, it is thought the oblique slings transmit the forces, intra- and inter-myofascially, from the lumbopelvic region to the contralateral shoulder region. The occurrence of SJD may be caused by impairment of one of the slings such that the net contractile force of the two no longer equals zero (Joseph, et al., 2014). Joseph and colleagues (2014) found that individuals with SJD had anteriorly translated humeral heads in the contralateral shoulder. It was theorized that this translation was the result of impaired myofascial force transmission in the oblique sling (Joseph, et al., 2014). The findings, from Joseph and colleagues, provide a basis for understanding the interconnectedness of fascia and skeletal muscle as well as the effect changes in one may have on the other. The study specifically looked at individuals with SJD and contralateral humeral head position without assessing how shoulder or hip anatomy and position may affect the results. For these reasons, it is important to understand the functional anatomy of the shoulder, activation of shoulder stabilizing muscles, motion as it occurs at the shoulder, how fascia is defined and how it may contribute to movement, how the oblique sling is defined and how it assists in force transmission, as well as how postural differences may affect the shoulder.

Shoulder

The shoulder is made up of four bones, superficial and deep muscles, tendons, and ligaments (Halder, Itoi, & An, 2000; Waite, Brookham, & Dickerson, 2010). The bones that comprise the shoulder complex include the sternum, clavicle, humerus, and the scapula. The muscles work in conjunction with tendons and ligaments to maintain the position of the humerus within the joint cavity as well as aid in strength, stability, and mobility of the shoulder (Goldstein, 2004; Halder, Itoi, & An, 2000; Waite, Brookham, & Dickerson, 2010).

The scapula plays an important role in the efficiency of the shoulder as it aids in the stability of the joint during movement (Goldstein, 2004; Moraes, Faria, & Teixeira-Salmela, 2008). Full functionality of the shoulder joint is not possible without mobility and full range of motion of the pectoral girdle and scapulothoracic joint (Amasay, & Karduna, 2009; Halder, Itoi, & An, 2000). The scapula is held in opposition to the thorax by several muscles. Its path of motion is to follow the curvature of the thorax during protraction and retraction. Muscles that aid in scapular stabilization against the oblique border of the chest wall are the serratus anterior, trapezius, and rhomboids (Goldstein, 2004). The muscles of the scapula aid in stabilization and allow rotator cuff muscles to function properly when the humerus is elevated (Moraes, Faria, & Teixeira-Salmela, 2008). Weaknesses in these muscles can lead to scapular malalignments such as protraction and upward rotation, retraction and downward rotation, and protraction with downward rotation, respectively. The lateral border of the scapula extends to form the glenoid fossa. The glenoid fossa is the site of articulation with the head of the humerus (Goldstein, 2004).

The glenohumeral joint is a ball and socket, synovial joint type (Goldstein, 2004; Halder, Itoi, & An, 2000; Hawkes et al, 2012; Terry, & Chopp, 2000). The glenoid cavity, which articulates with the humeral head, is created by the protruding lateral extension of the scapula facing upward and forward allowing the humeral head to position itself accordingly. The cavity is made deeper by a fibrocartilage ring, called the glenoid labrum, which is attached to the margins of the cavity (Goldstein, 2004). The humeral head lies superiorly, posteriorly, and medially in the joint cavity (Goldstein, 2004; Halder, Itoi, & An, 2000). This positioning causes the lesser tuberosity to face anteriorly and the greater tuberosity to face laterally. The rotator cuff muscles attach to these tuberosities to aid in movement and stabilization of the glenohumeral joint.

The shoulder has three degrees of freedom providing movements, including internal and external rotation, flexion and extension, and abduction and adduction (Goldstein, 2004; Halder, Itoi, & An, 2000; Terry, & Chopp, 2000). The primary movers for glenohumeral internal rotation are the pectoralis major, latissimus dorsi, teres major, and subscapularis. The primary movers of glenohumeral external rotation are the infraspinatus, teres minor, and posterior deltoid. The primary movers for glenohumeral flexion include the clavicular head of the pectoralis major and anterior deltoid while the primary movers for extension include the latissimus dorsi and posterior deltoid. The primary movers for glenohumeral abduction are the deltoid and supraspinatus and the primary movers for adduction are the pectoralis major, latissimus dorsi, teres major, and subscapularis (Goldstein, 2004). Achieving flexion and abduction of the arm requires mobility from both the pectoral girdle and the shoulder. The motion occurs in a number of steps. The deltoid and supraspinatus contract until about 90° of flexion at which point the greater tuberosity of the humerus limits further motion (it gets caught on the superior surface of the labrum). This causes external rotation of the humeral head via rotation of the pectoral girdle (aided by the trapezius and serratus anterior). Lateral flexion of the pectoral girdle allows for additional abduction (Goldstein, 2004; Halder, Itoi, & An, 2000).

