A BIOMECHANICAL ANALYSIS OF REHABILITATIVE EXERCISES FOR SUBACROMIAL IMPINGEMENT DYNDROME AND/OR ROTATOR CUFF TEARS

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GLOSSARY

3D	3-Dimensional
BWB	Body Weight Bearing Exercise
EMG	Electromyography
GH	Glenohumeral
IS	Infraspinatus
LT	Lower Trapezius
MT	Middle Trapezius
MVC	Maximum Voluntary Contraction
RCT	Rotator Cuff Tear
SA	Serratus Anterior
SAS	Subacromial Space
SAIS	Subacromial Impingement Syndrome
ScapSE	Scapular Stabilizer Strengthening Exercise
SS	Supraspinatus
ST	Scapulothoracic
UT	Upper Trapezius

ABSTRACT

Restrictions in range of motion (ROM) can occur due to subacromial impingement syndrome (SAIS) and rotator cuff tears (RCT). Alterations to scapular mobility reduces the subacromial space (SAS), compressing upon interposed tissues that reside within this area. This research examined muscle activity and co-activity among scapular stabilizer and rotator cuff musculature, and scapulothoracic kinematics. Thirty-two participants, sixteen male and sixteen female, completed two exercise sets; scapular stabilizer strengthening exercises (ScapSE) and body weight-bearing exercises (BWB). Exercises with low to moderate muscle activity of the rotator cuff (0-20%MVC, 20-40% MVC), higher scapular stabilizer activity, and advantageous co-activation (<80%) were recommended. ScapSE presented low to high activity in scapular stabilizer muscles, with Prone Shoulder Extension eliciting 11.9 ±10.6%MVC UT activity, and Y-Lifts eliciting 70 ±27.2%MVC. Moderate (21-40%MVC) scapular stabilizer muscle activity was expected throughout ScapSE; Serratus Anterior Strengthening, ranged from 21.4%MVC [UT] to 38.4%MVC [MT]. Lateral Flexion produced low SS activity of 3.1 ±2.2%MVC and IS activity of 14.2±8.1%MVC. Prone Shoulder Extension (UT/MT: 47%, UT/LT: 53%), Side Plank (39.0%, 39.7%, 41.1%), and Horizontal Abduction (UT/MT: 45%, UT/LT: 58%) presented advantageous co-activation. Exercises with ‘good’ to ‘excellent’ scapular muscle co-activity reduce UT hyperactivity, which may promote healthy upper limb kinematics. Exercises that presented with low to moderate muscle activity would be best suited in early-stage rehabilitation, while others with higher muscle activity may be better reserved for later-stage rehabilitation.

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1. Introduction

The shoulder is an integral part of upper limb movement, which requires coordination of the scapula, thorax, and humerus to perform everyday tasks. Stability of the scapula is essential in preventing musculoskeletal disease. Musculoskeletal exposures such as overhead work, repetitive motions about the shoulder and lifting may alter upper limb kinematics, consequently affecting the subacromial space size (Page 2011). The subacromial space (SAS) of the shoulder is the area between the superior aspect of the humeral head and the acromion process of the scapula, within which resides a number of soft tissues, including the subacromial bursa, supraspinatus tendon of the rotator cuff, biceps tendon and humeral ligament (Dhillon 2019; Page 2011). A reduction of the SAS can lead to compression of these tissues in a condition termed 'subacromial impingement syndrome' (SAIS) (Dhillon 2019; Page 2011). SAIS reportedly accounts for significant cases of shoulder pain and is commonly accompanied by limited range of motion, functional disability, joint pain, reduced muscle strength and flexibility, specifically in those who perform overhead tasks regularly (Umer et al. 2012; Page 2011). Additionally, SAIS precedes 95% of rotator cuff tears (RCTs), which are highly prevalent among older adults (Neer 1983).

Musculoskeletal exposures, namely repetitive overhead tasks, can induce scapulothoracic (ST) and glenohumeral (GH) kinematic adaptations which can subsequently lead to a reduction in the SAS and consequent compression and impingement of the aforementioned subacromial tissues. There are two kinematic mechanisms that result in SAS reduction; superior humeral head translation and scapular dyskinesis. Arising due to muscle imbalance, superior humeral head translation results in SAS reduction when coming into closer contact with the acromion, compressing the interposed tissues (Page 2011). Scapular dyskinesis is a deviation from the scapula's resting position and range of motion during shoulder movements, specifically reductions in rotational and scapular tilting (Page 2011).

Conservative rehabilitation approaches for SAIS and/or RCTs can be beneficial in improving patient-reported symptoms and correcting altered kinematics. Specifically, exercises that include stretching, range of motion and upper limb strengthening (including rotator cuff strengthening and scapular stabilizer strengthening), yielded positive effect sizes for pain, function/disability, strength, and biomechanical outcomes (Mahna 2022). Body weight-bearing exercises (BWB) have similarly demonstrated improvements in pain, self-reported function, mobility performance, and strength among older adults with lower limb musculoskeletal pathologies (Brenneman et al., 2016; Kuntz et al., 2018). It is important to ensure that exercises recommended for SAIS/RCT are not promoting disadvantageous biomechanics. For example, while scapular strengthening exercises have yielded positive improvements to patient-related symptoms, the muscle balance (co-activation ratios) of the scapular stabilizing musculature is important, as hyperactivity of the upper trapezius (UT) has also been shown to be mechanically disadvantageous (Cools et al., 2007). Thus, a comprehensive assessment of these exercises and how they affect upper limb mechanics is an important first step in designing biomechanically safe exercise for adults with SAIS and/or RCTs.

Research Objectives and Hypotheses

1. Determine whether exercises previously recommended for the conservative management of rotator cuff tears and/or SAIS: i) target the muscles they are intended to strengthen, and ii) promote advantageous co-activation ratios.

   Hypothesis: It is hypothesized that all exercises will elicit a moderate to high level of muscle activity from the muscles they intend to target, and will demonstrate mechanically advantageous co-activation ratios (Cools et al., 2007; Escamilla et al., 2009; Myers et al., 2009).

2. Determine whether BWB exercises that target the shoulder elicit advantageous muscle activation and co-activation ratios, and whether the activation and co-activation elicited by these BWB exercises are different from the recommended exercises for the conservative management of SAIS.

   Hypothesis: We expect that the muscle activity magnitudes elicited from BWB exercises will be lower than the recommended conservative exercises. However, we also expect that advantageous co-activation ratios will still be elicited.

3. Examine scapulothoracic kinematics across different exercises to determine the range of three-dimensional rotation, relative to a baseline/neutral posture, across participants for each exercise.

Hypothesis: We expect that certain exercises will exhibit disadvantageous 3-dimensional (3D) scapulothoracic kinematics, in the context of SAIS/RCT, relative to their resting scapular position.

2. Literature Review

2.1 Shoulder Anatomy and Mechanics

The shoulder has a high degree of flexibility and mobility that facilitates multiplane, kinematically complex movements (Timmons et al., 2012). Upper limb musculature, notably the rotator cuff and scapular stabilizing muscles work cohesively with many other muscles to facilitate movement and promote stability of the upper limb (Timmons et al., 2012). The GH joint of the shoulder is an articulation between the humeral head and the glenoid cavity of the scapula. It contains both dynamic and static stabilizers, notably the rotator cuff musculature and other soft tissues, that enable a high degree of mobility while restricting excessive translations of the humeral head that can lead to tissue injury (Curl and Warren 1996). The GH joint is intrinsically unstable as a result of its anatomy, and therefore must rely on the contributions of musculature to provide stability and permit movement (Rockwood and Matsen 2008). This inherent instability, however, permits high mobility and function (Rockwood and Matsen 2008). The four rotator cuff muscles (the supraspinatus, infraspinatus, teres minor and subscapularis) are important GH stabilizers that also contribute to upper limb function, including humeral elevation and internal/external rotation (Croci et al., 2023) (Table 1). The rotator cuff muscles act to compress the humeral head into the glenoid cavity in effort to reduce the shearing effect imparted by the deltoid, thereby stabilizing the GH joint and alleviating the risk of tissue injury, namely subacromial impingement syndrome (SAIS) and RCTs (Weiner and MacNab 1970; Chopp-Hurley et al., 2010) (*See 2.2 Subacromial Space and Subacromial Impingement Syndrome*).

Table 1. Scapulothoracic Muscles, with their location and function on the shoulder region.

Muscle of Interest	Origin/Insertion	Function/Action
Deltoid	O: One third of clavicle, acromion of scapula, spine of scapula I: Deltoid Tuberosity of Humerus	Flex, medially rotate humerus (anterior deltoid). Abduct humerus (*middle deltoid (MD)*). Extend, laterally rotate humerus (posterior deltoid).
Upper Trapezius (UT)	O: Base of skull I: Lateral third of clavicle	Elevate Scapula, upwardly rotate scapula (bringing glenoid cavity up for stability).
Middle Trapezius (MT)	O: Nuchal ligament I: Acromion of scapula	Retract Scapula, rotate scapula (bringing glenoid cavity up for stability).
Lower Trapezius (LT)	O: Spinous Processes (C7-T12) I: Spine of Scapula	Depress Scapula, upwardly rotate scapula (bringing glenoid cavity up for stability).
Serratus Anterior (SA)	O: Anterior wall of thoracic cage I: Ribs and intercostal muscles and laterally by axillary space	Protracts scapula, upward rotation of scapula, active in flexion.
Supraspinatus (SS)	O: Supraspinous Fossa of Scapula I: Greater Tubercle of Humerus (superior facet)	Abducts humerus, stabilizing shoulder joint through compression.
Infraspinatus (IS)	O: Infraspinous Fossa of Scapula I: Greater Tubercle of Humerus (middle facet)	Laterally rotates humerus, stabilizing shoulder joint.

2.2 Subacromial Space and Subacromial Impingement Syndrome

The subacromial space (SAS) of the shoulder is the distance between the superior aspect of the humeral head and the acromion process of the scapula (Figure 1). This space contains the tendons of the rotator cuff, the long head of biceps tendon, shoulder joint capsule, GH ligament, coraco-humeral ligament and subacromial bursa (Dhillon 2019). Reduction of this space leads to compression (impingement) of the interposed tissues and may subsequently result in pathologies such as SAIS and/or RCTs (Dhillon 2019). SAIS can be classified as having intrinsic or extrinsic origins (Bacha et al., 2022). Intrinsic impingement regards the gradual tissue degradation of the subacromial tissues, often age-related, that can lead to partial thickness tears or full thickness RCTs (Chopp-Hurley and Dickerson 2015). Extrinsic impingement is related to the external exposures that can alter GH and/or ST kinematics, specifically through overuse and overhead tasks, thereby leading to a reduction in the SAS and consequently impinging the interposed tissues (Ludewig and Cook 2000). Compression of SAS tissues can result in further deterioration of surrounding tissues and altered mechanics during musculoskeletal movements (Michener et al., 2003). The SAS width changes with musculoskeletal movement. The SAS in healthy individuals is approximately between 7mm to 14mm (Umer et al., 2012). Among healthy individuals, the SAS width has been shown to reduce during multiplane shoulder elevation, presenting a width between 1.2mm to 7.1mm (Bey et al., 2007).

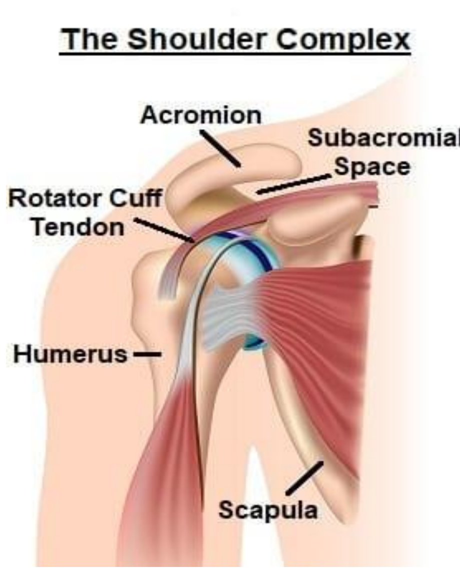


Figure 1. Anterior view of the shoulder region, encompassing the subacromial space along with humeral head and scapula (Wilson 2022).

2.3 Glenohumeral and Scapulothoracic Kinematics

GH and ST kinematics demonstrate characteristic patterns in healthy populations compared to those with RCTs and/or SAIS. In a healthy population, the rotator cuff muscles are important for providing upper limb mobility, while also being important GH stabilizers (Rockwood and Matsen 2008). The lines of action of the rotator cuff muscles are directed medially and inferiorly such that they provide a compressive effect on the GH joint and limit the upward shearing effect of the deltoid (Rockwood and Matsen 2008).

Glenohumeral kinematics (healthy): The range of motion and stability of the GH joint arise from the muscles, ligaments and the articulation of the humeral head with the glenoid cavity of the scapula (Karduna et al., 1996). The rotator cuff muscles elicit a compressive and resistive action on the humeral head, in attempt to mitigate superior humeral head translation caused by the shearing force of the deltoid muscle, which in turn restricts SAS narrowing (Ackland and Pandy 2009). Superior humeral translation of approximately 1.1mm can occur with every change in 30° during humeral abduction in healthy individuals (Ludewig and Cook 2002, Poppen and Walker 1976). The GH joint can still undergo superior translations of the humeral head during appropriate arm elevations, however, in those not experiencing RCTs nor SAIS, they experience less superior translation of the humeral head, as this musculature is able to stabilize the humeral head during abduction, consequently also reducing tension developed by ligaments (Page 2011).

