The Influence of Cervical Spine Positioning and Spinal Manipulation on Shoulder Rotation Strength

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Abstract

Shoulder rotation strength is included as part of an orthopedic examination for clinicians treating patients presenting with shoulder pathology. However, for populations prone to shoulder injury, such as overhead athletes and trades workers, shoulder function is required in non-neutral cervical spine positions, which differs from how it is assessed in clinic. Further, spinal manipulation is used in clinic to address shoulder issues arising from cervical radiculopathy and thoracic outlet syndrome. A case can be made for the functional positions of overhead athletes and trades workers mimicking mechanisms of injury for cervical radiculopathy and thoracic outlet syndrome. Therefore, the purpose of this dissertation was to examine the effects of a rotated cervical spine on shoulder rotation strength, to examine the effects of thoracic and cervicothoracic spinal manipulation on shoulder external rotation strength, and to see if spinal manipulation moderates the potential deleterious effect of an altered cervical spine position on shoulder rotation strength. Fifty-two healthy, active volunteers participated. Isokinetic external and internal rotation strength was assessed using an isokinetic dynamometer. Multilevel model analyses revealed a negative effect of a rotated cervical spine on shoulder rotation strength. There was no evidence found to support the use of spinal manipulation for improving shoulder rotation strength or for moderating the effect of a rotated cervical spine on shoulder rotation strength. The results of this study indicate the functional position for populations such as overhead athletes and trades workers may contribute to shoulder weakness. This may serve as a basis to help explain the higher injury rates in these populations.

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Chapter I

Introduction

Shoulder rotation strength testing is a standard clinical measurement to assess function of the shoulder.[1] Typically, in clinical settings, manual muscle testing is graded 0-5, with 0 being no activation at all, and 5 being able to fully resist a break test. In research settings, hand-held or isokinetic dynamometry is more often used due to greater reliability. Shoulder strength is used as an objective measure to track progress during rehabilitation from injury or part of a clinical examination to diagnose pathology.[1]

Pathologies that may affect shoulder rotation strength are damage to shoulder girdle tissue causing pain, such as strains of musculature or sprains of ligaments, and neuropathies.[2] While these pathologies are common detriments to shoulder strength, this dissertation will argue that cervical spine and shoulder position may also affect shoulder strength. Specifically, this dissertation focused on a mechanism where cervical spine and shoulder positioning may mimic certain signs and symptoms seen in cervical pathologies that affect the spinal nerve at the myotome level of shoulder musculature such as cervical spondylosis, stenosis, and cervical disc herniations, causing radiculopathies, and thoracic outlet syndrome.

Spondylosis is a degeneration of the disc and facet joints,[2] which are support structures that aid in spacing out the intervertebral foramen. Stenosis can occur at the intervertebral foramen,[2] resulting in reduced space for the spinal nerve as it exits the spinal column. Disc herniations are a protrusion of the intervertebral disc, which may compress spinal nerves against a bony structure.[2] Thoracic outlet syndrome is compression of the brachial plexus as it travels between the anterior and middle scalenes, the first rib and clavicle, or beneath the pectoralis minor.[2] The common theme of the above pathologies is shoulder function is affected by compressing spinal and/or peripheral nerves proximal to the innervated musculature. By positioning the cervical spine and shoulder, overhead athletes and trades workers may be causing signs and symptoms of these radicular pathologies that are not present in standard anatomical position.

Because of the coupling nature of the cervical spine,[3] cervical positioning may biomechanically mimic some of the effects of these cervical pathologies by altering the amount of compression on spinal and peripheral nerves. Therefore, it could be theorized many of the radiculopathy symptoms seen in cervical pathologies could be present in healthy populations if placed in cervical positions resulting in nerve compression. Populations that regularly place themselves in cervical rotation and glenohumeral abduction with external rotation while using their shoulders include overhead athletes, such as baseball pitchers, and manual trades workers,[4,5] such as electricians and plumbers. During the cocking phase, a baseball pitcher's shoulder is externally rotated and horizontally abducted with the shoulder girdle elevated and his cervical spine rotated contralaterally to look at home plate[6] (FIGURE 1). This combination of movements puts the throwing side scalenes on stretch, narrows the space between the first rib and clavicle, and places the pec minor on stretch,[7] all of which have the ability to compress the brachial plexus and are the three forms of thoracic outlet syndrome. After releasing the ball, the pitcher continues to rotate towards the non-throwing side as he decelerates his throwing arm with an eccentric posterior shoulder musculature contraction[8] to absorb kinetic energy (Wasserberger, unpublished). In order to keep his sight on home plate, his cervical spine is now side bent and rotated towards the throwing arm side and extended (FIGURE 2); a combination of movements that narrows the intervertebral foramen, potentially compressing the spinal nerves. Another example is an electrician or plumber working overhead. To look at their work, their cervical spine must be side bent and rotated towards his dominant arm and extended. This narrows the intervertebral foramen similarly to a baseball pitcher during follow through. In addition, with the shoulder girdle elevation and abduction needed to work overhead, this fulfills two of the three thoracic outlet criteria, potentially resulting in further restriction of the peripheral nerves prior to muscle innervation.