Activation of Shoulder Stabilizing Muscles

The rotator cuff is composed of the supraspinatus, infraspinatus, teres minor ,and subscapularis muscles (Terry, & Chopp, 2000). The supraspinatus originates from the supraspinous fossa and inserts into the greater tuberosity of the humerus (Halder, Itoi, & An, 2000; Terry, & Chopp, 2000). This muscles initiates glenohumeral elevation via innervation from the suprascapular nerve. The infraspinatus originates from the infraspinous fossa and scapular spine and inserts into the greater tuberosity of the humerus (Halder, Itoi, & An, 2000; Terry, & Chopp, 2000). This muscle aids in resisting posterior and superior humeral translation and force production for external rotation via innervation from the suprascapular nerve. The teres minor originates from the lateral border of the scapula and inserts onto the greater tuberosity inferiorly to the infraspinatus (Halder, Itoi, & An, 2000; Terry, & Chopp, 2000). This muscle, though innervated by the axillary nerve, has the same action as the infraspinatus but produces less of the required external rotation forces. The subscapularis originates in the subscapular fossa and inserts into the lesser tuberosity of the humerus (Halder, Itoi, & An, 2000; Terry, & Chopp, 2000). This muscle aids in the resistance of anterior and inferior translation as well as increased force production for internal rotation via innervation from the subscapular nerve (Halder, Itoi, & An, 2000). A study conducted by Hawkes and colleagues (2012) showed mean electromyographical amplitudes of 113 ± 2, 115 ± 2, and 117 ± 3 (expressed as mean ± standard error of the mean) for the supraspinatus, infraspinatus, and subscapularis, respectively, during elevation of the arm at the glenohumeral joint. These means differed, in a statistically significant manner, from the mean activations during humeral depression which were 89 ± 2, 90 ± 1, and 85 ± 3 (expressed as a percentage of the mean signal amplitude measured during the elevation phase), respectively (Hawkes et al, 2012). This decreased activation, during depression, suggests that humeral elevation above the head requires additional activation from the rotator cuff muscles.

Previous studies have indicated that elevation of the glenohumeral joint from 30º to 90º increases activation of the deltoid (all three heads), infraspinatus, and trapezius by an average of 84%. Arm elevation above 90º requires additional muscle activation to support the limb throughout the range of motion. The external moment, which increases as the arm is elevated, is maximized at 90º; therefore, additional motor units are recruited to support the joint when elevation exceeds this point (Antony & Keir, 2010). Interestingly, a study provided evidence that abduction and elevation of the arm from 120º to 150º solicits the greatest activation in the lower trapezius muscle. It could be theorized that this increased activation is the result of the subject lying in the prone position, where gravity could act on the system, as well as the use of a heavy, 5-repetition maximum load which would cause additional motor unit recruitment. During the same study, the upper trapezius evidenced greater activation at elevations up to 90º (Nakamura, Tsuruike, & Ellenbecker, 2016).

In another study, the latissimus dorsi evidenced statistically significant differences in activation during elevation and lowering of the arm at the glenohumeral joint. Mean activation during arm elevation was much higher in comparison to during depression, when the arm was being lowered (Hawkes et al., 2012). This difference in activation may serve to further substantiate that as the angle of elevation increases the activation of muscles increases, as well (Antony & Keir, 2010). Additionally, healthy functioning of the rotator cuff muscles assists the maintenance of adequate subacromial space by preventing excessive activation of the upper trapezius and anterior deltoid muscles. When these two muscles are over-activated the humeral head translates superiorly and the scapula tilts anteriorly causing decreased subacromial space and less optimal rotator cuff activity (Nakamura, Tsuruike, & Ellenbecker, 2016). Over-active upper trapezius and anterior deltoids, coupled with weak rotator cuff muscles, can cause shoulder impingement. Decreases in subacromial space, weak muscles, and overactive muscles can cause decreased shoulder functionality (Marta et al, 2013; Nakamura, Tsuruike, & Ellenbecker, 2016).