Glenohumeral kinematics (SAIS): Patients with SAIS and/or RCT can demonstrate superior humeral head translation, and consequently a reduction in SAS and possible compression of the subacromial tissues (Ludewig and Reynolds 2009). This does not allow for appropriate range of motion and shoulder function, resulting in symptoms such as pain and increased risk of further tissue compression and damage, notably of the rotator cuff tendon (Page 2011). Superior humeral head translation results from the inability of the rotator cuff muscles to resist the upward shear forces of the deltoid muscle, resulting in a SAS that can demonstrably reduce to approximately 3mm (Michener et al., 2003; Graichen et al., 1999).

ST Kinematics Healthy: Healthy individuals experience ST movements that act to widen the SAS, including increased scapular upward rotation, external rotation, and posterior tilting during multiplane elevation tasks (Chopp-Hurley and Dickerson 2015; Ludewig and Braman 2012). During normal scapular movements, the ranges of motion can be assessed during multiplane elevations of the ST joint; specifically, during flexion, scapular plane abduction (scaption) and coronal plane abduction (abduction) (Figure 2) (Ludewig et al., 2009). ST movement was previously measured with bone-fixed pins during multiplane elevation (Ludewig et al., 2009). Scapular internal rotation decreased an average of 2° (37° resting to 35° end range of motion), upward rotation increased an average of 39° (11° resting to 50° end range of motion), and posterior tilting increased an average of 21° (-13° resting to 8° end range of motion); all rotations that act to widen the SAS (Ludewig et al., 2009). The clavicle has also been assessed with ST motions and arm elevations, which have enhanced the final scapular position on the thorax, specifically with decreases in clavicular retraction, as the scapula increases in posterior tilt and upward rotation relative to the clavicle (Figure 3) (Ludewig et al., 2009).

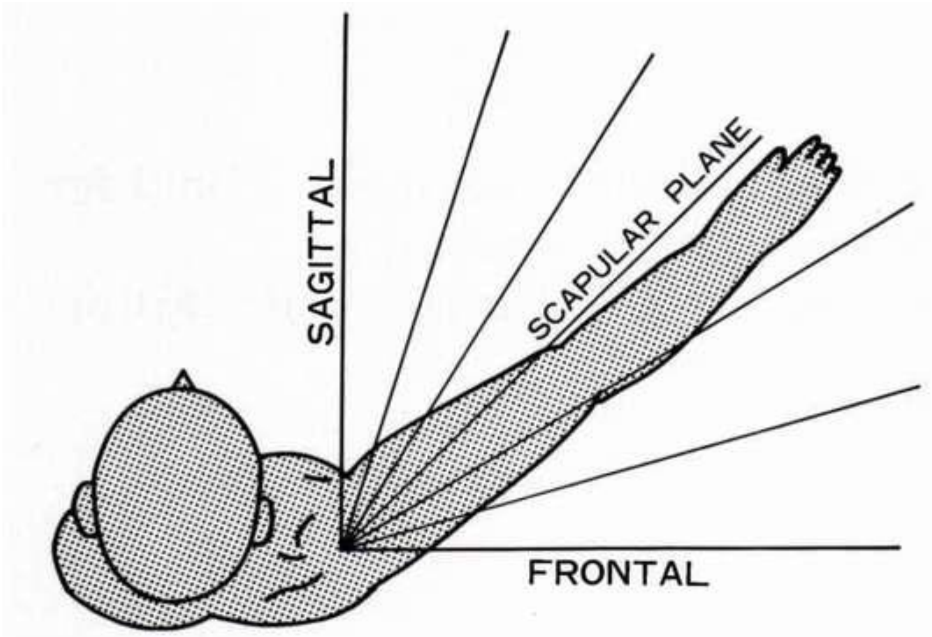


Figure 2. Scapular plane in relation with sagittal and frontal (coronal) planes of motion outlined from Ludewig et al. (2009), presenting three planes that shoulder moves to perform every day tasks.

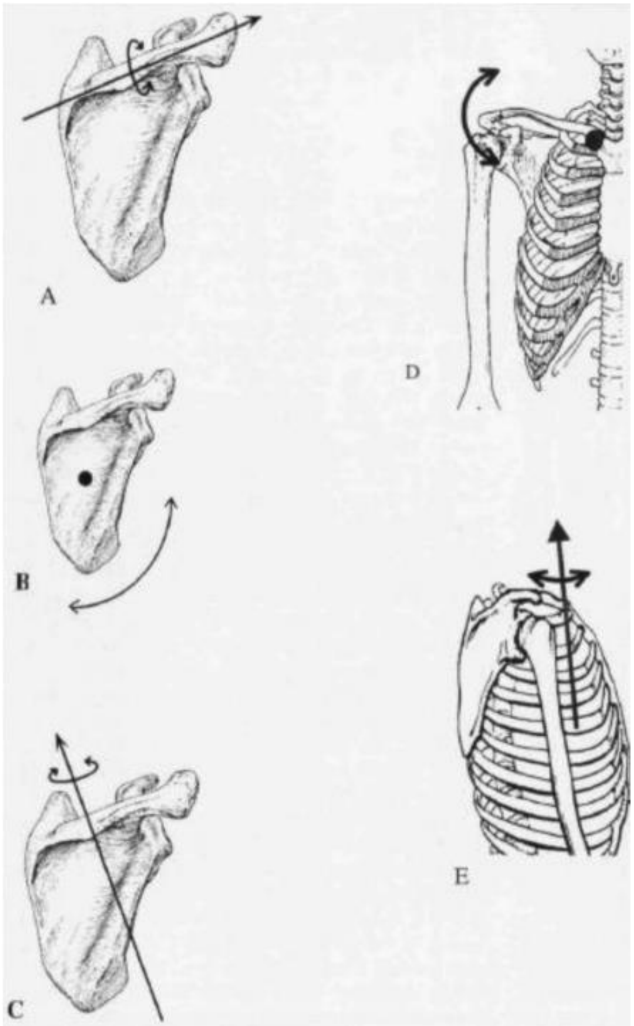


Figure 3. Scapular and clavicular motions referenced from the work of McClure et al. (2006). A) Scapular posterior tilt, B) scapular upward rotation, C) scapular external rotation D) clavicular elevation, E) clavicular retraction.

ST Kinematics SAIS/RCT: Scapular dyskinesis is the abnormal movement of the scapula that acts to reduce the SAS and subsequently pose risk for SAIS and RCT (Page 2011). Specifically, this abnormal movement is described as reductions in upward rotation, external rotation, and posterior tilt of the scapula relative to the thorax (Ludewig and Reynolds 2009; Roche et al., 2015). These alterations in scapular position are due to the instability of the scapula and ST musculature, evident in its abnormal positioning, resulting in inappropriate motions during elevation and abduction tasks in those with SAIS/RCT (Umer et al., 2012).

2.4 Rehabilitation Exercises for the Conservative Management of SAIS/RCT

Treatment methods for SAIS and/or RCT aim to alleviate SAS compression and other risk factors for SAIS. Conservative treatments, including exercise therapy and other rehabilitative interventions are often the first mode of treatment for those with RCTs (Ainsworth and Lewis 2007). A recent systematic review explored therapeutic exercise for the conservative management of SAIS and RCT and identified forty-one exercises which were classified within seven exercise modalities: stretching, range of motion techniques, rotator cuff strengthening exercises, scapular stabilizer strengthening (ScapSE) exercises, scapular neuromuscular control training, postural exercises, and exercises for strengthening upper limb muscles aside from the shoulder (Mahna et al., 2022). Positive effect sizes for pain, function, strength, and biomechanical outcomes were identified on average all across included exercises. Conservative exercise techniques present advantageous responses towards rehabilitation efforts in those with SAIS, where less pain is evident, as the strengthening and stretching exercises facilitate co-contraction of rotator muscles and stability of the scapular musculature and neuromuscular control as demonstrated by sEMG (Escamilla et al., 2014; Cools et al., 2007). Researchers suggest that early rehabilitation of the rotator cuff should elicit scapular muscle activity while maintaining a low level of rotator cuff muscle activity so as not to overload these vulnerable tissues (Escamilla et al., 2009). Moderate to high levels of activity are suggested for advanced rehabilitation (Escamilla et al., 2009). Shoulder rehabilitation exercise intensities have been previously classified: low activity (0-20%MVC), moderate activity (21-40%MVC), high activity (41-60%MVC) and very high activity (>60%MVC) (Escamilla et al., 2009). Utilizing these strengthening tasks, this can provide insight of the ST region and muscle responses to dynamic exercises used in daily tasks, and it should be expected the tasks in this protocol will elicit moderate to high levels of muscle activity (Escamilla et al., 2009).

Apart from muscle activity level, relative muscle activity or muscle co-activation is an important consideration when biomechanically evaluating rehabilitative exercises for the shoulder stability (Cools et al., 2007). When assessing rehabilitation exercises for those with SAIS or RCTs, the co-activation ratios between muscles such as upper trapezius, middle trapezius, lower trapezius, and serratus anterior can indicate which exercises are more or less mechanically advantageous in the context of SAIS (Cools et al., 2007). These co-activation ratios are calculated with the upper trapezius as the numerator and either middle trapezius, lower trapezius, or serratus anterior as the denominator. Ratios between 80%-100% are deemed 'moderate', 60%-80% is deemed 'good', while ratios less than 60% are considered 'excellent' (Cools et al., 2007). Hyperactivity of the upper trapezius can lead to further scapular motion abnormalities, specifically due to compensating muscle activity for a weaker serratus anterior muscle, subsequently presenting instability of the scapula and its musculature (Ludewig et al., 2004).

Scapular stabilizer muscle activity has been previous assessed for a variety of yoga-based postures (Chopp-Hurley et al., 2018). Certain postures elicited moderate muscle activity (>20% MVC) for upper trapezius, middle trapezius, lower trapezius, and serratus anterior, including locust arms forward, side angle and plank, upward dog, and dancer's foot left (Chopp-Hurley et al., 2018). These exercises consisted of isometric postures identified to activate scapular stabilizing muscles, where it was evident that three moderate activity exercises (eliciting greater than 20% MVC) from at least two of the muscles assessed (middle, lower trapezius) promote scapular retraining, without the use of exercise equipment (Chopp-Hurley et al., 2018).

2.5 Current Gap in Literature

A comprehensive biomechanical assessment of the recommended exercises for conservative management of SAIS and/or RCT has not been evaluated. This research will review and compare scapular strengthening exercises (Mahna et al., 2022) and BWB tasks (Chopp-Hurley et al., 2018), in effort to determine mechanically advantageous exercises to include in a clinical exercise intervention trial. This research is part of a multi-institution collaborative study with researchers from the University of Manitoba (Scribbans, Harrison). These researchers will study a selection of the other exercise modalities described in Mahna et al., (2022) using the same experimental methodologies.

3. Methods

3.1 Participants

Participants included men (n=16) and women (n=16), between 18-35 years with no self-reported shoulder pain or injury in the past year (mean age ± SD: 22.8 ± 2.7 years). Exclusion criteria were also verified using five clinical impingement tests that have been shown to identify those with or without rotator cuff related shoulder pain. The Hawkins-Kennedy test placed the participant's shoulder in 90° flexion with the elbow also flexed 90°, whilst internally rotating arm (Hawkins and Kennedy 1980). The Neer test stabilizes individual's scapula, while passively flexing the arm whilst being internally rotated (Neer 1983). The Jobe test (empty can test) involves positioning the individual's shoulder at 90° abduction and internally rotated, where the examiner then applies downward pressure against the arm (Jobe and Moynes 1982). The painful arc test asks the participant to abduct their arm in the scapular plane as high as possible (Kessel and Watson 1977). The external rotation resistance test was performed by placing the arm at the individual's side and flexing their elbow to 90°, where force was applied onto their forearm to resist shoulder rotation (Michener et al., 2009). Positive tests were indicated through any sharp pain or restricted range of motion throughout tests; soreness was not a reason for positive test. If three of the five clinical tests were positive, then the participants were excluded due to these tests confirming risk of SAIS (Michener et al., 2009).

Table 2. Anthropometric findings for participants in collection.

Age (yrs)	22.8 ± 2.7
Sex (M/F)	16 M/16 F
Mass (kg)	66.8 ± 11.2
Height (m)	172.1 ± 9.0
BMI (kg/m^2)	22.4 ± 2.5

Hand dominance	30 R / 2 L

3.2 Surface Electromyography

Surface electromyography (SEMG) was collected using a Delsys Trigno system (Delsys Inc, Natick, MA). Specifically, muscle activity was recorded from the upper trapezius, middle trapezius, lower trapezius, serratus anterior, supraspinatus, infraspinatus, middle deltoid using published guidelines (Criswell and Cram 2011). Prior to electrode placement, the skin was shaved and cleaned with alcohol wipes. Data was sampled at 2000Hz (bandwidth of 20-450Hz). Trigno Avanti sensors with 10mm interelectrode spaced silver (99.99%) bar electrodes were placed over the muscle belly of the muscles of interest.

3.3 Motion Tracking (Tracking Scapular Kinematics)

An 8-camera Vicon Vero system (Vicon Motion Systems, Oxford, UK) was used to track upper limb kinematics. Retroreflective markers were placed on anatomical markers in the upper limb according to International Society of Biomechanics (ISB) recommendations (Wu et al., 2005). Specifically, markers were placed on the C7 and T8 spinous processes, the deepest point of Incisura Jugularis (suprasternal notch), the xiphoid process, acromioclavicular joint, Trigonum spinae scapulae (root of the spine), inferior angle of the scapula, acromial angle of the scapula, lateral and medial epicondyle, radial and ulnar styloid (Wu et al., 2005). Additionally, markers affixed to rigid tracking clusters were placed on the (1) posteromedial acromion (meeting point between the acromion process and scapular spine) (Shaheen et al., 2011), (2) lateral aspect of the humerus, to track ST and humerothoracic kinematics, respectively. The humeral and forearm clusters were not used for purpose of this research, rather to uphold ISB recommendations. The relationship between rigid cluster tracking markers and anatomical markers was defined during the calibration trial. Using kinematics captured from the rigid clusters during kinematic trials, virtual markers were generated, and anatomical markers reconstructed to calculate 3D joint angles according to ISB recommendations (Wu et al., 2005). Kinematics were sampled at 100Hz.