https://clients.chrisoleary.com/portals/31/Clients/Pitching/Images/Rivera_Mariano_2013.05.25_001.jpg?ver=2016-01-14-220621-477

Figure 1. Cocking phase of a pitch

https://lh3.googleusercontent.com/proxy/8dQzplgco-DtQ-efYyMSK8RJKs3jnKYXY-VfKgzusHe1ztQ8EyybZgBgrXfzDZR8q1s9O_GYJmpGMIfdf4n8Q46C9BH7L0wCA5p_N7MVfbdHX75x8Jwcy3-PfwzW5CK7_JXC4frbLrP7XNt5OJ-mnYkk

Figure 2. Follow-through of a pitch

Because of the compressive etiology, cervical radiculopathy symptoms,[9] such as strength deficit,[10] are often treated through spinal manual therapy.[11,12] Mobilizing the cervical spine results in increased cervical rotation range of motion,[13] which could allow greater range before restrictions result in compression of the spinal nerves. In addition, mobilizing inferior to the cervical spine has also shown benefits to cervical range of motion,[12] as increasing the mobility of the upper thoracic spine allows the cervical spine to be positioned in a more favorable position.

The effects of cervical positioning on shoulder rotation strength are only beginning to be examined (Giordano, unpublished). By rotating the cervical spine and the combination of abduction and external rotation of the humerus, neural tissue may be compressed or stretched, potentially reducing nerves' capability to activate muscular motor units. This is clinically relevant because populations such as overhead athletes and manual trades workers regularly perform tasks in these humeral and cervical spine positions, therefore, further investigation into the effects of cervical position on shoulder rotation strength is warranted. In addition, while the effects of spinal manipulation have been examined in cervical pathological populations, the interaction of manipulations affecting shoulder rotation strength in varying cervical positions has not. Examining the effects of cervical and shoulder positioning on shoulder rotation strength in healthy subjects may help explain the etiology of shoulder pathology in injury prone populations.

Purpose

The purpose of this study was to examine the effects of cervical positioning and thoracic and cervicothoracic junction manipulations on shoulder internal and external rotation strength in healthy, young adults.

Research Questions

RQ1) Does cervical positioning affect shoulder external rotation strength?

RQ2) Does cervical positioning affect shoulder internal rotation strength?

RQ3) Do spinal manipulations to the thoracic spine and cervicothoracic junction affect shoulder external rotation strength from pre to post manipulation and to a 30-minute follow-up?

RQ4) Do spinal manipulations to the thoracic spine and cervicothoracic junction affect shoulder internal rotation strength from pre to post manipulation and to a 30-minute follow-up?

RQ5) Do spinal manipulations moderate the effect of cervical position on shoulder external rotation strength from pre to post manipulation and to a 30-minute follow-up?

RQ6) Do spinal manipulations moderate the effect of cervical position on shoulder internal rotation strength from pre to post manipulation and to a 30-minute follow-up?

Hypotheses

H1) External rotation strength will be greatest in the neutral cervical position, followed by the contralateral rotation position, followed by the ipsilateral rotation position.

H2) Internal rotation strength will be greatest in the neutral cervical position, followed by the contralateral rotation position, followed by the ipsilateral rotation position.

H3) Spinal manipulations will result in increased shoulder external rotation strength compared to sham manipulation following manipulation and 30 minutes following manipulation.

H4) Spinal manipulations will result in increased shoulder internal rotation strength compared to sham manipulation following manipulation and 30 minutes following manipulation.

H5) Spinal manipulation will result in a greater increase in external rotation strength in the rotated cervical spine positions than the neutral cervical spine position following manipulation and 30 minutes following manipulation.

H6) Spinal manipulation will result in a greater increase in internal rotation strength in the rotated cervical spine positions than the neutral cervical spine position following manipulation and 30 minutes following manipulation.

Chapter II

Review of Literature

The purpose of this study was to examine the effects of cervical positioning (neutral vs. full ipsilateral rotation vs. full contralateral rotation) and thoracic and cervicothoracic junction manipulations on shoulder internal and external rotation strength in healthy, young adults. This will serve to investigate a potential injury mechanism for populations prone to shoulder injuries, such as overhead athletes and trades workers, and provide a basis for treatment in such populations. This chapter provides a review of the literature relevant to this dissertation, and will be broken down into the following subsections: (1) anatomy of the cervical spine and innervation to shoulder girdle musculature; (2) biomechanics of altered cervical spine positions and abducted testing position; (3) the influence of cervicothoracic spine range of motion and cervical radiculopathy on shoulder function; and, (4) the effects of cervicothoracic spinal manual therapy on shoulder dysfunction.