Motion at the Shoulder

Normal shoulder motion is made possible by a combination of dynamic muscle forces and static forces resulting from anatomical structures such as the joint capsule, glenoid labrum, and glenoid ligaments (Karduna, et al., 1996; Ludewig, et al., 2009; Terry, & Chopp, 2000; Wilk, et al., 1997). When all are functioning properly, the humeral head maintains a position within 1 to 2 mm of the joint center. This precise position is maintained throughout the arc of shoulder motion of which the glenoid joint is capable (Howell, et al., 1988; Terry, & Chopp, 2000). The position of the articular surfaces and the shape of the humeral head produce a concavity-compression effect that directs forces toward the glenoid joint center (Terry, & Chopp, 2000). In normal shoulders, superior-inferior translation of the humeral head is about 0.3 to 0.35 mm in length when performing active and passive arm elevation. During flexion, the average anterior translation is 3.8 mm while the posterior translation measures approximately 4.9 mm during extension. Additionally, during horizontal extension, the head translates 4 mm posteriorly. The shape of the glenoid causes larger translations in the anterior-posterior direction. These larger translations are the result of the concavity of articulating surfaces (Goldstein, 2004; Halder, Itoi, & An, 2000). For example, the radius of curvature in the anterior-posterior direction is 40.6 ± 14 mm while the radius of curvature in the superior-inferior direction is 32.2 ± 7.6 mm. The increased concavity of the super-inferior direction causes decreased translation in that direction (Halder, Itoi, & An, 2000).

A study conducted by Karduna and colleagues (1996) assessed humeral translation, using normal human glenohumeral joints previously frozen, as it is affected by elevation of the arm at various angles. The researchers tested elevation both actively (A) and passively (P1- full range of motion) to determine net translations. All measurements were conducted in the anterior-posterior (A-P) axis as well as the superior-inferior (S-I) axis. At 0 º elevation, A produced 3.9 ± 1.0 mm translation in the A-P axis and 2.6 ± 0.4 mm in the S-I axis while P1 produced 7.5 ± 0.7 mm and 4.0 ± 0.5 mm of translation in each axis, respectively. At 30 º elevation in the posterior plane, A produced 1.6 ± 0.2 mm translation in the A-P axis and 1.6 ± 0.4 mm in the S-I axis while P1 produced 9.7 ± 1.0 mm and 4.3 ± 0.5 mm of translation in each axis. At 30 º elevation in the scapular plane, A produced 1.7 ± 0.4 mm translation in the A-P axis and 1.3 ± 0.2 mm in the S-I axis while P1 produced 9.4 ± 0.9 mm and 4.6 ± 0.7 mm of translation in each axis. At 30 º elevation in the anterior plane, A produced 2.1 ± 0.4 mm translation in the A-P axis and 1.4 ± 0.3 mm in the S-I axis while P1 produced 7.3 ± 0.5 mm and 4.2 ± 0.7 mm of translation in each axis. At 60 º elevation in the posterior plane, A produced 2.0 ± 0.4 mm translation in the A-P axis and 2.0 ± 0.6 mm in the S-I axis while P1 produced 9.8 ± 1.6 mm and 4.0 ± 1.0 mm of translation in each axis. At 60 º elevation in the scapular plane, A produced 2.1 ± 0.4 mm translation in the A-P axis and 1.6 ± 0.6 mm in the S-I axis while P1 produced 7.4 ± 1.1 mm and 4.4 ± 0.8 mm of translation in each axis. At 60 º elevation in the anterior plane, A produced 1.5 ± 0.3 mm translation in the A-P axis and 1.4 ± 0.4 mm in the S-I axis while P1 produced 6.1 ± 1.0 mm and 4.0 ± 0.8 mm of translation in each axis. Statistical comparison between A and P1 produced p-values all of which were statistically significant as indicated by values ranging from 0.001 to 0.040 in comparison to an alpha value of 0.05 (Karduna, et al., 1996).