Figure 4. Protocol set up demonstration, with participants having placed Delsys EMG wireless electrodes. Scapulothoracic kinematic reflective markers placed in single marker form, triangle cluster form, and scapular tracking cluster form.

3.4 Procedure

Overview

Participants completed one data collection session. Following EMG and Motion Capture instrumentation, participants completed (1) Calibration/Rest Trials, (2) MVC Trials, (3) Multiplane Elevation Trials, and (4) Exercise Trials.

Instrumentation & Calibration/Rest Trials

A 5-second static quiet standing trial was completed for which kinematic data were recorded. During this trial, it was ensured that all landmarks and rigid cluster markers were visible. Further, a 5-second rest trial with the participant sitting on chair was completed for which EMG data was be recorded.

Muscle Specific MVCs

A series of manual muscle tests that have been reported to obtain maximal activity from the muscles of interest (Table 2) were conducted in a random order (Boettcher et al., 2008). All MVCs were performed twice.

1. Empty Can: Shoulder abducted 90° in scapular plane, internally rotated humerus and elbow extended, arm abducted as resistance applied on wrist.
2. Shoulder Flexion to 125°: Shoulder flexed to 125° as resistance applied above elbow and at inferior angle of scapula attempting to de-rotate scapula with subject sitting in erect posture with no back support.

3. External Rotation to 90°: Shoulder abducted 90° in scapular plane, with 45° internal humeral rotation, while the elbow was flexed 90°, where resistance was applied at the wrist when arm was externally rotated.
4. Palm Press: Shoulders flexed 90° bilaterally, with heel of hands together and elbows flexed approximately 20° as arms were horizontally abducted.

Table 3. MVC tests used from the work of Boettcher et al. (2008), where the activity of more than one muscle that was highly activated was measured.

MVC Test	Muscles Tested
Empty Can 	**Supraspinatus, Upper/Middle/Lower Trapezius, Serratus Anterior, Middle**/Posterior Deltoid, Upper Subscapularis.
External Rotation to 90° 	**Supraspinatus, Infraspinatus, Middle/Lower Trapezius, Serratus Anterior, Middle Deltoid.**
Shoulder Flexion to 125°	**Supraspinatus, Infraspinatus, Upper/Middle/Lower Trapezius, Serratus Anterior, Middle Deltoid**, Upper Subscapularis.

	
Palm Press 	**Serratus Anterior**, Upper Subscapularis, Pectoralis Major.

Multiplane Elevation Trials

5-second static elevation trials were performed at 0°, 30°, 60°, 90°, and 120° of elevation in the scapular plane, which is 30° anterior to the coronal plane (Borsa et al., 2003). Two repetitions of each trial, one on each arm side, were completed in a block randomized order, meaning that all 5 were completed in a random order, followed by a second set of randomized trials. Next, 10-second dynamic multi-plane elevation trials were completed. Participants elevated their arm in flexion, abduction, and scaption with each phase (raising the arm and lowering the arm) being completed in 3-second bouts aided by a metronome. Dynamic trials were also repeated two times, dominant and non-dominant arm, in a random order.

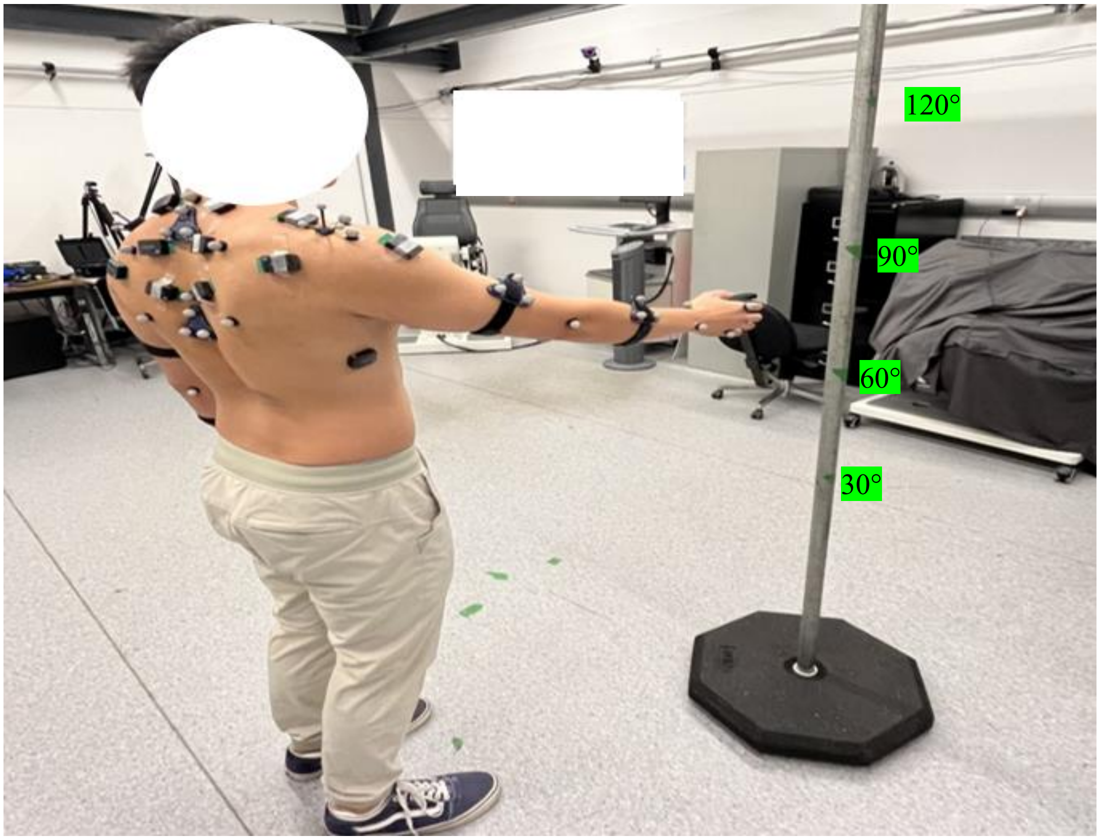


Figure 5. Participant performing elevation trial, standing in front of pole with outlined angle markers (seen in green), elevating arm in flexion motion.

Exercise Trials

Two repetitions of each exercise trial were completed in a block randomized order. Specifically, 17 ScapSE exercises (Table 3) and 6 BWB exercises (Table 4) were be performed (n=46 total; 23 exercises x 2 repetitions). Exercises were static or dynamic in nature. As such, static exercises were held for 5 seconds, whereas dynamic exercises involved 5 repetitions of the same motion (i.e., 5 rowing motions) for a single trial.

Table 4. Scapular Stabilizer Strengthening Exercises selected from the work of Mahna (2022) and in consultation with a certified yoga instructor, were performed for two repetitions, included with rationale directly listed from the work of same author for treatment for those with SAIS or RCT.

Exercise	Description	Biomechanical Rationale with SAIS
Seated Rows/Scapular Retraction	Elbows flexed 90°, shoulder in neutral position and arms by the side, pinching the scapulae together.	Strengthening of middle trapezius, lower trapezius, rhomboids. Middle trapezius contributes to scapular retraction, lower trapezius contributes to upward rotation, depression, and possibly posterior tilt and external rotation of the scapula, decreasing risk of impingement during elevation.
Low Rows	Back straight, with elbows extended. Hands are folded into fists and ulnar sides of fists are pushed back and scapulae are retracted.	Strengthening of the lower trapezius muscle: Lower trapezius contributes to upward rotation, depression, and possibly posterior tilt and external rotation of the scapula.
Prone Shoulder Extension	Prone, with shoulders resting in 90° of forward flexion. From this position, participant performs extension of shoulder to a neutral position with shoulder in neutral rotation.	Strengthening of middle trapezius, triceps brachii. Middle trapezius contributes to scapular retraction, decreasing risk of impingement. The long head of the triceps acts to stabilize the humeral head in the glenoid cavity, helping to prevent displacement of the humerus.
Horizontal Abduction	Prone horizontal abduction of the GH joint with external rotation of the humerus such that the radial aspect of the wrist is facing upwards.	Strengthening of middle and lower trapezius. Promotes early activation of the middle trapezius and lower trapezius muscle relative to the upper trapezius. Strengthening of Supraspinatus and deltoid muscles throughout external rotation exercise.
Prone Lower/Middle Trapezius Lifts (T-Lifts and Y-Lifts)	In prone, arms abducted to 90°, then flexed elbows to 90°, scapulae are retracted and arms externally rotated. While maintaining retraction of scapula, arms are lifted above head to form letter Y	Strengthening of the lower and middle trapezius muscle: Middle trapezius contributes to scapular retraction, lower trapezius contributes to upward rotation, depression, and possibly posterior tilt and external rotation of the scapula, decreasing risk of impingement during elevation.

Push-up Plus	In prone, supported at forearm level, trunk is lifted upwards such that scapulae are protracted for five (5) repetitions.	Strengthening of serratus anterior: Serratus anterior has been shown to play a large role in scapular upward rotation and posterior tipping, therefore increasing subacromial space width. *Push-up Plus and Serratus Anterior Strengthening tasks* also elicit activity of the infraspinatus throughout tasks.
Serratus Anterior Strengthening in Quadruped position	In quadruped position, with the back flat, hips aligned vertically over knees, and hips flexed 90°, patient instructed to push into floor repeatedly for five (5) repetitions.	
Supine Press	In supine, arms lifted superiorly such that shoulders are lifted and scapulae are protracted	
Wall Push Up	In standing, facing a wall, with palmar aspect of hands-on wall, elbows are extended and flexed while keeping body in a straight line	
Shoulder Shrug	In seated position, back upright, shoulders are elevated in motion bringing them medially toward neck region.	Strengthening of upper trapezius, which can help with scapular upward rotation, improving subacromial space.
Lateral Flexion	Kneel in table pose, straighten right arm out to the right with fingertips on the floor, then lift the right arm to shoulder height, press the left hand into the floor and rotate the ribcage up to the right for five repetitions.	Strengthening of serratus anterior: Serratus anterior has been shown to play a large role in scapular upward rotation and posterior tipping, therefore increasing subacromial space width.
Cat & Cow	Kneeling in table position, move vertebra in flexion, where head is brought down, then subsequently head is brought up to	Strengthening of lower trapezius and serratus anterior: Serratus anterior has been shown to play a large role in scapular upward rotation and posterior tipping, therefore increasing subacromial space width. Also benefits towards both scapular

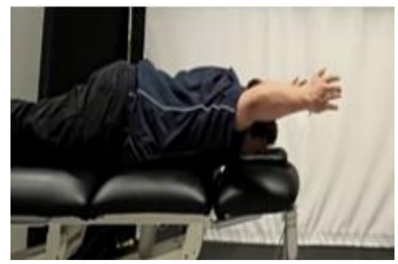
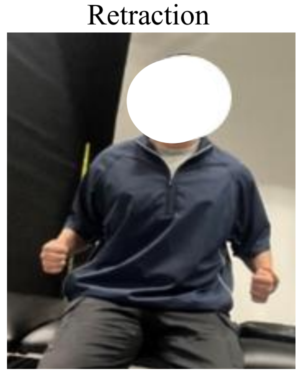
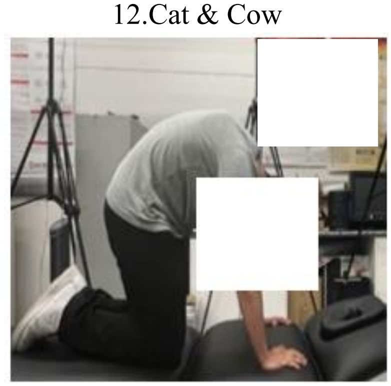
	extend vertebra in end range.	protraction and retraction during the flexion and extension motions.

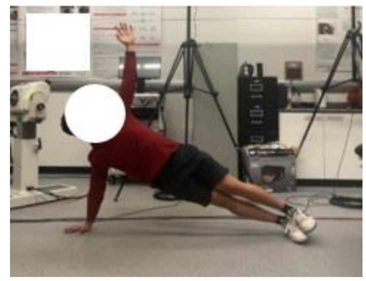
Table 5. Body weight-bearing Exercises from the work of Mahna et al. (2022) and Chopp-Hurley et al. (2018) to be performed for three repetitions, included with rationale for treatment for those with SAIS/RCT directly listed from the work of both authors with respect to each exercise.