Anatomy of the Cervical Spine and Innervation of Shoulder Girdle Musculature

The cervical spine has seven vertebrae. The third vertebrae from the skull, and below, share a similar shape[14] with a vertebral body and vertebral arch made up of the pedicle and lamina. The arch is vertically thinner than the body with articular processes protruding superiorly and inferiorly, articulating with adjacent vertebrae. The combination of the thinner arch and the articulating processes creates gaps, known as the intervertebral foramen, where spinal nerves exit[14] the spinal canal (FIGURE 3). Cervical spinal nerves 5-8 (named for the cervical vertebra they are above, with the 8th nerve falling between the 7th cervical vertebra and first thoracic) and thoracic spinal nerve 1 (arises from below the first thoracic vertebra) give rise to the brachial plexus[14] – a complex system of nerves that innervates the upper extremity. The muscle tissue innervated by nerves arising from a certain spinal level is known as a myotome.

While variations in the brachial plexus[15,16] and myotomes[17,18] exist, standard anatomy follows the following innervation for neck and shoulder musculature.[7,14] The upper division of the trapezius muscle is innervated by the spinal accessory nerve (cranial nerve XI) with fibers from C3 and C4. The sternocleidomastoid is also innervated by the spinal nerve (cranial nerve XI) with fibers from C2 and C3. The scalenes are innervated by the ventral rami of C3 to C6. The anterior and posterior deltoid divisions are both innervated by the axillary nerve with fibers from C5 and C6. The sternal head pectoralis major is innervated by the medial and lateral pectoral nerves with fibers from C7 to T1. The serratus anterior is innervated by the long thoracic nerve with fibers from C5 to C7. The infraspinatus is innervated by the suprascapular nerve with fibers from C5 and C6. The teres minor is innervated by the axillary nerve with fibers from C5 and C6.

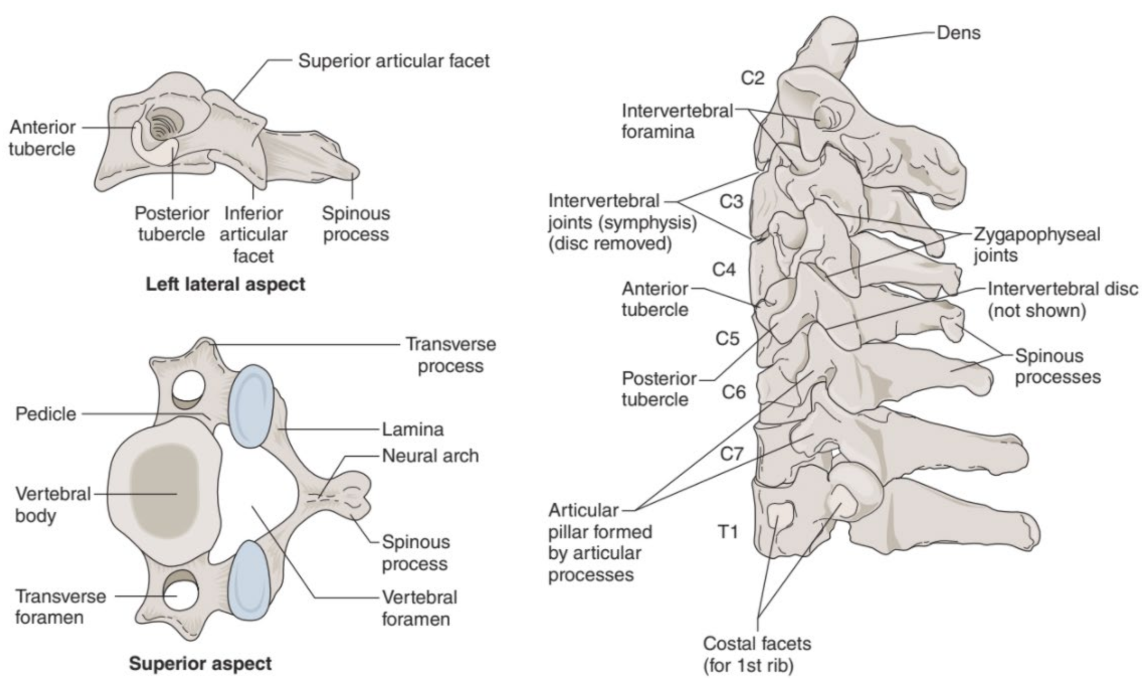


Figure 3. Bony anatomy of the cervical spine[2]

Biomechanics of Altered Cervical Spine Position and Abducted Testing Position

Motions in the cervical spine are coupled.[3] This means a vertebral body translates or rotates about an axis consistently with rotation or translation about another axis.[19] In the cervical spine, below the C2 level, side-bending and rotation are coupled in the same direction.[3,20-23] This is meaningful because all of the muscles discussed earlier in this chapter are part of myotomes below the C2 level (the stenocleidomastoid is the lone exception with innervation from C2 in addition to C3). This coupling motion means that as the cervical spine is rotated and side bent, the intervertebral foramen will be reduced on the ipsilateral side.[7,24] That means when placed in a coupled motion of cervical rotation and side-bending, there is potential for the ipsilateral cervical spinal nerves to be compressed.[24-26] Therefore, this dissertation proposes that placing the cervical spine in a rotated, side-bent position may impact the function of musculature in the myotome of the compressed spinal nerves.[24] It should be noted that the upper division of the trapezius and the sternocleidomastoid are innervated by the spinal accessory nerve,[14] which does not pass through an intervertebral foramen, meaning they would not be affected by potential spinal nerve compression.