Shoulder kinematics can be altered by pathologic conditions which detrimentally effecting arthrokinematics, osteokinematics, as well as various other musculoskeletal kinematics

(Goldstein, 2004; Halder, Itoi, & An, 2000; Karduna, et al., 1996; Ludewig, et al., 2009; Terry, & Chopp, 2000). For example, superior translation of the humeral head, during elevation, is caused by force imbalance between the deltoid and rotator cuff muscles (Halder, Itoi, & An, 2000). Translation of the humeral head is made possible due to the shallow nature of the glenoid fossa. The glenoid fossa is not deep enough to fully encompass the humeral head which makes translation across the articulating surface more likely to occur (Harryman, et al., 1990). Anterior shoulder instability causes the humeral head to be positioned more anteriorly which places the arm in horizontal extension and external rotation (Halder, Itoi, & An, 2000; Howell, et al., 1988). This is compounded in stiff shoulder joints where the humeral head superiorly translates within the first degrees of arm elevation (Halder, Itoi, & An, 2000). Instability of the shoulder is defined as unwanted translation between the humeral head and glenoid fossa, which leads to discomfort and loss of function at the shoulder. This is not to be confused with laxity, which is defined as the passive ability of the humeral head to translate within the glenoid fossa (Wilk, et al., 1997). Weakness or injury to the rotator cuff muscles, specifically the subscapularis or infraspinatus, results in significant joint weakness due to the superiorly migrated humeral head. The migration of the head occurs because the infraspinatus and the subscapularis are responsible for compressing the humeral head into the glenoid fossa which prevents upward displacement (Goldstein, 2014).

Fascia

Fascia is a densely innervated connective tissue network containing free nerve endings, mechanoreceptors, nociceptors, and sympathetic nerve fibers (Barker, Briggs, & Bogeski, 2004; Kwong, & Findley, 2014; Mense, 2019). It has been defined as a three-dimensional network that is comprised of all types of connective tissues which form connections with both muscles and internal organs (Mense, 2019). Additional characteristics of fascia include the description of both extramuscular and intramuscular connective tissue characteristics (Yucesoy, Baan, & Huijing, 2010). This definition includes examples of fascia such as aponeuroses, ligaments, tendons, joint capsules, the endomysium, perimysium, and epimysium (do Carmo Carvalhais et al., 2013; Schleip, Klingler, & Lehmann-Horn, 2005). One of the most commonly referred to examples of fascia is the aponeurotic fascia which covers all skeletal muscles. Aponeurotic fascia is made up of two to three layers of collagen fibers, parallel to each other, that are each separated by a thin layer of loose connective tissue. This layer of connective tissue provides the fascial layers with the ability to slide over one another (Stecco, et al., 2013). The epimysium is a connective tissue layer, comprised of collagen fibers, which is continuous with tendons that form attachments from muscle to bone (Purslow, 2010). This layer surrounds each muscle and provides insertional points for the aponeurotic fascia. The epimysial fascial layer plays a fundamental role in the transmission of force generated by skeletal muscles (Purslow, 2010; Stecco, et al., 2013). The perimysium divides the muscle into fascicles, also known as muscle fiber bundles, that span the length of the muscle (from tendon to tendon). The end of the muscle fibers form the myotendinous junction with the tendon (Purslow, 2010). The myotendinous junction is the primary site at which forces generated within the sarcomeres may be transmit to bone in order to control body movement (Yucesoy, Baan, & Huijing, 2010). The perimysium merges into the epimysium at the surface of the muscle where it is mechanically connected. The endomysium is a continuous network of connective tissue that acts to separate the individual muscle fibers (Purslow, 2010). Fascia is capable of both producing and transducing force (Schleip, Klingler, & Lehmann-Horn, 2005; Yucesoy, Koopman, Baan, Grootenboer, & Huijing, 2003).