Exercise	**Description**	**Biomechanical Rationale with SAIS**
Chin Tucks	Apply pressure to the chin with the fingers as the head is pulled back.	Strengthening of postural muscles: Forward head posture increases risk of impingement by altering scapular kinematics and promoting ST muscle imbalance.
Thoracic Extensions	Arms behind back, retracting shoulder blades, upper trunk lifted relative to flat surface.	Strengthening of thoracic extensors, postural correction. Thoracic extension posture shown to increase shoulder range of motion "Slouched" posture observed were increased superior translation of the scapula, decreased upward rotation, posterior tilt, and slightly increased internal rotation during arm abduction.
Modified Plank (Hands Clasped)	In a push up position, flex elbows to 90°, grasping hands together, as support, ensuring the back is flat and shoulders overtop of elbows. Hold for period of time.	Moderate activity in serratus anterior, and it is known to increase scapular protraction and upward rotation of scapula, thus, strengthening this muscle can reduce risk of impingement.
Locust Arms (Forward)	Lying prone, hips in contact with mat, with legs extended (at the knee), spine and trunk slightly extended, with chest off the mat. Scapula and shoulder retraction, arms in 'V' shape, elevated.	Elicits greatest muscle activity in upper trapezius muscles, eliciting moderate muscle activity, about 20% MVC in serratus anterior, thus, greater risk of impingement and may be ideal for those in later rehabilitation stages.
Reverse Tabletop	Originally in sitting position, arms extended in contact with mat (shoulder width apart), hands directed anterior to wards feet,	Elicits low muscle activity, specifically in the three trapezius muscles (upper, middle, lower) and serratus anterior. Middle trapezius contributes to scapular retraction, lower trapezius contributes to

	knees flexed 90°, back is flat, aligned with hips, chin flexed slightly.	upward rotation, depression, and possibly posterior tilt and external rotation of the scapula, decreasing risk of impingement during elevation.
Side Plank	From push up position, shift body weight to only right hand, where left shoulder aligns on top of right, spine neutral, legs stacked, arms aligned, shoulders depressed.	Elicits moderate muscle activity, specifically in the three trapezius muscles (upper, middle, lower) and serratus anterior. Preferred in later stage of rehabilitation in those with SAIS, due to moderate to high activation levels in two or more muscles.

Table 6. Scapular stabilizer strengthening tasks (#1-13) and body weight-bearing postures (#14-19) outlined and displayed.

1.Prone Shoulder Extension 	2.Horizontal Abduction 	3.Serratus Anterior Strengthening in Quadruped 
4.Supine Press 	5. T Lifts 	6.Y Lifts 
7.Push-up Plus 	8.Seated Rows/Scapular Retraction 	9.Wall Push Up 
10.Shoulder Shrug 	11.Lateral Flexion 	12.Cat & Cow 

13.Low Rows 	14.Thoracic Extensions 	15.Modified Plank (Hands Clasped) 
16.Locust Arms (Forward) 	17.Reverse Table Top 	18.Side Plank 
19.Chin Tucks 		

3.5 Data Analysis

Signal Processing

Electromyography data were high pass filtered with a 30Hz high pass filter (Drake and Callaghan 2005). The average rest trial was subtracted from all signals, following which all signals were full wave rectified and low pass filtered with a 4Hz cut off. Trial data were normalized to muscle-specific peak activity recorded from all MVC trials.

3D kinematics data were low pass filtered with a 4Hz cut off, following which local coordinate systems were created using digitally recreated (virtual) scapula markers and thorax markers as per International Society of Biomechanics (ISB) recommendations (Wu et al., 2005). ST joint angles were calculated from relative rotation matrices using a Y-X-Z rotation sequences, corresponding to scapular retraction/protraction (γ), upward/downward rotation (β), and anterior/posterior tilt (α). For static trials, average joint angles were calculated across the two repetitions. For dynamic trials, the average minimum and maximum range within a particular trial were used for comparative purposes.

Data Interpretation

Muscle activity and related co-activation ratios were assessed using guidelines from previous literature. Specifically, activity for each muscle was classified as low activity (0-20% MVC), moderate activity (21-40% MVC), high activity (41-60% MVC), or very high activity ($\geq$ 60% MVC) (Escamilla et al., 2009).

Relative co-activity ratios amongst scapular stabilizer muscles during multiplane elevation motions and exercise trials were calculated between upper trapezius and lower trapezius, upper trapezius and middle trapezius, and upper trapezius and serratus anterior (Cools et al., 2007). Further, the ratio of the deltoid to each rotator cuff muscle (supraspinatus, infraspinatus) was calculated (Myers et al., 2009). Scapular co-activation ratios between 80%-100% were classified as 'moderate', 60%-80% as 'good', while ratios less than 60% were deemed 'excellent' (Cools et al., 2007). Similar guidelines were applied to the deltoid – rotator cuff ratios. These guidelines from this previous study enhanced this protocol's reliability and analysis of co-activity in scapular stabilizer muscles. Dynamic scapular kinematic data for elevation trials were assessed in 30° increments, where calibration reference trials at 0° and 60° were used for comparison from resting. 0° and 30° elevation data followed the static calibration reference at 0°, where as 60°, 90° and 120° elevation trials followed the static 60° reference trial.

NOTE: Due to nature of marker placement and exercise demands, kinematics could not be obtained for all exercises due to blocked markers. Whereas the exercises with angles obtained, these were used and reported in the assessment. The kinematic data that was included was utilized for further support of muscle activity and co-activation findings.

3.6 Statistical Analysis

Recall Hypothesis 1: It is hypothesized that all exercises will elicit a moderate to high level of muscle activity from the muscles they intend to target, and will demonstrate mechanically advantageous co-activation ratios.

To evaluate this hypothesis, the activation magnitude, and co-activation of each exercise were examined in the context of existing literature. Exercises were classified as having low activity (0-20% MVC), moderate activity (21-40% MVC), high activity (41-60% MVC), or very high activity (≥ 60% MVC). Further, co-activation ratios were evaluated using the guidelines described by Cools et al. (2007) where co-activation ratios between 80% and 100% were 'moderate', 60% to 80% were considered a 'good' ratio, while anything less than 60% was deemed 'excellent'. To assess co-activation ratios of the deltoid with respect to the rotator cuff muscles, these muscle groups have not been compared directly, however, it has been evaluated that decreased rotator cuff activity during humeral elevation can be an indication of RCT and SAIS (Myers et al., 2009). Humeral head translation can be attributed towards a reduction in rotator cuff activity rather than increased deltoid activity, yet an increased co-activation ratio between rotator cuff muscles may also indicate GH joint instability rather than migration (Myers et al., 2009). The risk of superior humeral head translation will be implied using these co-activation ratios (Myers et al., 2009).

Recall Hypothesis 2: We expect that the muscle activity magnitudes elicited from body weight-bearing exercises will be lower than the recommended conservative exercises. However, we also expect that advantageous co-activation ratios will still be elicited.

One-way Analysis of Variance (ANOVA) were performed for each muscle to evaluate the effect of exercise type on muscle activity. Co-activation ratios for body weight-bearing postures were classified using guidelines described by Cools et al. (2007).

Recall Hypothesis 3: We expect that certain exercises will exhibit disadvantageous 3-dimensional (3D) scapulothoracic kinematics, in the context of SAIS/RCT, relative to their resting scapular position.

One-way ANOVAs were performed to examine the effect of exercise on the change in scapular position (upward/downward rotation, anterior/posterior tilt, protraction/retraction) from individualized baseline measurements.

4. Results

4.1 Overall Muscle Activity

When assessing the activity across the seven muscles during each exercise, the recommendations outlined by Escamilla et al. (2009) for muscle activity throughout rehabilitative tasks were used. Scapular stabilizer muscle activity was deemed low (<20%MVC) to moderate (21-40%MVC) in both subsets of exercises (ScapSE, BWB), where low activity was evident in all tasks except six exercises: (1) Locust Arms outstretched Forward (BWB) where 6 dominant sided muscles averaged from 23.3 ±10.7% to 40.9 ±18.6%MVC, (2) Horizontal Abduction (ScapSE) where 6 dominant sided muscles activated from 25.8±13.5% up to 85.0 ±53.9%MVC, (3) Shoulder Shrugs (ScapSE) where 3 dominant sided muscles activated at 38.3 ±18.3% ranging to 55.0 ±32.3%MVC, (4) Push-Up Plus (ScapSE) where 6 muscles ranged from 24.7 ±21.6% to 68.7 ±30.8%MVC on dominant side, (5) T-Lifts (ScapSE) where 6 muscles on both dominant and non-dominant side range from 27 ±13.6% to at least 78 ±39.7%MVC on average, and (6) Y-Lifts (ScapSE) where 4 muscles on both sides to have very high muscle activity reaching an average maximal activity of 89.3 ±35.7%MVC (Table 7). Exercises with lower muscle activity include Lateral Flexion where the dominant sided muscles elicited activity from 3.1 ±2.2% in the SS to 18.9 ±15.7% MVC in the LT, Chin Tucks (BWB) produced Middle Deltoid activity as low as 3.3 ±2.8% MVC and reached a maximal value of 10.5%MVC in the dominant sided LT. Tasks such as Side Plank (BWB) presented low activity across all muscles except two (dominant sided MT and SA), where moderate activity was produced (MT: 23.7 ±32.1%MVC; SA: 27.9 ±18.4% MVC). Rotator cuff muscle activity in these same tasks was deemed generally moderate or high (41-60%MVC) across the exercise trials, seen in exercises like Horizontal Abduction (ScapSE) with all 3 muscles eliciting activity from 25.8 ±13.5% MVC to 46.2 ±31.7%MVC (high activity), Push-Up Plus where 3 muscles ranged from 29.3 ±28.1% MVC to 43.1 ±20.6%MVC on average, T-Lifts with muscle activity reaching 38.4 ±15.1%MVC in SS (moderate activity), and Y-Lifts averaging high to very high muscle activity ranging from 40.6 ±24%MVC in IS to 60.7 ±14.4%MVC in SS. Apart from these tasks, Horizontal Abduction in the dominant arm elicited moderate activity in the rotator cuff muscles, while Cat & Cow, Wall Push-Up, and Supine Press elicited moderate to high activity strictly in the scapular stabilizer muscles (See Table 7).

Table 7. Muscle activity of four scapular stabilizer muscles and three rotator cuff muscles for scapular stabilizer strengthening exercises, indicating their activity level across the exercise set from protocol, classified into four categories; Low represented in green (0-20% MVC), Moderate in yellow (21-40% MVC), High in grey (41-60% MVC) and Very High Activity in red (>60% MVC).

	Muscle Activity (%MVC) [Dominant;Non-Dominant]							Muscle Activity Level	
Exercise	UT	MT	LT	SA	SS	IS	MD	Scapular	Rotator Cuff
Cat & Cow	17.6(20.8); 16.0(17.8)	30.4(45.9); 28.8(28.0)	27.7(18.7); 30.4(20.4)	30.3(18.9); 32.2(19.3)	10.6(8.9); 11.0(8.6)	18.3(15.3); 19.8(13.7)	13.8(11.8); 12.1(9.5)	Low-Moderate	Low
Horizontal Abduction	30.6(17.2); 37.3(18.2)	85.0(53.9); 77.0(33.0)	59.8(24.9); 62.6(23.6)	12.5(11.3); 11.8(9.6)	28.3(13.9); 37.8(15.5)	46.2(31.7); 40.6(20.9)	25.8(13.5); 37.8(13.6)	Low in dominant side, Moderate in Non-Dominant side	Moderate
Lateral Flexion	6.5(6.9); 5.3(4.0)	11.6(11.1); 11.5(7.4)	18.9(15.7); 20.7(15.3)	35.5(21.3); 28.4(16.4)	3.1(2.2); 4.1(3.8)	14.2(8.1); 19.0(20.3)	9.9(8.2); 9.3(7.5)	Low-Moderate	Low
Low Row	10.0(7.3); 10.2(7.0)	26.9(61.9); 22.2(24.3)	16.2(11.8); 18.9(12.8)	23.1(20.5); 24.1(18.4)	10.0(6.9); 11.6(8.7)	15.5(24.9); 15.2(9.0)	11.3(7.5); 9.8(5.2)	Low-Moderate	Low
Prone Shoulder Extension	11.9(10.6); 14.2(9.3)	37.5(35.3); 38.9(24.5)	25.8(15.9); 27.1(16.9)	22.7(20.9); 18.8(16.1)	7.5(5.2); 10.8(7.2)	28.8(30.3); 24.7(23.7)	8.0(5.8); 13.6(10.0)	Low-Moderate	Low
Push Up Plus	24.7(21.7); 29.2(28.1)	42.9(43.4); 36.9(29.4)	39.1(19.4); 42.1(21.7)	68.7(30.8); 55.6(22.0)	19.5(13.5); 19.8(15.4)	37.9(19.4); 43.1(16.4)	31.2(14.1); 31.4(12.9)	Moderate-Very High	Moderate
Serratus Anterior Strengthening in Quadruped Position	21.4(23.4); 20.5(22.2)	38.4(32.1); 39.9(32.7)	37.1(20.4); 37.4(24.0)	37.4(28.8); 33.2(23.2)	15.5(14.9); 16.4(15.7)	23.6(27.9); 25.9(24.4)	13.7(10.6); 12.8(9.6)	Moderate	Low-Moderate
Seated Rows	24.7(19.8); 23.8(16.9)	39.7(32.1); 43.7(29.3)	35.0(19.6); 34.6(22.6)	20.9(14.9); 21.5(13.2)	24.1(16.5); 25.2(15.4)	18.9(15.8); 19.0(12.7)	12.1(7.1); 15.2(10.6)	Low	Low-Moderate
Shoulder Shrug	55.0(32.3); 57.1(34.8)	41.8(49.7); 30.0(28.9)	20.4(18.0); 20.2(14.6)	11.0(13.0); 11.6(9.8)	38.3(18.3); 43.0(20.6)	17.1(20.7); 12.2(9.0)	2.3(2.2); 2.2(1.9)	Moderate-High	Low-Moderate
Supine Press	15.9(15.4); 19.5(24.8)	39.7(40.1); 38.5(33.7)	34.3(22.5); 42.2(30.2)	30.9(20.2); 25.4(14.9)	13.8(13.7); 15.9(14.9)	12.6(7.5); 15.6(15.9)	7.5(4.0); 7.7(4.9)	Low-Moderate	Low
T Lifts	32.3(22.4); 43.7(30.0)	80.9(52.5); 78.3(39.8)	45.5(23.0); 46.0(24.0)	18.4(19.0); 16.0(15.8)	30.7(16.3); 38.4(15.1)	32.0(16.2); 29.8(15.0)	26.9(13.6); 32.4(13.9)	Moderate-High	Moderate
Wall Push Up	24.5(17.0); 24.6(18.2)	39.4(47.5); 29.0(21.4)	22.3(14.8); 27.2(20.9)	25.3(20.2); 21.6(13.3)	19.9(9.4); 9.8(11.2)	16.1(22.6); 11.8(8.2)	11.3(7.2); 8.9(5.1)	Moderate	Low
Y Lifts	70.0(27.2); 68.5(31.2)	85.0(39.9); 89.3(35.7)	70.7(23.4); 78.5(24.2)	65.1(39.8); 43.6(24.7)	47.3(16.9); 60.7(14.4)	47.8(24.2); 40.6(24.0)	42.4(14.6); 50.2(13.8)	Very High	Very High

Table 8. Muscle activity of four scapular stabilizer muscles and three rotator cuff muscles for body weight-bearing exercises, indicating their activity level across the exercise set from protocol, classified into four categories; Low represented in green (0-20% MVC), Moderate in yellow (21-40% MVC), High in grey (41-60% MVC) and Very High Activity in red (>60% MVC).