Additionally, when rotated and side-bent ipsilateral toward the involved shoulder, the length of musculature connecting the shoulder girdle to the cervical spine is altered. Further, the testing position of having the humerus in 90° of elevation also impacts the length of musculature. The ipsilateral sternocleidomastoid is lengthened with ipsilateral cervical rotation and shortened with ipsilateral cervical side-bending, likely resulting in moderate shortening if the motion is initiated with cervical rotation. The upper portion of the trapezius would shorten with the coupled side-bending coming from ipsilateral cervical rotation. When combined with 90° of humeral elevation, it further shortens from shoulder girdle elevation and upward rotation.[27,28] The levator scapula likely remains in a relatively neutral length due to the slight lengthening occurring during scapular upward rotation[27,28] from its attachment site at the superomedial aspect of the scapula, and the slight shortening occurring during ipsilateral rotation from its attachment on cervical transverse processes.[14] This is meaningful as function of the upper extremity is reliant on a stable scapula, and muscle length affects force production[29,30] capabilities.

Rotation of the cervical spine contralateral to the involved shoulder does not result in the potential for spinal nerve compression on the working side. However, it can affect muscle function by altering length-tension ratios through position, neural tissue compression via secondary entrapment, and stretching of neural tissue. Active contralateral cervical spine rotation results in ipsilateral sternocleidomastoid activation to create the movement,[7] which also shortens the muscle. Conversely, the contralateral sternocleidomastoid lengthens. The upper division of the ipsilateral trapezius likely remains in a relatively neutral length. It is slightly lengthened by the contralateral rotation of the cervical spine, however the 90° of humeral abduction for the testing position results in scapular upward rotation and elevation, which would shorten the muscle.[27,28] The ipsilateral levator scapula is lengthened by contralateral cervical spine rotation and side-bending combined with its medial attachment on the scapula, which upwardly rotates with humeral abduction.[7,27,28]

While the coupled motion of contralateral rotation and side-bending will not affect spinal nerves by compressing the intervertebral foramen, it will place neural tissue in a tensile position.[31-34] This may be significant because of the scalenes and testing position of the shoulder. The scalenes run relatively vertical from the first two ribs to the cervical transverse processes.[14] While the scalenes are slight contralateral rotators, end range contralateral cervical rotation results in the attachment sites crossing in the transverse plane, meaning end range contralateral rotation will place the scalenes on stretch.[7] This is furthered with the coupled motion of contralateral cervical side-bending.[3] Consequently, scalene involvement in thoracic outlet syndrome is well documented.[35-40] Combining the nerve root tension created by contralateral cervical rotation[31-34] with the brachial plexus running between the stretched scalenes results in two potential mechanisms to impact motor neurons to shoulder musculature.

In addition to the cervical position, the testing position of the shoulder may alter length-tension relationships and further elicit signs and symptoms of neural tension and/or compression. The seated testing position used in the present study, and many others, places the humerus in an abducted and externally rotated position to begin the test. First, the abducted humerus increases the moment arm of the teres minor, with its attachment inferior to the supraspinatus as the scapula upwardly rotates during abduction. Accordingly, the teres minor is biased in the abducted testing position compared to the infraspinatus in an adducted testing position.[41] This shoulder position also places the anterior portion of the brachial plexus on stretch,[2,33,42-45] furthering the potential to impact motor output. Additionally, in the common posture deficit of forward head and rounded shoulders, individuals use greater scapular elevation to reach the testing position of 90° abduction.[46] Further, scapular elevation is also used as compensation for weakness in shoulder abduction.[47] Because participants will be performing maximal contractions, it is likely they will naturally compensate to increase force output. Therefore, many participants will likely perform their strength testing with scapular elevation, which was anecdotally noted in a previous study with similar methodology (Giordano, unpublished). This is important, because scapular muscle activation is dependent on scapular positioning.[48,49] Specifically, superior shoulder muscle activity, such as the upper trapezius and deltoid increase with scapular elevation contrasted with lower activity of the lower trapezius and serratus anterior.[48] Further, lower scapular musculature activation has been associated with improved cervical spine posture compared with upper activation.[49]

Scapular elevation while performing strength testing may further elicit nerve entrapment by reducing the space between the first rib and clavicle,[7] and by placing the pectoralis minor on stretch.[38,50] It is common for the brachial plexus to be compressed between the first rib and clavicle,[35,44] and elevating the shoulder girdle will exacerbate this problem, particularly while in shoulder abduction and external rotation. The pectoralis minor is commonly shortened from forward head and rounded shoulders posture.[46] By placing the muscle on stretch through scapular abduction and elevation to reach the testing position, this risks nerve entrapment between the pectoralis minor and scapula.[35,44,50] These factors combine to illustrate how compression of the brachial plexus, responsible for 95% of thoracic outlet syndrome cases,[51] can occur through testing position.