Though the precise mechanism behind fascial mechanotransduction is yet to be fully understood, it is widely accepted that fascia aids in force transduction. It has been noted that fascia may transmit force from agonist muscles (once contracted) to antagonist muscles via connections within the muscle tissue (do Carmo Carvalhais et al., 2013; Yucesoy, Baan, & Huijing, 2010; Yucesoy et al., 2003). Additionally, force may be transmitted through insertion points of tendons into the fascial layers within muscles (do Carmo Carvalhais et al., 2013; Rijkelijkhuizen, Baan, de Ruiter, & Huijing, 2005; Yucesoy et al., 2003). Fascia is well innervated and comprised of tensile myofascial bands that are all interconnected to create one large sensory organ covering the entire body (Branchini et al., 2015; Tozzi, 2014). Fascial collagen contains crystalline strands with dielectric and electric conductive properties. These properties make fascia sensitive to mechanical pressure, electromagnetic fields, pH changes, and ionic balance. Additionally, the fascia will respond to electrical stimuli by producing vibration also known as mechanical motion. It will produce electrical currents when mechanical stress such as compression, shear stress, or tension are applied (Tozzi, 2014).

When mechanical force is applied cell signaling, gene expression, cellular matrix adhesion, and connective tissue tension are all modulated via morphological transformations of myofibroblasts. For example, in two-dimensional models, mechanical straining results in cellular proliferation and the secretion of inflammatory mediators (Kwong, & Findley, 2014). Expressions of ASMA have been found in crural fascia, tendons, and ligaments. This is theorized to be the crucial factor that allows fascia to actively contract similarly to smooth muscle. Contractile properties are stimulated by specific cytokines and mechanical stress causing the cells to either contract like smooth muscles or, display phenotypical contractile properties of fibroblasts.

A differential biomarker for myofibroblasts is α-smooth muscle actin (Yucesoy, Baan, & Huijing, 2010). Myofibril contractile force is correlated with ASMA expression. Mechanoreceptors within the fascia aid in muscle activation by providing proprioceptive feedback that aids in muscular coordination. For example, low threshold mechanoreceptors utilize the γ-muscle spindle system and high threshold mechanoreceptors directly affect the α-motor neuron. In this way, increasing fascial stiffness increases mechanoreceptor signaling. This increased mechanoreceptor signaling prompts a shift from low- to high-threshold activity due to the quicker response to sudden changes. Conversely, if fascial stiffness was decreased, mechanoreceptor function would decrease, and muscle activation would decrease, as well. This cascading effect of decreased function has been shown in patients with chronic low back pain (Branchini et al., 2015; Schleip, Klingler, & Lehmann-Horn, 2005). The patients exhibited fewer mechanoreceptors, in the lumbar fascia, which is theorized to have caused the impaired lumbar proprioception and motor coordination exhibited within the lumbar fascia (Joseph, et al., 2014).

Oblique Sling

Myofascial sling is a term used to describe anatomically linked, or interconnected, musculature. The slings are thought to facilitate the transmission of force across the trunk and from lower to upper extremities. One example of myofascial sling is the oblique sling (Kim, et al., 2014). The oblique sling spans both the anterior and posterior of the body. The anterior oblique sling includes connections of the pectoral fascia, pectoralis major, internal and external obliques, transverse abdominis, anterior trunk fascia, and the pubic bone (Joseph et al., 2014). The posterior oblique sling is a term used to describe the muscular and fascial connection between the gluteus maximus, thoracolumbar fascia, and the contralateral latissimus dorsi and lower trapezius (do Carmo Carvalhais et al., 2013; Joseph et al., 2014; Schleip, Klingler, & Lehmann-Horn, 2005). Its anterior and posterior nature has been described as two elastic cables, the net torque of which must equal zero. When excessive force is produced in either portion of the sling and the net force is compromised, the force balance shifts, and myofascial transmission is impaired. Impaired force transmission, as a result of the compromised net force, can cause injuries such as excessive anterior shoulder translation, which can lead to glenohumeral joint dysfunction (Joseph et al., 2014).