Exercise	Muscle Activity (%MVC) [Dominant;Non-Dominant]							Muscle Activity Level	
	UT	MT	LT	SA	SS	IS	MD	Scapular	Rotator Cuff
Chin Tuck	5.9(4.5); 2.1(1.7)	8.0(7.7); 3.3(3.7)	10.4(7.5); 3.2(3.6)	7.0(8.3); 3.9(8.1)	5.9(3.4); 2.7(2.8)	4.9(3.8); 1.6(1.2)	3.3(2.8); 1.0(2.6)	Low	Low
Locust Arms Forward	29.8(15.1); 33.8(22.0)	36.3(25.0); 42.2(27.5)	40.9(18.6); 44.1(21.4)	35.6(17.5); 28.6(18.7)	23.3(10.7); 29.2(13.7)	19.3(10.8); 15.2(7.2)	23.0(8.0); 26.6(10.1)	Moderate	Low
Plank Hands Clasped	2.8(2.2); 3.5(4.4)	3.1(2.4); 3.5(3.0)	3.1(3.4); 3.5(4.7)	39.7(24.0); 31.8(18.4)	2.3(1.7); 2.8(3.2)	11.6(6.7); 14.2(8.8)	14.8(8.1); 14.4(7.4)	Low	Low
Reverse Table Top	4.3(6.4); 4.7(3.5)	12.4(8.1); 15.8(10.0)	12.1(10.3); 13.2(8.7)	8.5(6.7); 8.6(10.9)	2.8(5.3); 4.6(6.9)	8.2(6.8); 8.1(5.7)	5.8(6.8); 8.9(7.9)	Low	Low
Side Plank	7.0(9.9); 8.0(10.4)	23.7(32.1); 20.4(11.6)	16.6(10.7); 14.8(13.2)	27.8(18.4); 23.8(14.1)	6.2(8.0); 5.4(3.5)	15.5(11.5); 13.6(8.1)	20.1(9.6); 19.2(8.0)	Low	Low
Thoracic Extension	6.0(5.8); 7.3(5.8)	16.6(9.9); 21.5(18.7)	10.8(7.0); 11.5(7.8)	12.0(10.3); 11.0(10.7)	2.7(3.3); 4.7(3.5)	13.0(12.2); 9.6(5.7)	4.9(5.1); 7.2(7.3)	Low	Low

4.2 Muscle Activity Comparisons: Scapular Stabilizer Strengthening versus Body Weight-Bearing

When drawing comparisons between ScapSE exercises with BWB postures, the dynamic nature of the strengthening tasks caused for increased muscle activity in some exercises. All muscles except for dominant IS ($p=0.15$) demonstrated a significant effect of exercise type ($p<0.05$) on muscle activity where scapular stabilizer exercises exhibiting statistically significant greater average muscle activity compared to BWB postures ($p<0.05$). These muscles included UT, MT, LT, SA, SS in ScapSE exercises, on average. BWB posture muscle activity was different from the ScapSE exercises, specifically seen in prone exercises, like Y-Lifts with a maximal activity level averaged to 89.3 ±35.7% MVC in MT, compared to Plank Hands Clasped that expressed a mean MT activity of 3.5 ±4.7%MVC; 85.8% difference. The BWB postures predominantly elicited lower muscle activity, seen in Chin Tucks, where UT activity was 5.9 ±4.5% MVC; all muscles elicit low activity (<10.5 ±7.5%MVC). A ScapSE exercise that presented higher UT activity included Horizontal Abduction (30.7 ±17.2%MVC) and T-Lifts (32.3 ±22.4% MVC), drawing an increase in UT activity of 24.8% and 26.4% relative to that of Chin Tucks (BWB). Modified plank with hands clasped followed a similar trend, with all muscles eliciting low activity (<18.9 ±12.8%MVC), except for the SA muscle (Dominant: 39.7 ±24%MVC; Non-Dominant: 31.8 ±18.3%MVC), as UT activity averaged 2.9 ±2.3% MVC. Shoulder Shrug (ScapSE) activity is high where UT and MT elicit 55.1 ±32.3% MVC and 41.8 ±49.7% MVC, where a BWB posture that elevates the shoulders, such as Locust Arms Forward averaged 29.9 ±15.1% MVC and 36.3 ±25% MVC in those two muscles; 25.2% and 5.5% decrease in the BWB task. These same exercises, Locust Arms (BWB) and Shoulder Shrug (ScapSE) presented differing rotator cuff muscle activities, with Shoulder Shrugs eliciting high (40-60%MVC) activity in SS averaging 43.1 ±20.6% MVC in non-dominant hand, compared to 29.2 ±13.7% MVC in the non-dominant SS during Locust Arms; 13.9% higher activity in the ScapSE.

4.3 Muscle Co-Activation

The muscles' respective co-activation ratios were interpreted using Cools et al. (2007) recommendations for co-activation throughout the rehabilitative tasks. Various exercises produced generally excellent (<60%), good (60-80%) and/or moderate (80-100%) co-activation ratios in the scapular stabilizer and rotator cuff muscle groups. Prone Shoulder Extension (ScapSE) produced excellent co-activation in the scapular stabilizer muscles of UT/MT (47.1 ±35.3%), UT/LT (53.4 ±36.3%), while eliciting a 52.9 ± 64.1% average MD/IS ratio. Seated Rows (ScapSE) presented good and moderate co-activation ratios, ranging from 63.1 ±40.3% in UT/MT to 77.2 ±69.7% in MD/SS ratios, whilst presenting moderate scapular stabilizer ratios, UT/LT (95.7 ±103.7%), and rotator cuff ratio in MD/IS (80.9 ±42%). Thoracic Extensions (BWB) presented predominantly good and excellent co-activation ratios in both scapular stabilizer muscles and rotator cuff muscles, where UT/MT averaged 42.8 ±29.9%, UT/LT averaged 63.2 ±47.1%, and MD/IS averaged 56.2 ±90.6%. There were possible contradicting outcomes amongst both scapular stabilizer and rotator cuff muscle groups, where scapular stabilizer muscle group co-activation was deemed advantageous (<80%), yet the rotator cuff muscle group expressed a disadvantageous (>100%) ratio; or vice versa. These exercises include Push-Up Plus where scapular ratios such as UT/SA averaged 45.3 ±54.4%, UT/LT averaged 78.1 ±79.7% yet MD/SS and MD/IS produced 292 ±332.6% and 103.6 ±85.6%, on average. Side Plank also followed this trend, evident in the excellent (<60%) ratios produced in the scapular stabilizer muscle group (UT/MT: 39.8 ±32.1%, UT/LT: 41.2 ±26.8%, UT/SA: 39.0 ±57.9%) and disadvantageous ratios in the rotator cuff group (MD/SS: 272.9 ±232.4%, MD/IS: 196.5

±177.9%). Shoulder Shrugs (ScapSE) (MD/SS: 6.3 ±6.2%, MD/IS: 23.4 ±31.1%, UT/MT: 279.3 ±397.2%, UT/LT: 392.6 ±317.9%), and Chin Tucks (BWB) (MD/SS: 65.0 ±55.7%, MD/IS: 53.5 ±54.6%, UT/MT: 162.9 ±263.2, UT/SA: 138 ±113.5%), expressed advantageous rotator cuff ratios (<80%) while also exhibiting disadvantageous ratios for the scapular muscle group; creating array of suggestions that can be produced from differing findings. Exercises where both scapular stabilizer and rotator cuff muscle co-activation ratios were strictly moderate to disadvantageous ratios include Locust Arms outstretched Forward ranging from 81.9 ±45.8% to 202.9 ±113.3% on average, Modified Plank with Hands Clasped producing ratios from 123.0 ±121.6% to 174.4 ±210.8% on average (excluding excellent UT/SA ratios), Wall Push-Ups with all the ratios except for MD/SS produced a ratio of at least 111.3 ± 83.4% (MD/IS), and Y-Lifts with all co-activation ratios being greater than 82.2 ±20.2% and all dominant sided data exceeding an average 100.02 ±53.9% (See Table 8). Scapular stabilizer muscle activity was deemed low to moderate in both subsets of exercises, specifically in the ScapSE, where it was notably low in all tasks except for Locust Arms outstretched Forward, Horizontal Abduction in the non-dominant arm, Shoulder Shrugs, Push-Up Plus, T-Lifts, and Y-Lifts (See Table 8). Rotator cuff muscle activity in these same tasks was deemed moderate (21-40%MVC) or high (41-60%MVC) across the exercise trials, predominantly in the non-dominant side. These include Horizontal Abduction, Shoulder Shrugs, Push-Up Plus. T-Lifts, Y-Lifts. Apart from these tasks, Horizontal Abduction in the dominant arm elicited moderate activity in the rotator cuff muscles, while Cat & Cow, Wall Push-Up, Supine Press elicited moderate to high activity strictly in the scapular stabilizer muscles.

4.4 Muscle Co-Activation Comparisons

There are differences in the muscle co-activation levels across the two subsets of exercises, evident in the activity of UT during shoulder elevation tasks. Exercises like Shoulder Shrugs (ScapSE) and Y-Lifts (ScapSE) produced disadvantageous UT/MT, UT/LT and UT/SA (Shrugs: 279.3 ±397.2%, 392.6 ±317.9%, 1013.2 ±910.2%; Y-Lifts: 104.7 ±58.5%, 112.5 ±65.8%, 160 ±121.5%) ratios, specifically due to the elevation of the shoulders, but when comparing it to a BWB with similar shoulder elevation, in Locust Arms, the ratios are of lower magnitudes (UT/MT: 129.4 ±164.3%, UT/LT: 81.9 ±45.8%, UT/SA: 99.4 ±51.8%), with larger differences in ratios to Shoulder Shrugs. Side Plank (BWB) created abduction about the scapula, presenting excellent UT/MT, UT/LT and UT/SA ratios (39.8 ±32.1%, 41.2 ±26.8%, 39.0 ±57.9%), with increased rotator cuff ratios (MD/SS: 530.9 ±402.7%, MD/IS: 196.5 ±177.9%). When comparing it to a ScapSE exercise that also abducts about the scapula, such as Horizontal Abductions, with UT/MT ratio increasing by 6%, UT/LT ratio increasing by 17.1% and UT/SA ratio increasing by 383.4%. Yet, the co-activation ratios were more advantageous (<100%) in Horizontal Abductions (MD/SS: 107.9 ±64.8%, MD/IS: 83.2 ±80.9%), decrease of 423% and 113.3% on average. Other BWB postures produced more advantageous co-activation ratios in the scapular stabilizer muscle group, seen in Thoracic Extensions (UT/MT: 42.8 ±29.9%, UT/LT: 63.2 ±47.1%, UT/SA: 80.3 ±74.1%), when being compared to Prone Shoulder Extension (ScapSE), results varied, where UT/MT had increased co-activity by 4.3% and UT/SA increased by 9.8%, yet the BWB's MD/SS and MD/IS ratios were greater on average by 79.4% and 3.3% than in Prone Shoulder Extensions.

Table 9. Muscle co-activation ratios of Upper Trapezius compared relatively to three other scapular stabilizer muscles, and of Middle Deltoid compared relatively to two rotator cuff muscles, and co-activation level labelled across set of scapular stabilizer strengthening exercises, classified into four categories; Excellent represented in green (<60%), Good in yellow (60-80%), Moderate in grey (80-100%), Disadvantageous in red (>100%).