This section reviewed the literature on how positioning of the cervical spine and shoulder girdle may impact shoulder strength both by altering the length of musculature and how neural tissue may be stretched and compressed. Muscle length is important because many factors may result in altered scapular kinematics or glenohumeral joint positioning for testing.[46,47,52,53] Neural tissue is worth considering because nerves largely glide rather than stretch,[54,55] so if nerves are stretched towards the spine and then entrapped by closing of the intervertebral foramen[7] or thoracic outlet structures,[43-45] this may mimic pathology leading to cervical radiculopathy or thoracic outlet syndrome.

Influence of Cervicothoracic Spine Range of Motion and Cervical Radiculopathy on Shoulder Function

This section explores the relationship of cervicothoracic range of motion and radiculopathy on the function of the shoulder complex. Normal shoulder range of motion allows for roughly 180° of flexion and abduction, 60° of extension, 70° of internal rotation, 90° of external rotation with the humerus abducted and 50° with the humerus adducted, and 8° of adduction.[2,7,56] This can be further broken down due to scapulohumeral rhythm, which shows a 2:1 ratio of movement occurring at the glenohumeral joint to movement of the scapula[27] when elevating the humerus. Movement of the scapula occurs at the acromioclavicular and sternoclavicular joints. The acromioclavicular joint allows for approximately 30° of upward rotation and 17° of downward rotation.[57] The sternoclavicular joint allows for 10-15° of elevation, 15-30° of protraction, retraction and posterior rotation.[57] Additionally, the thoracic spine plays a role in achieving end range humerus elevation,[58,59] indicating limitations in thoracic mobility may inhibit full function of the shoulder.

The norm values from the previous paragraph can be influenced by spinal mobility. In fact, lack of spinal and first rib mobility has been associated with decreased shoulder mobility.[60] This is important because of the abducted testing position with contralateral cervical spine rotation in which overhead athletes must function. In addition to factors mentioned in the previous section, tenderness and lack of mobility in the first rib has been shown to be a risk factor for thoracic outlet syndrome.[39,40,61-63] This adds to the combination of ways overhead athletes stress nervous tissue along the tract from the cervical spine through the thoracic outlet. Additionally, if lost spinal mobility results in decreased glenohumeral mobility, this may be problematic for populations such as baseball pitchers, where decreased throwing arm range of motion is established as a risk factor for injury.[64]

Posture has also been shown to influence the shoulder girdle. Forward head, rounded neck posture results in altered scapular kinematics while elevating the humerus.[46] Specifically, glenohumeral elevation is performed under greater scapular activation. Additionally, poor posture impacts performance on testing of shoulder musculature.[65] If there are unilateral mobility deficits, this may result in an asymmetrical presentation of scapular kinematics – known as scapular dyskinesis.[66,67] Scapular dyskinesis has been identified in symptomatic and asymptomatic populations[68] and is not a risk factor for injury[69] in isolation. However, due to length-tension ratios and altered scapular kinematics may result in different scapular musculature activation patterns while elevating the shoulder.[48] This may be significant because posture and muscle imbalances play a role in subacromial impingement[70] and instability, which is associated with decreased shoulder strength.[71] Further, scapular positioning and kinematics are different in individuals with impingement when compared to healthy counterparts.[72]

Subacromial impingement syndrome is a common pathology in overhead athletes, such as baseball players,[73] and in trades workers.[4,5] The spine has implications in the etiology of subacromial impingement. In a large study of industry workers, cervical spine mobility deficits were associated with retrospective complaints of shoulder pain.[74] Further, the same investigator followed a similar cohort for a two-year follow-up and found an 84% positive predictive rate of shoulder injury from cervicothoracic spine mobility deficits.[75] In college baseball pitchers, limitations in the cervical flexion-rotation test was prospectively associated with throwing arm injury during the season.[76] Interestingly, this examination technique may also be limited by first rib mobility,[2] which could impact neural output to shoulder function via contributing to thoracic outlet syndrome.[40,63] Subacromial impingement results in both decreased strength[77] and altered electromyographic muscle activity of shoulder girdle musculature.[78]

There is a growing body of work demonstrating cervical spine involvement in shoulder pathologies such as impingement. Clinicians have documented cervicogenic weakness of the rotator cuff, resulting in subacromial impingement.[79] Thirty-five prcent of patients with subacromial impingement also had nerve root compression on the same side.[80] This is important, because cervical radiculopathy (result of nerve root compression) can display similar symptoms at the shoulder as subacromial impingement.[80] Further, 31% of patients with suprascapular neuropathy – the nerve that innervates the supraspinatus and infraspinatus[14] – also had cervical radiculopathy on the same side.[81] Additionally, patients with nerve root compression in addition to suprascapular neuropathy, known as "double crush syndrome,[82,83]" achieved less supraspinatus activation than patients with an isolated peripheral suprascapular neuropathy.[81] Not surprisingly, patients with nerve root compression did not respond as well to common treatment for distal neuropathy symptoms as those without radiculopathy.[81,82] This is meaningful, as in professional tennis players, a population prone to rotator cuff and suprascapular nerve injuries, 60% had infraspinatus muscle atrophy.[84] This may be partially explained through neural deficits, as tennis players, along with other overhead athletes, regularly produce high rotary forces at the shoulder in cervical spine and shoulder girdle positions (see previous section on biomechanics of altered cervical spine and abducted testing positions) which compress or stretch motor nerves to shoulder musculature.