Previous research provided evidence that the fascia of the oblique sling does possess the above-mentioned fascial properties, including dense innervation and contractile capabilities (Mense, 2019; Schilder et al., 2014; Tesarz, Hoheisel, Wiedenhöfer, & Mense, 2011). Additionally, current research indicates that extensive connections exist between the superficial lamina of the thoracolumbar fascia, latissimus dorsi, and gluteus maximus. This connection between the three structures suggests that myofascial force transmission occurs between them. The connection and force transmission between the structures is also indicative of the possibility of a force coupling mechanism existing between the muscles and fascial connection. Lumbar fascia is morphologically similar to crual fascia (Schleip, Klingler, & Lehmann-Horn, 2005). Additionally, it has been demonstrated in cadavers that tension of the latissimus dorsi or the gluteus maximus displaces the thoracolumbar fascia; however, studies have yet to reproduce this in vivo. In vivo investigations conducted by do Carmo Carvalhais and colleagues (2013) produced evidence that force is transmitted from the latissimus dorsi to the gluteus maximus. It was theorized the transduction occurred via the connective tissue overlaps between the muscles, however, this study did not assess the effect of changing joint angles.

Posture

A study conducted by Mckenna and colleagues assessed changes in scapular orientation as a result of postural differences. For scapular orientation, the variables assessed included scapular elevation, upward rotation, posterior tilt, and lateral translation (McKenna,Cornwall, & Williams, 2017). When comparing sitting and standing positions in healthy populations, sitting can increase thoracic kyphosis (trunk flexion) while standing increases lumbar lordosis in comparison to standing (de Carvalho, et al., 2010; Kuo, et al., 2010; McKenna, et al., 2017;

Tully, et al., 2005). It may be that differences in thoracic kyphosis and lumbar lordosis, as they are affected by seated versus standing, are the result of some compensatory mechanism used to maintain body stability with changing postural demands. Changes in scapular orientation as a result of seated versus standing postures have only been noted when the arm is in a neutral position. At 120º of glenohumeral elevation in the scapular plane, no differences were found in scapular elevation, upward rotation, posterior tilt, lateral translation between seated and standing postures (McKenna, Cornwall, & Williams, 2017). Conversely, in individuals with glenohumeral instability, decreased scapular abduction and lateral rotation were noted during humeral elevation. In healthy adult subjects, humeral elevation elicited posterior tipping, lateral rotation, and upward rotation of the scapula. This causes decreases in the subacromial space, which can lead to compression of the supraspinatus tendon. Decreases in subacromial space, such that the supraspinatus tendon is impinged, is typical of the pathology of shoulder impingement and instability. The ratio of humeral elevation to scapular upward rotation in healthy persons has been reported from 1.35:1 to 7.9:1 over the entire range of motion. It has also been described as one degree of scapular rotation for every two degrees of humeral elevation (Finley, & Lee, 2003). This 2:1 ratio is also described as the ratio for glenohumeral to scapulothoracic movement (Kebaetse, McClure, & Pratt, 1999). The 2:1 ratio was first described by Inman and colleagues (1944) within a study conducted on the function of the shoulder. Inman described scapulothoracic rhythm as an arc of motion in which the sternoclavicular joint passes through its greatest range of motion during the first phases of humeral elevation. In the terminal phase, of elevation, the acromioclavicular passes through its greatest range of motion. Inman also described the glenohumeral and scapulothoracic articulation ratio such that for every 15 degrees of humeral elevation, the glenohumeral and scapulothoracic joints contribute 10 º and 5 º, respectively (Inman, et al., 1944). Seated versus standing posture did not have a statistically significant effect on scapular elevation; however, slouched posture, in a seated position, decreases the functionality of the shoulder by affecting the range of motion (McKenna,Cornwall, & Williams, 2017).

A study conducted by Thigpen and colleagues (2010) produced evidence that humeral elevation elicited greater muscular activation and altered scapular kinematics in individuals without shoulder pain. Excessive thoracic kyphosis (trunk flexion) alters scapular kinematics by increasing upward rotation of the scapula (Kanlayanaphotporn, 2014; Thigpen et al., 2010). Excessive thoracic curvature negatively impacts scapular position and force production as well as muscular weakness and decreased range of motion at the glenohumeral joint (Kanlayanaphotporn, 2014; Kebaetse, McClure, & Pratt, 1999). This detrimental curvature also causes increased clavicular elevation. As the serratus anterior is responsible for upward/downward rotation as well as anterior/posterior scapular tilting, excessive thoracic kyphosis would lead to decreased activity of the serratus anterior. The serratus anterior and upper trapezius operate as a force couple in which the serratus anterior is able to produce rotation as a result of sufficient counterforce supplied by the trapezius (Thigpen, et al., 2010). When considering humeral elevation, it is important to note that motion, in the frontal plane, increases the activation of the trapezius muscles (Thigpen et al., 2010). Additionally, a study conducted by Kanlayanaphotporn (2014) further augmented this point by including that even slight modifications in thoracic kyphosis need to be considered when evaluating the shoulder, due to the subsequent significant changes in range of motion at the glenohumeral joint.