	Co-Activation Ratios (%) [Dominant;Non-Dominant]					Co-Activation Level	
Exercise	UT/MT	UT/LT	UT/SA	MD/SS	MD/IS	Scapular	Rotator Cuff
Cat & Cow	116.0(161.9); 92.6(128.2)	110.4(186.0); 79.6(137.7)	69.4(68.0); 78.4(106.6)	216.3(190.5); 211.9(265.2)	92.3(77.3); 65.8(38.2)	Moderate-Disadvantageous	Moderate-Disadvantageous
Horizontal Abduction	45.7(26.1); 58.1(38.2)	58.2(40.2) 68.0(39.7)	422.3(405.5) 614.0(785.2)	107.9(64.8) 119.4(70.7)	85.7(95.0) (129.5(127.6)	DOM: **Good-Excellent** **Non-DOM**: Disadvantageous	**DOM**: Good-Excellent **Non-DOM**: Disadvantageous
Lateral Flexion	88.1(64.2); 65.3(77.2)	51.4(48.7); 46.2(81.5)	24.1(25.8); 26.2(24.3)	415.0(368.5); 381.1(331.8)	80.9(56.6); 62.2(40.4)	Excellent	Disadvantageous
Low Rows	160.3(183.6); 107.7(155.5)	101.5(119.3); 126.3(301.5)	66.3(54.5); 73.4(73.3)	195.3(327.3); 127.1(107.0)	99.5(56.0); 73.0(38.7)	Moderate-Disadvantageous	Moderate-Disadvantageous
Prone Shoulder Extension	47.0(35.3); 44.6(34.9)	53.3(36.3); 63.8(48.6)	90.1(94.1); 128.5(116.4)	129.5(102.2); 188.7(249.0)	89.8(76.2); 65.7(44.3)	Good-Excellent	Good-Excellent
Push Up Plus	91.9(98.5); 111.1(110.1)	78.1(79.7); 83.3(90.2)	45.2(54.4); 55.3(60.5)	292.0(332.7); 362.0(467.0)	103.6(85.6); 73.9(26.4)	Good-Excellent	Disadvantageous
Serratus Anterior Quadruped	84.6(99.8); 72.6(103.6)	76.3(115.7); 67.5(102.4)	73.8(78.6); 91.9(98.0)	254.8(419.5); 230.1(347.3)	88.5(72.5); 63.7(38.5)	Good-Moderate	Good-Moderate
Seated Row	71.4(61.2); 63.0(40.3)	95.7(103.8); 89.5(74.3)	153.8(140.7); 170.4(187.0)	77.2(69.7); 93.0(91.0)	80.9(43.0); 85.4(42.0)	Good-Moderate	Good-Moderate
Shoulder Shrug	279.3(397.2); 275.5(227.8)	392.5(317.9); 429.2(522.4)	1013.2(1102.2); 767.4(699.4)	6.3(6.3); 8.6(20.8)	23.4(31.1); 21.0(13.3)	Disadvantageous	Excellent
Supine Press	70.1(77.1); 67.5(87.5)	66.9(67.4); 74.2(124.5)	80.7(97.3); 102.5(124.1)	175.9(250.3); 191.0(337.9)	80.4(72.3); 65.2(45.9)	Good-Moderate	Good-Moderate
T Lifts	48.1(30.9); 60.3(31.6)	77.3(51.9); 98.5(63.8)	365.2(413.0); 559.7(700.9)	96.3(47.1); 92.9(56.6)	97.7(60.0) 126.0(60.0)	Good-Moderate	Good-Moderate
Wall Push Up	161.2(183.3); 124.2(123.2)	154.0(127.4); 153.9(220.7)	139.3(130.3); 166.7(160.5)	71.3(72.6); 56.9(36.7)	111.3(83.4); 98.4(56.8)	Moderate-Disadvantageous	Moderate-Disadvantageous
Y Lifts	104.6(58.5); 94.2(71.2)	112.5(65.8); 89.3(45.6)	160.0(121.5); 270.7(319.0)	100.0(53.9); 82.2(20.2)	150.6(128.9); 172.5(87.2)	Moderate-Disadvantageous	Moderate-Disadvantageous

Table 10. Muscle co-activation ratios of Upper Trapezius compared relatively to three other scapular stabilizer muscles, and of Middle Deltoid compared relatively to two rotator cuff muscles, and co-activation level labelled across set of body weight-bearing exercises, classified into four categories; Excellent represented in green (<60%), Good in yellow (60-80%), Moderate in grey (80-100%), Disadvantageous in red (>100%).

Exercise	Co-Activation Ratios (%) [Dominant;Non-Dominant]					Co-Activation Level	
	UT/MT	UT/LT	UT/SA	MD/SS	MD/IS	Scapular	Rotator Cuff
Chin Tuck	162.9(263.2); 129.0(129.5)	82.8(73.1); 154.2(167.1)	138.1(113.5); 153.1(142.0)	65.0(55.7); 70.0(78.6)	83.2(80.9); 53.4(54.6)	DOM: Moderate-Disadvantageous	Good-Excellent
Locust Arms	129.4(164.3); 111.0(101.8)	81.9(45.8); 92.8(80.8)	99.4(51.8); 190.7(225.7)	117.7(64.2); 105.7(56.0)	167.8(153.9); 202.8(113.3)	Moderate-Disadvantageous	Moderate-Disadvantageous
Plank Hands Clasped	125.2(107.6); 123.0(121.6)	144.1(133.2); 174.4(210.8)	8.1(5.5); 13.9(18.7)	830.5(615.4); 913.7(674.3)	159.0(137.1); 121.6(69.5)	Moderate-Disadvantageous	Moderate-Disadvantageous
Side Plank	39.7(32.1); 39.7(34.2)	41.1(26.8); 63.4(58.3)	39.0(57.9); 44.1(62.2)	530.9(402.7); 198.4(169.9)	272.9(232.3); 179.6(93.3)	Excellent	Disadvantageous
Reverse Table Top	38.9(33.3); 37.5(31.8)	49.2(44.2); 72.8(147.2)	68.2(60.2); 119.2(142.2)	332.3(377.0); 329.0(266.2)	89.9(91.7); 130.44(101.2)	Good-Excellent	Moderate-Disadvantageous
Thoracic Extension	42.8(29.9); 46.5(36.2)	63.2(47.1); 74.2(124.5)	80.3(74.1); 153.8(173.6)	208.9(179.7); 183.8(154.5)	56.2(90.6); 89.5(89.7)	Some Excellent, Some Disadvantageous	Most Excellent, MD/SS: Disadvantageous

4.5 Scapulothoracic Kinematics Findings

Joint angles and ranges of motion were assessed through static, dynamic elevation trials and exercises. Data used for analyses included joint angles calculated for static elevation trials, and for 14/23 exercise trials. Significant limitations with data acquisition or processing were evident following data processing (e.g. blocked markers), which left 9 ScapSE tasks and 5 BWB exercises used for assessment, where at least 50% of participant data (n=16) was acquired, see *Limitations*. Due to the limitations a narrative description of findings was presented, rather than statistical comparisons. When included the kinematic data were acquired from the dominant arm in Chin Tucks, Horizontal Abduction, Low Rows, Lateral Flexion, Locust Arms Forward, Prone Shoulder Extension, Modified Plank with Hands Clasped, Seated Rows, Serratus Anterior Strengthening in Quadruped Position, Side Plank, Shoulder Shrugs, Thoracic Extensions, T-Lifts, Wall Push Ups. Exercises excluded are not advised to not be performed, however data was insufficient to be reported for analysis. Single sided dynamic exercises such as Horizontal

Abduction (ScapSS) using the dominant arm (n=31), presented mean joint angles of 0.316 ± 20.89° (Table 8) of upward rotation, 30.57 ± 43.14° of posterior tilt, 21.35 ± 65.51° of retraction (external rotation of scapula), when performing the flexion motioned task. Prone Shoulder Extension (ScapSS) of the dominant limb (n= 31) elicited 6.83 ± 17.41° of upward rotation, 27.73 ± 53.78° of posterior tilt, and 29.8 ± 59.65° of retraction. Dynamic tasks that involved both arms such as Seated Rows (ScapSS) (n=31), produced upward rotation of 7.91 ± 11.82°, posterior tilt of 8.16 ± 28.62° and retraction of 26.68 ± 31.5° on the dominant side. Static exercises were also collected for assessment, including Locust Arms with arms outstretched Forward (BWB) (n=21), which presented upward rotation of 7.1 ± 32.11°, posterior tilt of 16.9 ± 70° and external rotation of 26.0 ± 75.22° (See Tables 11-13). The mean joint angles produced by the five static exercises were compared to joint angles calculated for range of motion elevation tasks across each plane (abduction, flexion, scaption). The upward/downward range of motion joint angles were 4.4 ±16.1° downwardly rotated at 0° range of motion, and 7.9 ±19.2° upwardly rotated at 120° abduction, 6.7 ±17.5° at 120° flexion and 6.4 ±18.6° at (120° scaption (See Table 11). The scapula anterior/posterior tilt 12.1 ±25.2° of posterior tilt at 0° elevation, while at the end ranges of 120°, the scapula remained posteriorly tilted at 2.1 ±27.5° during abduction motions, 7.3 ±16.5° during flexion and 8.8 ±16.1° during scaption. During the static exercises, the scapula retracted, starting at 23.9 ±39.7° (0°), and increased to 34.4 ±11.4° during abduction movements, 43.0 ±14.7° during flexion and 37.6 ±13.4° in scapular plane motions.

Table 11. Dynamic exercises listed below, all of which were included with at least 16 participants' data (n=16) due to limitations in bodily positions during various exercises. The scapular planes of motion are outlining the range of motion in scapular stabilizer strengthening tasks (dynamic), and body weight-bearing postures (static) mean movement of scapula throughout tasks.

Exercise	Type	Motion	Upward/Downward Rotation (°)	Anterior/Posterior Tilt (°)	Protraction/Retraction (°)
Horizontal Abduction (n=31)	Dynamic	Abduction	-0.316 (20.89)	-30.569 (43.14)	21.355 (65.5)
Low Rows (n=32)	Dynamic	Flexion	-0.812(17.87)	-15.973(31.51)	26.945 (40.76)
Lateral Flexion (n=31)	Dynamic	Flexion	-9.419(21.32)	-20.8(30.21)	50.842(36.86)
Prone Shoulder Extension (n=32)	Dynamic	Flexion	-6.832(17.42)	-27.737(53.78)	29.797(59.66)
Seated Rows (n=31)	Dynamic	Flexion	-7.919(11.82)	-8.162(28.62)	26.685(31.5)
Serratus Anterior Strengthening in Quadruped (n=16)	Dynamic	Flexion	2.342(29.56)	-8.498(62.67)	36.659(67.46)
Shoulder Shrug (n=32)	Dynamic	Abduction	-4.602(19.01)	-19.543(31.81)	14.673(44.27)
T Lifts (n=16)	Dynamic	Scaption	12.031(24.42)	-15.675(68.76)	28.93(80.52)
Wall Push Up (n=27)	Dynamic	Flexion	-12.457(12.84)	-13.222(28.51)	30.104(30.09)
Locust Arms (Forward) (n=21)	Static	Scaption	-7.089(32.11)	-16.933(70.00)	25.965(75.23)
Plank Hands Clasped (n=24)	Static	Flexion	-6.77(18.84)	3.465(63.42)	56.03(35.34)
Side Plank (n=32)	Static	Abduction	10.837(23.04)	-5.051(62.92)	18.51(56.49)
Thoracic Extension (n=26)	Static	Scaption	16.693(16.35)	-44.736(37.12)	-29.894(99.04)

Chin Tuck (n=32)	Static	Abduction	-9.157(20.61)	-8.436(40.09)	35.8(34.15)

Table 12. Scapulothoracic kinematic findings of static postures and body weight bearing exercises, outlining Scapular Upward Rotation caused, along with start and end ranges during static elevation trials at 0° and 120°.

	Exercises				
	Locust Arms Forward (n=21)	Plank Hands Clasped (n=24)	Side Plank (n=32)	Thoracic Extension (n=26)	Chin Tuck (n=32)
Mean Upward Rotation (°)	7.09	6.77	10.84	16.69	9.16
Upward Rotation at 0°	4.4 (16.12)	4.4(16.12)	4.4(16.12)	4.4(16.12)	4.4(16.12)
Upward Rotation at 120° Abduction	7.93(19.18)	7.93(19.18)	7.93(19.18)	7.93(19.18)	7.93(19.18)
Upward Rotation at 120° Flexion	6.69(17.53)	6.69(17.53)	6.69(17.53)	6.69(17.53)	6.69(17.53)
Upward Rotation at 120° Scaption	6.44(18.58)	6.44(18.58)	6.44(18.58)	6.44(18.58)	6.44(18.58)

Table 13. Scapulothoracic kinematic findings of static postures and body weight bearing exercises, outlining Scapular Posterior Tilt caused, along with start and end ranges during static elevation trials at 0° and 120°.

	Exercises				
	Locust Arms Forward (n=21)	Plank Hands Clasped (n=24)	Side Plank (n=32)	Thoracic Extension (n=26)	Chin Tuck (n=32)
Mean Posterior Tilt (°)	16.93	3.46	5.05	44.73	8.44
Posterior Tilt at 0°	12.06 (25.18)	12.06(25.18)	12.06(25.18)	12.06(25.18)	12.06(25.18)
Posterior Tilt at 120° Abduction	2.11(27.51)	2.11(27.51)	2.11(27.51)	2.11(27.51)	2.11(27.51)
Posterior Tilt at 120° Flexion	7.34(16.49)	7.34(16.49)	7.34(16.49)	7.34(16.49)	7.34(16.49)
Posterior Tilt at 120° Scaption	8.78(16.13)	8.78(16.13)	8.78(16.13)	8.78(16.13)	8.78(16.13)

Table 14. Scapulothoracic kinematic findings of static postures and body weight bearing exercises, outlining Scapular Retraction caused, along with start and end ranges during static elevation trials at 0° and 120°.