Because of the prevalence of cervical radiculopathy in shoulder pathology,[80,81] there is rightfully a fair amount of research dedicated to determining the presence of cervical radiculopathy in shoulder pathology.[26,85,86] There is documented theory that proximal compression of nerve roots may disrupt axonal flow to distal structures, resulting in distal pathology.[87,88] This is supported by individuals with cervical spondolysis and radiculopathy at C5 and C6 - the primary shoulder myotomes - having a greater incidence of shoulder pathology.[89,90] With the presence of cervical radiculopathy in many cases of shoulder pathology,[80,81] cervical radiculopathy increasing incidence of shoulder pathology[89,90] and the incidence of shoulder injury in populations such as overhead athletes and manual trades workers that require use of their shoulders in altered cervical positions, there is reason to believe the functional cervical position during shoulder use may influence shoulder injury. This section summarizes how the spine influences shoulder function with an emphasis on pathology in injury prone populations and highlights that there is reason to believe postures placing nerve tissue on stretch or under compression may mimic radiculopathies, which could, in part, explain shoulder injury in overhead athletes and manual trades workers.

Effects of Cervicothoracic Spinal Manual Therapy on Shoulder Dysfunction

This section discusses the process and effects of spinal manual therapy on the shoulder. Manual therapy interventions are performed by many health professions including physical therapy, osteopathic medicine, chiropractic medicine and a few others. Joint mobilizations are a subset of manual therapy in which the therapist passively moves the joint, broken down into two large categories: osteokinematic and arthokinematic. Osteokinematic, or physiologic movements, are movements an individual can actively perform, such as flexion/extension, ab/adduction, and internal/external rotation Arthokinematic, or passive accessory, motions occur during osteokinematic motion at the joint level and consist of roll, glide and spin.[91] Arthrokinematic movements are typically based on the concave-convex rule,[92-94] which states if a concave surface is moving on a convex surface, the roll and glide of the bone will be in the same direction and if a convex surface is moving on a concave surface, the roll and glide of the bone will be in opposite directions (FIGURE 4).

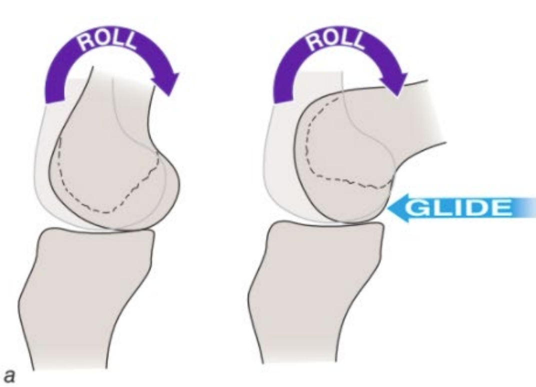


Figure 4. Concave-convex rule[2]

Mobilizations can be broken down into five grades, according to Maitland theory (FIGURE 5). Grade I involves low amplitude mobilizations not far from the resting position. Grade IV is a low amplitude mobilization up to end physiologic range. Grade V is a low amplitude, high velocity thrust that goes just beyond end physiologic range of the joint, staying within the anatomic limit.

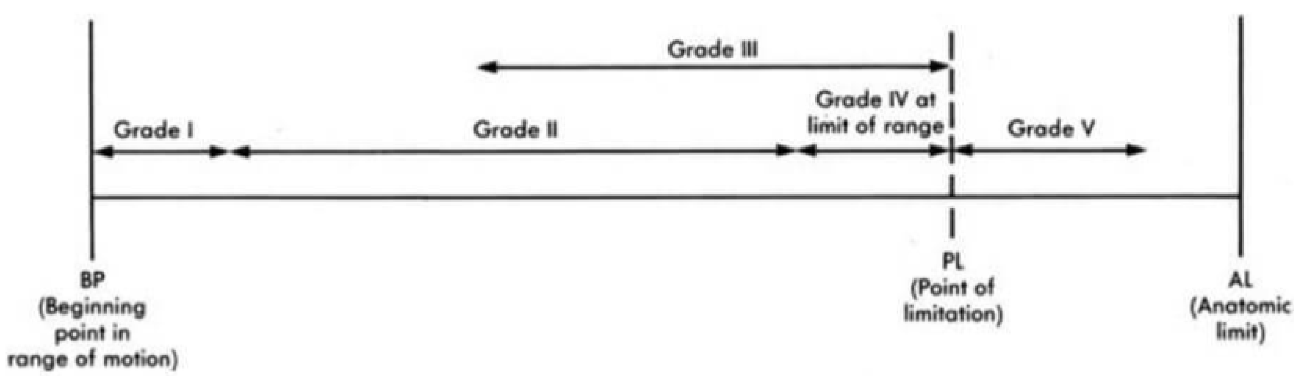


Figure 5. Maitland grades of mobilization[95]

Mobilization of the spine has shown to be effective at reducing spinal pain and increasing spinal range of motion.[12,13,96-98] Due to the compressive nature of cervical radiculopathy, increasing available range of motion may reduce the effects of the compression due to function occurring farther from the limits of motion. Due to the cervical etiology of many shoulder symptoms,[80,81] the ability of spinal mobilization to reduce cervical spine symptoms[99] may prove beneficial to many patients with shoulder pathology.