Previous research indicates seated and standing postures affect trunk kinematics differently. A study conducted by Al-Eisa, Egan, Deluzio, and Wassersug (2006) reported similar effects between seated and standing positions. Pelvic asymmetry caused functional compensation in the lumbar region. In the healthy control, pelvic asymmetry led to more compensation in the trunk motion than in the lumbar which was noted in the group of individuals with low back pain. This was true in both seated and standing positions. Therefore, the researchers concluded that changes in pelvic position elicit changes further up the kinetic chain, in this case the lumbar and trunk, as compensatory mechanisms. It is theorized this is aided by force coupling between the upper and lower body as a result of the change in position (Al-Eisa, Egan, Deluzio, & Wassersug, 2006). Considering the posterior oblique sling connects the gluteus maximus, thoracolumbar fascia, and the contralateral latissimus dorsi and lower trapezius, it could be theorized that the sling is representative of the force coupling described here. This theory is further compounded by the fact that Joseph and colleagues (2014) found that impaired myofascial transmission in the oblique sling can lead to excessive humeral translation and, if left unattended, glenohumeral joint dysfunction.

Summary

Overall shoulder girdle function is a result of coordinated muscle activation, scapulothoracic articulation, and spinal alignment (Finley, & Lee, 2003; Kanlayanaphotporn, 2014; Kebaetse, McClure, & Pratt, 1999). Activation and efficient functioning of the scapular stabilizing and rotator cuff muscles is imperative for proper glenohumeral function. These muscles include the trapezii, serratus anterior, supraspinatus, infraspinatus, teres minor, and subscapularis (Terry, & Chopp, 2000). There are important fascial connections that occur within the posterior oblique sling. These aid in force production and transduction across muscular force couples within the posterior kinetic chain (Schleip, Klingler, & Lehmann-Horn, 2005; Yucesoy, Koopman, Baan, Grootenboer, & Huijing, 2003). For example, force produced within the gluteus maximus is theorized to be transduced to the contralateral latissimus dorsi via the thoracolumbar fascia (do Carmo Carvalhais et al., 2013; Schleip, Klingler, & Lehmann-Horn, 2005). Understanding how fascia is able to promote mechanotransduction across the body can aid in both injury prevention as well as rehabilitative measures for individuals with low back pain or shoulder instability. Posture also plays a role in glenohumeral functionality (Kanlayanaphotporn, 2014; Thigpen et al., 2010). Due to the multifactorial nature of glenohumeral function, in order to understand how changing hip position affects scapular kinematics in the contralateral shoulder, it is important to consider shoulder anatomy, activation of the rotator cuff muscles, fascia, and posture.

At the conclusion of this review, several unknowns are apparent. Currently in the research, there is general consensus on the anatomy and function of the shoulder, the effect of posture (seated versus standing) on scapular kinematics, activation of the shoulder stabilizing muscles (as they effect function of the glenohumeral joint), and the force transmission capabilities of the fascia. What is yet to be understood through the lens of a combined anatomical approach considering skeletal muscle, fascia, and posture is how all of these variables work together to affect scapular kinematics. It still unknown how these variables effect scapular kinematics, and therefore shoulder function, as a result of changing hip position.

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Appendix A: Journal Guidelines to Authors

Journal of Orthopaedic Research

Journal Guidelines to Authors

https://onlinelibrary.wiley.com/page/journal/1554527x/homepage/ForAuthors.html#3

Citation Example Provided by Journal of Orthopaedic Research Website:

Mackay D, Wood L, Rangan A. 2000. The treatment of isolated ulnar fractures in adults: a systematic review. Injury 31: 565–573.

Appendix B: Training Procedures

Prior to involvement with the study, researchers and research assistants were required to provide proof of CITI training to ensure proper handling of human subjects.