	Exercises				
	Locust Arms Forward (n=21)	Plank Hands Clasped (n=24)	Side Plank (n=32)	Thoracic Extension (n=26)	Chin Tuck (n=32)
Mean Scapular Retraction (°)	25.96	56.03	18.51	29.89	35.8
Scapular Retraction at 0°	23.93 (39.66)	23.93(39.66)	23.93(39.66)	23.93(39.66)	23.93(39.66)
Scapular Retraction at 120° Abduction	34.43 (11.36)	34.43(11.36)	34.43(11.36)	34.43(11.36)	34.43(11.36)
Scapular Retraction at 120° Flexion	43.03 (14.71)	43.03(14.71)	43.03(14.71)	43.03(14.71)	43.03(14.71)
Scapular Retraction at 120° Scaption	37.6 (13.42)	37.6(13.42)	37.6(13.42)	37.6(13.42)	37.6(13.42)

5. Discussion

It was hypothesized the muscle activity in ScapSE exercises would be greater than the activity across the BWB exercises, with both exercise groups presenting advantageous co-activity. Although the ScapSE exercises elicited greater activity in both the scapular stabilizer and rotator cuff groups, the co-activation was predominantly moderate and disadvantageous across these exercises and the BWB. Scapulothoracic kinematic findings were outlined in the dominant arm of exercise sets, as it was anticipated that disadvantageous scapular positions would be produced during ScapSE trials, compared to their resting position, but after completing the analysis, it was found that upward rotation of scapula was evident across most of the accepted exercises, where these tasks would be expected to increase SAS in their dominant sided arm (See *Limitations* for explanation of having kinematic data for 14/23 exercises).

5.1 Electromyography Analysis

Based on the activity elicited, there can be suggestions made accordingly with respect to the two muscle groups; scapular stabilizers and rotator cuff muscles. Tasks with low (0-20% MVC) to moderate activity (20-40% MVC) will be recommended for initial use when assessing SAIS rehabilitation, whereas tasks that generally elicited high (40-60% MVC) to very high activity (> 60% MVC) in either muscle group can be expected to be recommended during later stages of rehabilitation (Escamilla et al., 2009; Cools et al., 2007; Uhl et al., 2010). Myers et al. (2009) describes how strengthening of rotator cuff muscles will allow for improvements in humeral head positioning with improving muscle force, therefore these exercises with low activity will be optimal to initialize rehabilitation and enhance repetitions of these tasks for individuals with SAIS or RCT. Similarly, with respect to the calculated co-activation ratios outlined, exercises that produced UT activity less than 60% of the activity produced by the other scapular stabilizer muscle had 'excellent' co-activation which can be recommended for clinical use, which was also incorporated for the analysis of exercises with 60-80% UT activity that have 'good' co-activation. The exercises that produced 80-100% co-activation (moderate) or greater than 100% UT or MD activity relative to their co-activating muscle groups (disadvantageous) were not to be initially recommended (Cools et al., 2007; Uhl et al., 2010).

The goal of this study was to determine if these subsets of exercises would target the muscles intended to strengthen by producing moderate activity, and promote advantageous co-activation ratios. It was anticipated that all targeted muscles would produce moderate to high muscle activity, with advantageous co-activation, however, most exercises elicited lower to moderate activity. For the purpose of this research, initial recommendations were based on lower to moderate activity levels and good and/or excellent co-activation ratios. This created three classifications for the exercises, where they are initially recommended, recommended later in rehabilitation or some that need further analysis. Initially recommended exercises include six ScapSE exercises: **Horizontal Abduction (ScapSE), Prone Shoulder Extension (ScapSE), Seated Rows (ScapSE), Serratus Anterior Strengthening in Quadruped Position (ScapSE), T Lifts (ScapSE), Supine Press (ScapSE)**. From the work of Cools et al. (2007), Horizontal Abduction was one exercise that was advised for shoulder rehabilitation, and findings from this study suggest the muscle activity was moderate to high in the two muscles intended to target (MT: 85.1 ±53.9%MVC, LT: 59.8 ±25%MVC), but still expressed moderate activity in the UT and SA (30.7 ±17.2%MVC) (Escamilla et al., 2009). The co-activity of UT/MT and UT/LT are advantageous (45.7 ±26.1%, 58.2 ±40.2%), therefore causing for potential use for rehabilitation due to UT not exhibiting hyperactivity. This exercise produced excellent MD/IS co-activation ratio, suggesting the shear effect caused by the deltoid is mitigated; thereby preventing SAS reduction (Myers et al., 2009; Ackland and Pandy 2009). Prone Shoulder Extension presented the ability of having low to moderate muscle activity throughout both muscle groups (UT: 12.0 ±10.7%MVC, MT: 37.6 ±35.3%MVC, SS: 7.6 ±5.2%MVC, IS: 28.8 ±30.3%MVC), whilst expressing excellent co-activation ratios (UT/MT: 47.1 ±35.3%, UT/LT: 53.4 ±36.2%, MD/IS: 52.9 ±64.1%), making it an exercise to recommend due to its minimal risk of UT activation compared to MT specifically (targeted muscle), also recommended by Cools et al. (2007). It is important to maintain lower UT co-activation ratios while increasing SA activity for future clinical use and on shoulders experiencing SAIS and/or RCT. An exception to this, is evident in the muscle activity during the T-Lift (ScapSE) exercise, where it presents moderate to high activity (UT: 32.3 ±22.4%MVC, MT: 80.9 ±52.5%MVC, LT: 45.5 ±23%MVC) (Escamilla et al., 2009); due to its advantageous co-activation ratios (UT/MT: 48.1 ±30.9%, UT/LT: 77.4 ±51.9%), this task can be performed in later stages of rehabilitation. In the work by Oyama et al. (2010), similar exercises were used to represent scapular retraction, specifically resembling the T-Lift exercise in this current study, and results were similar, where MT was the most active muscle (66.0 ±25.1% MVC), with moderate UT activity (45.4 ±27.3%MVC). The exercise presented by Oyama et al. (2010) was referred for those with SAIS, which can be similarly done in this study. Exercises such as Prone Shoulder Extension (ScapSE) and Lateral Flexion (ScapSE) are advantageous specifically for the side the task they are performed on due to their moderate muscle activity (Lateral Flexion: UT; 6.5 ±6.9%MVC, SA; 35.5 ±21.3%MVC) with advantageous co-activation for SA, the targeted muscle (UT/SA: 24.2 ±25.8%); becoming an exercise that can be utilized exclusively for unilateral cases (Escamilla et al., 2009).

Another objective of this study was to compare the muscle activity and co-activation between the two subsets of exercises: ScapSE tasks and BWB postures. When comparing the ScapSE and BWB postures, the increased activity in UT, MT, LT in strengthening exercises was evident and anticipated, however, there were weight-bearing postures that elicited a decrease in muscle activity of UT, MT, LT, and as anticipated, produced excellent co-activation ratios, those being Side Plank (BWB) and Chin Tucks (BWB). Side Plank expressed low to moderate muscle activity (UT: 7.1 ±9.9%MVC, MT: 23.7 ±32.1%MVC, LT: 16.6 ±10.7%MVC, SS: 6.3 ±8%MVC, IS: 15.5 ±11.5%MVC), evidently lower than most strengthening exercises, but their scapular stabilizer co-activation remains advantageous (UT/MT: 39.8 ±32.1%, UT/LT: 41.2 ±26.8%). Chin tucks in turn presented low muscle activity (UT: 5.9 ±4.5% MVC, MT: 8.1 ±7.7%MVC, LT: 10.5 ±7.5%MVC, SS: 5.0 ±3.8%MVC, IS: 3.3 ±2.8% MVC), with rotator cuff co-activity deemed advantageous (MD/SS: 65.0 ±55.7%, MD/IS: 83.2 ±80.9%), allowing for recommendation for rehabilitation of those with RCT, specifically due to the minimal shearing effect of the deltoid elicited, which does not restrict the SAS (Myers et al., 2009; Ackland and Pandy 2009). These BWB exercises produced reduced muscle activity on the targeted muscles compared to strengthening tasks, and still presented similar findings for muscle-coactivation.

Although the initially recommended exercises posed differences in muscle activity and similarities in co-activation, the subset of exercises that are not to be recommended can pose varying results. Exercises that are to be excluded from initial recommendation include Shoulder Shrugs (ScapSE), Locust Arms Outstretched Forward (BWB), Low Rows (ScapSE), Plank with Hands Clasped (BWB), and Y-Lifts (ScapSE). Most of this subset of exercises elicit low to moderate muscle activity in both groups, however, their co-activation ratios were all deemed ‘moderate’ or ‘disadvantageous’. In the case of Low Rows, muscle activity was low to moderate

(UT: 10 ±7.4%MVC, MT: 27.0 ±61.9% MVC, LT: 16.2 ±11.9%MVC, SS: 10.0 ±6.9%MVC, IS: 15.6 ±24.9%MVC), but co-activity was disadvantageous (UT/MT: 160.3 ±183.6%, UT/LT: 101.5 ±119.3%). The targeted muscle, LT, did express moderate activity, however, the hyperactivity of UT during this exercise, poses risk during initial rehabilitation in those with impeded SAS (Ludewig et al., 2004). Shoulder Shrugs targeted UT, where activity about this muscle during task repetitions increased with high activity (UT: 55.1 ±32.3% MVC) and posed disadvantageous co-activation for all 3 UT ratios; UT/MT: 279.3 ±397.2, UT/LT: 392.6 ±317.9%, UT/SA: 1013.2 ± 1102.2%). Y-Lifts targeted MT and LT, where both muscles had very high activity (UT: 70.0 ±27.2%MVC, MT: 85.1 ±39.9, LT: 70.7 ±23.4% MVC, SS: 47.3 ±16.9%MVC), and increased co-activation ratios (UT/MT: 104.7 ±58.5%, UT/LT: 112.5 ±65.7%, MD/SS: 100.0 ±53.9%); expressing large increase compared to the muscle activity produced during BWB exercise.

5.2 Scapulothoracic Kinematic Analysis

Scapulothoracic kinematic data presented in this thesis include that from 14 exercises, with varying participant sample size for each task due to errored data and challenges with scapular cluster during exercise (see *Limitations*). Scapulothoracic findings of the dominant arm were assessed and provide insight towards the changes or potential compensations made by individuals when performing these exercises, specifically during the ScapSE exercises. The scapular planes of motion, abduction, flexion, scaption, were assessed through static elevation and range of motion trials, where different end ranges were evaluated when elevating to 120°.

An objective of this study was to examine scapulothoracic kinematics during these exercises to understand the rotation and changes in scapular position relative to their resting position, and it was anticipated that certain exercises would exhibit disadvantageous changes in scapular position. In Table A-1 (See *Appendix*), it can be seen Modified Plank with Hands Clasped did not remain within the ranges of motion across the three scapular planes of motion at 120°, exhibiting risk of abnormal scapular positions through increased anterior tilt. In the present study, the dynamic exercise trials can be compared to the work of Ludewig et al. (2009), that reported joint angles produced during scapulothoracic elevation on 12 individuals with transcortical bone pins affixed to the scapular, clavicle and humerus. In a previous study by Ludewig et al. (2009), transcortical pin placement into the clavicle, scapula and humerus allowed for accurate findings with regard to humeral movement in different planes, which compares to this study's protocol where no bone pins were used; drawback in elevation trial analysis. Mean joint angles were within the reported angles about the three planes of motion, where upward rotation increased an average of 39° (11° resting to 50°). To assess the exercise data, which exhibited considerable variability in the current research, comparisons can be made with research by McClure et al. (2004) who assessed those with SAIS across an exercise program. Although this intervention was one visit, compared to the 6-week study outlined in McClure et al. (2004), there was an increase in posterior tilt of about 3-4° from neutral position, increase in upward rotation of 5° from starting position, and retraction plateauing about 6-7° from resting position. This is important to know, given the exercise protocol in the McClure et al. (2004) study involves movements such as Scapular retraction, shoulder flexion where shoulders are in neutral position and punch forward, extending arms (similar to Seated Rows with advantageous changes), shoulder abduction in scapular plane (similar to Y-Lifts or Locust Arms Forward with disadvantageous changes).

At elevated shoulder positions in scapular plane, reaching about 120°, upward rotation increases approximately 60° (10° resting to 70° end range), posterior tilt increasing 12° (2° resting to 14° end range), and external rotation increasing 12° (-40° start to -28° end range) (McClure et al., 2004). This resembles the work in this present study, looking at exercises that exhibit flexion, abduction and scapular plane motions in the shoulder, where postures can be held at specific elevation angles across a set time frame. ScapSE tasks such as T-Lifts (ScapSE) exhibit similar findings based on the study by McClure et al. (2004), outlining angles when looking at all three of upward rotation, posterior tilt and retraction changes, as the mean joint angles for this task fall within the expected ranges. In the study by Oyama et al. (2010), the exercise that resembled T-Lifts (Exercise 5 from study, where arms elevated at 45° and elbows flexed at 90°, asked to retract) exhibited increased upward rotation, posterior tilt and retraction (19.7 ±8.5°, 8.5 ±6.7°, 31.3 ±5.7°), presenting significant changes in scapular position from resting, where moving the scapula about multiple axes is critical for rehabilitation purposes. Seated Rows (ScapSE) with mean joint angles of 7.9 ±11.8°, 8.2 ±28.6°, 26.7 ±31.5° in all three scapular rotation planes (upward rotation, posterior tilt and retraction) can be compared to the exercise outlined in McClure et al. (2004) exercise program study, where mean posterior tilt and retraction follow similar trends post trials. Serratus Anterior Strengthening in Quadruped position (ScapSE) is another exercise that their respective mean joint angles (Upward: 2.3 ±29.6°, Posterior: 8.5 ±62.7°, Retraction: 36.7 ±67.5° fall within two of the three scapular planes of motion ranges outlined by McClure et al. (2004) study, indicating potential improvement in abduction and flexion motions that can be initially recommended for use.