While sub-manipulation levels of mobilization have been effective at relieving symptoms,[96] spinal thrust manipulations have been shown to be superior in reducing spine and shoulder symptoms when compared to lower grade mobilizations[98,100,101] in some studies, and of equal effect in others.[102] Interestingly, furthering the points from the previous section on the cervical spine's influence on the shoulder, mobilization of an asymptomatic cervical spine has produced symptom relief and increased shoulder range of motion in patients with shoulder pain, with effects lasting through a five day follow-up.[103] Additionally, spinal manipulations increase both muscle activity and muscle strength,[104,105] even in healthy individuals, with a more forceful thrust resulting in greater muscle activation.[106,107] This is thought to be due to neuroexcitation, where the physical stimulus of the therapist to the spine excites central nervous tissue, resulting in increased afferent sympathetic output, causing hypoalgesia and strength increase.[104,108]

Evidence justifies the use of joint manipulations to both the cervical and thoracic spines in neck and shoulder treatment. There are established clinical prediction rules for the use of thoracic spine manipulations in the treatment of cervical spine pain.[109] While cervical spine manipulation proved superior to thoracic spine manipulation using these prediction rules,[110] there is efficacy in the use of thoracic and cervicothoracic junction manipulation, particularly in less skillful manual therapists, due to the increased risk of injury in cervical spine manipulation.[111,112]

Therapists opting for thoracic manipulation still have positive treatment outcomes for patients with cervical spine disorders,[12,98,109] including radiculopathy, with effects lasting through a two-to-three day follow-up compared to sham manipulation.[12] Further, including manipulation of the thoracic and cervicothoracic spines proved superior to manipulation of the cervical spine alone for cervical spine outcomes.[97]

Not only does spinal manipulation have the potential to indirectly improve shoulder dysfunction through addressing cervical impairments, but evidence directly supports its use in shoulder pathology. Limited shoulder flexion and internal rotation, a negative Neer test, not taking pain medication and symptoms under 90° of shoulder elevation were all positive predictors of cervicothoracic manipulation improving shoulder outcomes[113] in individuals with shoulder pain. Thoracic manipulation resulted in decreased shoulder pain, improved shoulder range of motion and patient reported function in patients with a primary complaint of shoulder pain.[114] In patients with shoulder impingement, a syndrome common to overhead athletes and trades workers, thoracic manipulation improved symptoms through a 48-hour follow-up.[115] Further, when spinal manipulation was implemented in shoulder rehabilitation in addition to standard treatment, patients receiving spinal manipulation as part of their treatment had better outcomes than traditional treatment alone at a one-year follow-up.[116]

This section summarizes the uses of spinal manual therapy in treatment. It defines commonly used therapist terminology, and when different forms of mobilization have use. The literature shows positive effects of spinal manipulative therapy to both the cervical and thoracic spines on treatment of the cervical spine and shoulder.

Summary

This chapter reviews the anatomy and biomechanics of the neck and shoulder, and how they are affected by bilateral cervical rotation and elevating the humerus to 90° for the testing position. The testing positions are compared to functional positions of populations prone to shoulder injury, such as overhead athletes and manual trades workers. For example, a baseball pitcher, to look at home plate during his follow-through must have his cervical spine ipsilaterally side bent and rotated, and extended. An electrician working overhead will have his neck in a similar position. This combination of movements results in shrinking the intervertebral foramen from which the spinal nerve exits, resulting in potential compression.[26] Any overhead athlete, during the cocking phase, has his head contralaterally rotated, placing the nerve roots on stretch, with his humerus abducted and in external rotation, likely with scapular elevation, all factors that may lead to neural compression along the thoracic outlet.[50] Typically, shoulder rotation strength is tested in a neutral cervical position, and only recently has investigation indicated decreased strength in altered cervical positions during testing (Giordano, unpublished). Clinicians should be aware that patients in populations prone to shoulder injury may be symptomatic in their functional cervical spine positions even if test results are negative in a neutral cervical spine position.

Furthering this theoretical basis for why functional positioning of overhead athletes and manual trades workers may place them at increased risk of shoulder injury is evidence in the literature for the cervical spine's influence in shoulder pathology.[74,76,80,81] Shoulder dysfunction is a common sign of cervical radiculopathy.[89,90] Additionally, underlying cervical nerve root compression has been discovered in 30-35% of common shoulder injuries, such as impingement and rotator cuff weakness.[80,81] With the known impact of cervical nerve root compression on shoulder function and the compression and tension biomechanically placed on neural tissue by overhead athletes and trades workers, there is reason to believe that positioning of the cervical spine and shoulder girdle may be mimicking symptoms of cervical radiculopathy and thoracic outlet syndrome. Furthermore, imitating these altered cervical and shoulder positions during strength testing may elucidate mechanisms of shoulder dysfunction and injury in overhead athletes and trades workers.