ScapSE exercises that presented advantageous muscle activity and co-activation, such as Horizontal Abduction and Prone Shoulder Extension, can draw comparisons to previous work from Oyama et al. (2010) with regard to their mean joint angles. Horizontal Abduction (Upward: -0.3 ±20.9°, Posterior Tilt: -30.6 ±43.1°, Retraction: 21.3 ±65.5°) compared to the mean joint angles of the 2nd exercise (90° abduction occurred laying prone with external rotation and thumb pointing toward ceiling) outlined in this study; Upward Rotation: 20.2 ±8.5°, Posterior Tilt: 0.9 ±8.0°, Retraction: 29.2 ±5.2°. This current study's upward rotation was smaller in magnitude compared to that of the work from Oyama et al. (2010), which also presents increased posterior tilt by almost 30°, and lower retraction with less variability. Prone Shoulder Extension (Upward: 6.8 ±17.4°, Posterior Tilt: -27.7 ±53.8°, Retraction: 29.8 ±59.7°) compared to the 6th exercise outlined by Oyama et al. (2010), with an exercise that fully extends shoulder behind back whilst laying prone (Upward: 1.5 ±10.6°, Posterior Tilt: -15.8 ±10.5°, Retraction: 17.1 ±5.7°). The Prone Shoulder Extension findings suggest on average, there was a decrease in posterior tilt and retraction, and can be compared to Horizontal Abduction where decreases in upward rotation and posterior tilt occurred.

There was the expectation some exercise trials would exhibit disadvantageous kinematics, those would follow the ranges of motion using the 120° elevation end ranges, where as mentioned, Thoracic Extensions and Modified Plank with Hands Clasped (Upward: 6.8 ±18.8°, Posterior: 3.5 ±63.4°, Retraction: 56.0 ±35.3°) presented mean joint angles outside of the expected range of motion (See Tables 9-12).

5.3 Exercise Recommendations

Based on the EMG and kinematic findings of this research, recommendations can be made for certain ScapSE exercises and some BWB exercises. Exercise tasks that presented advantageous muscle activity and co-activation ratios of the two muscle groups included **Horizontal Abduction, Prone Shoulder Extension, Serratus Anterior Strengthening in Quadruped Position, T-Lifts, Seated Rows and Supine Press.** Although Supine Press did not include kinematic data, of these five exercises, all but Prone Shoulder Extension presented advantageous scapular positions with regard to improving the SAS, seen through appropriate increases in scapular upward rotation, posterior tilt and retraction.

6. Limitations

Throughout the protocol and analysis of this study, there were specific matters that limited the ability to fully interpret data collected. Scapulothoracic joint angles represent data measured from 32 participants for static elevation and range of motion trials. Unexpectedly, 5 exercises were excluded due to errors in the results, evident through sporadic joint angle increases and jumps from the expected ranges of motion, or angles that were unrealistic from anatomical perspective, specifically in rotation of the scapula. Exercises that were included presented data from at least 16 participants; half the sample size (See Appendix A). Due to these limitations, a narrative description of findings was presented, rather than statistical comparisons. Included data were acquired from the dominant arm in Chin Tucks, Horizontal Abduction, Low Rows, Lateral Flexion, Locust Arms Forward, Prone Shoulder Extension, Modified Plank with Hands Clasped, Seated Rows, Serratus Anterior Strengthening in Quadruped Position, Side Plank, Shoulder Shrugs, Thoracic Extensions, T-Lifts, Wall Push Ups. Single sided dynamic exercises such as Horizontal Abduction (ScapSE) using the dominant arm (n=31), presented mean joint angles of 0.32 ± 20.89° (Table 9) of upward rotation, 30.57 ± 43.14° of posterior tilt, 21.35 ± 65.51° of retraction (external rotation of scapula), when performing the flexion motioned task. Prone Shoulder Extension (ScapSE) of the dominant limb (n= 31) elicited 6.83 ± 17.41° of upward rotation, 27.73 ± 53.78° of posterior tilt, and 29.8 ± 59.65° of retraction. Dynamic tasks that involved both arms such as Seated Rows (ScapSE) (n=31), produced upward rotation of 7.91 ± 11.82°, posterior tilt of 8.16 ± 28.62° and retraction of 26.68 ± 31.5° on the dominant side. Static exercises were also collected for assessment, including Locust Arms with arms outstretched

Forward (BWB) (n=21), which presented upward rotation of 7.1 ± 32.11°, posterior tilt of 16.9 ± 70° and external rotation of 26.0 ± 75.22° (See Table A-1). The mean joint angles produced by the five static exercises were compared to joint angles calculated for range of motion elevation tasks across each plane (abduction, flexion, scaption). The upward/downward range of motion joint angles were 4.4 ±16.1° downwardly rotated at 0° range of motion, and 7.9 ±19.2° upwardly rotated at 120° abduction, 6.7 ±17.5° at 120° flexion and 6.4 ±18.6° at (120° scaption (See Table 9). The scapula anterior/posterior tilt 12.1 ±25.2° of posterior tilt at 0° elevation, while at the end ranges of 120°, the scapula remained posteriorly tilted at 2.1 ±27.5° during abduction motions, 7.3 ±16.5° during flexion and 8.8 ±16.1° during scaption. During the static exercises, the scapula retracted, starting at 23.9 ±39.7° (0°), and increased to 34.4 ±11.4° during abduction movements, 43.0 ±14.7° during flexion and 37.6 ±13.4° in scapular plane motions.

Troubleshooting efforts were extensively performed at the data analysis stage in attempt to correct the errored data, where the issues could not be rectified through data processing. Unfortunately, this suggests it was related to the acromial cluster/scapular tracker. Issues between this tracking cluster and participants laid in prone position for several exercise tasks presented errors, specifically when the acromioclavicular joint reflective marker was not visible at all times. This led to missing various bouts of the exercise tasks, resulting in inconclusive findings in prone tasks or even two-handed exercises but specifically in the non-dominant sided data. In relation to participants laying prone for various exercises, the mass of the tracker could have caused the inaccuracies found through the data processing stage, where the weight could be pulling downwards due to gravity, instead of remaining upright. The BWB exercise trial data for the non-dominant side was altered, specifically through the range of motion analysis and through exercise comparison in both limbs. Using the outlined joint angles from previous literature, McClure et al. (2004), an assessment performed for the BWB exercises, following the range of motion data, using the 0° start and 120° end ranges. The non-dominant sided mean joint angle for each of the exercises were predominantly outside of all three planes of motion ranges (120° abduction, flexion, scaption), suggesting it would not be appropriate to include this data, due to potential inaccuracies in the non-dominant side. This was also presented in anterior/posterior tilt and protraction/retraction data. When comparing dominant and non-dominant sided data, outlier data seen through maximal and minimal values was also significantly greater in the non-dominant side, where scapular positions would experience continuous increases between the expected angles and 180°; results in quadrant shift artifact that can misrepresent scapular motions (See Appendix A). However, the dominant data still experienced limits on the full participant pool inclusion on various exercises, resulting in exclusion of prone tasks where markers may not have been visible throughout entire trials; Push Up Plus, Reverse Table Top, Y-Lifts. Despite these limitations, the impact of missing kinematic information across multiple exercises did not eliminate the findings for exercises that can be recommended for initial rehabilitative use; the missing information will need to be further assessed in future work.

7. Conclusion

Across twenty-three exercises and postures, muscle specific maximal voluntary capacity tests, multiplane elevation trials, and scapular motion analysis, a subset of recommended exercises can be outlined for future rehabilitation use, to reduce the risk of subacromial impingement syndrome and/or rotator cuff tears through the reduction of upper trapezius hyperactivity and altered kinematic parameters such as downward rotation of the scapula, anterior tilt and external rotation. The ScapSE tasks that presented low to moderate muscle activity, good to excellent co-activation ratios and stayed within the advantageous ranges for scapular planes of motion, were to all be included in future recommendation, whereas the exercises with high muscle activity, disadvantageous co-activation ratios and scapular positions were not to be recommended. Therefore, Horizontal Abduction, Prone Shoulder Extension, Serratus Anterior Strengthening in Quadruped Position, T Lifts, Seated Rows, Supine Press, Lateral Flexion, Chin Tucks and Side Plank are all to be recommended for future clinical use to reduce SAIS risk, and mitigate SAS reduction.

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Appendix

A) Examples of errored kinematic trials of body weight-bearing exercises (static exercises) that were excluded from analysis due to inaccuracies and continuous jumps in data on non-dominant limb.

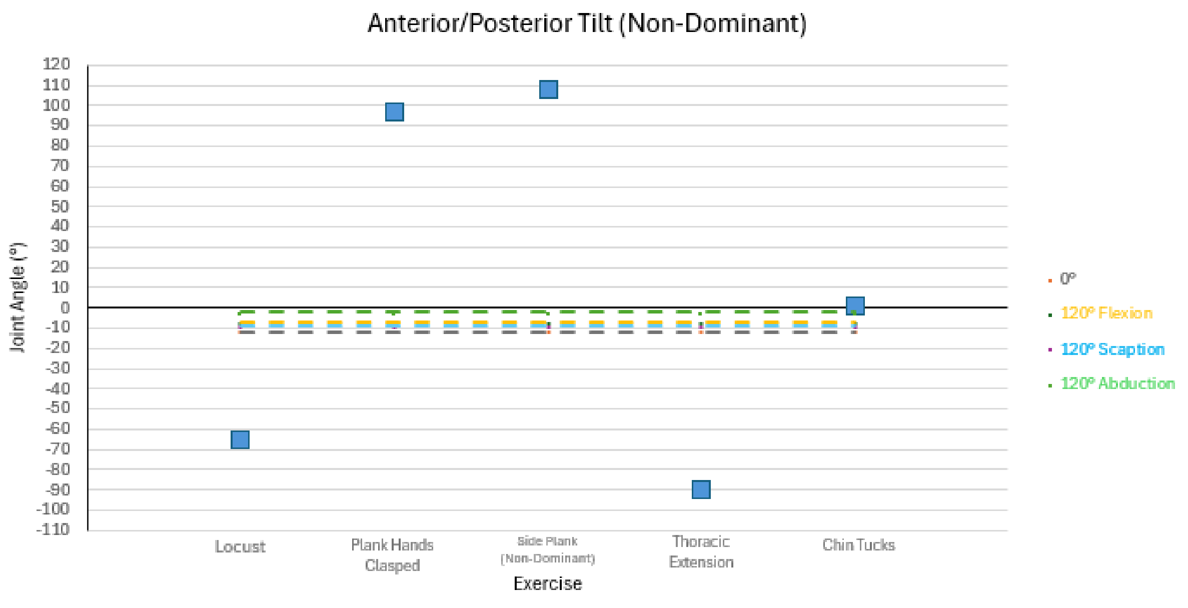

Figure 1. Anterior and/or Posterior tilt of scapula assessed of non-dominant limb across five body weight-bearing postures. Negative values suggest an increase in posterior tilt.

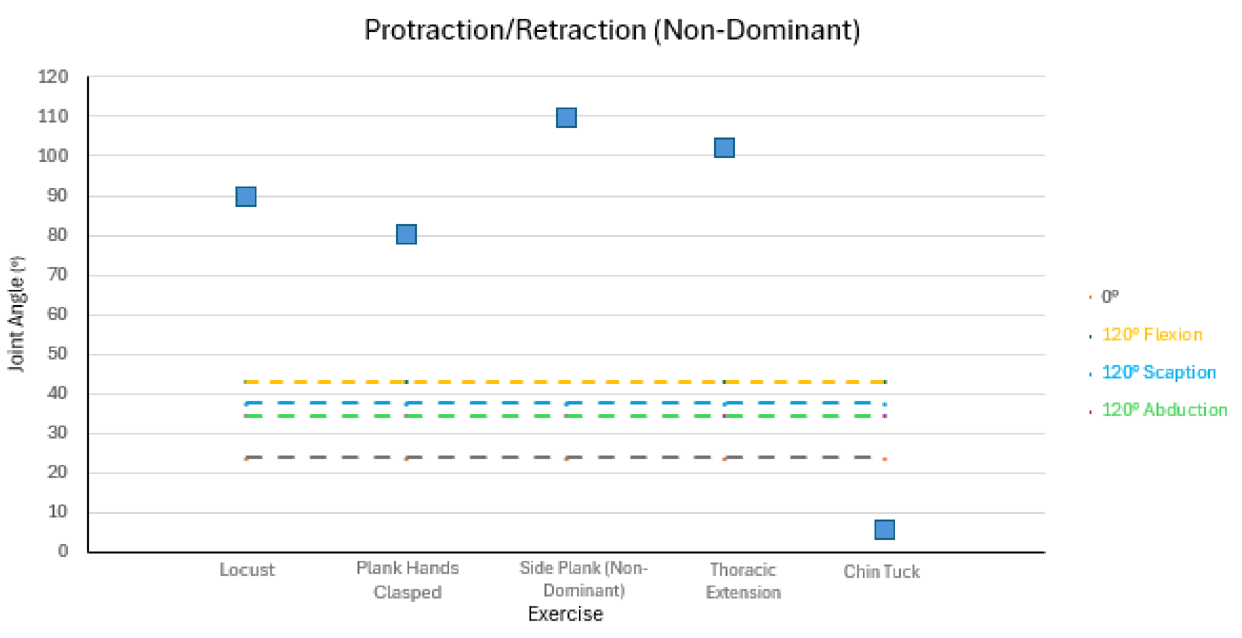

Figure 2. Scapular Protraction and/or Retraction assessed of non-dominant limb across five body weight-bearing postures. Positive values suggest an increase in retraction (external rotation).

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