Spinal manipulation may be able to mitigate some of the effects of altered cervical and shoulder positioning on shoulder rotation strength. Because spinal manipulation increases range of motion of the cervical spine,[12,13,96-98] the rotated cervical positions overhead athletes and trades workers must operate under may be further from end range, potentially alleviating compression on nerve roots. There is also thought to be an afferent neuroexcitatory component to spinal manipulation[104,108] that may counteract some of the deleterious effects of nerve tension and compression resultant of altered cervical and shoulder positions. Consequently, spinal manipulation may mediate the outcomes of strength and muscle activation in altered cervical spine positions.

Chapter III

Methods

The purpose of this study was to examine the effects of cervical positioning and thoracic and cervicothoracic junction manipulations on shoulder internal and external rotation strength in healthy, young adults. This chapter discusses the methodology to achieve this research goal.

Experimental approach to the problem

Participants will have shoulder internal and external rotation strength tested seated in an isokinetic dynamometer. With the shoulder abducted in the frontal plane, participants will have isokinetic strength tested through a 90° arc from the forearm traveling from the frontal plane to the transverse plane, moving in the sagittal plane. In this shoulder position, strength will be tested with the cervical spine in neutral and with the cervical spine maximally rotated away from the testing side. The same procedure will be performed with the humerus elevated 45° anterior to the frontal plane with the cervical spine in neutral and with the cervical spine maximally rotated towards the working side. The order will be randomized. Participants will then receive either a manipulation to the thoracic and cervicothoracic spine or a sham manipulation to the same area. Testing procedures will be repeated following the treatment and again, 30 minutes following the treatment. Between the second and third tests, participants will pedal an arm ergometer to keep their upper extremities and postural muscles warm.

Participants

Fifty-two participants (18 Male, 32 Female, 170±10 cm, 73±18 kg, seven left-hand dominant) were recruited to participate. Using the effect size from data from a similar study (Giordano, unpublished), α set *a priori* at 0.05, power of β = 0,80, 22.9 participants, rounding up to 23 per group are required (calculated in RStudio). Participants will be between the ages of 18-

35 and at least recreationally active (30+ minutes of exercise most days of the week). Exclusion criteria will be an injury to the dominant shoulder or spine in the last six months, current pain in the shoulder or spine, surgery to the dominant upper extremity in the past 12 months, and any history of major cervical or thoracic spine surgery. Prior to collection, participants will be randomly assigned to either a spinal manipulation group (n = 26) or control group (sham manipulation; n = 26).

Participants were recruited through the university through emails (Appendix A), flyers (Appendix B), SONA (Auburn University College of Education program to find research participants), and instructors verbally advertising to their respective classes. The Institutional Review Board approved all testing protocols. Prior to testing, all procedures will be explained to the participant, who verbally acknowledged understanding before signing the informed consent. (Appendix C).

Setting

All testing protocols were performed in the Auburn University School of Kinesiology Building room 260 by members of the Sports Medicine and Movement Laboratory.

Instrumentation

Isokinetic Strength

Shoulder internal and external rotation concentric isokinetic strength will be measured using a Biodex Isokinetic Dynamometer (System 4 Pro, BioDex Medical Systems, Shirley, NY, USA). The Biodex Isokinetic Dynamometer has shown to be reliable for isokinetic internal and external rotation in both the frontal and scapular planes.[117,118] Maximum torque readings will be extracted and included in a multilevel model analysis. Torque readings throughout the entire trial will be extracted to be compared in a statistical parametric mapping analysis.

Procedures

Participants wore loose-fitting athletic top for testing. Upon arrival, participants were verbally asked to verify they did not meet any of the exclusion criteria. The primary investigator presented the informed consent, verbally summarized it, and obtained written consent from participants.

Following consent, participants were taken through a standardized warm up, which consisted of two cycles of the following: 10 small (20cm diameter) arm circles forward then backward, 10 big (1m diameter) arm circles forward then backward, 10 oscillations of shoulder ab/adduction, 10 oscillations of shoulder horizontal ab/adduction, 10 oscillations of shoulder internal and external rotation with the humerus abducted to 90°, and 10 “snow angels” (full range of motion abduction and adduction while maintaining scapular retraction and vertically oriented forearms).

When the participant was warm, they were familiarized with the isokinetic dynamometer. Participants were allowed as many practice trials as it took to become comfortable with the isokinetic nature of the test. When participants deemed themselves ready, they performed two continuous repetitions of isokinetic concentric shoulder internal and external rotation in the following testing positions: seated with the shoulder abducted 90° in the frontal plane with the cervical spine in neutral (FIGURE 6),[119,120] seated with the shoulder abducted 90° in the frontal plane with the cervical spine maximally rotated away from the dominant shoulder (FIGURE 7), seated with the shoulder elevated 90° in the scapular plane (45° anterior to the frontal plane) with the cervical spine in neutral (FIGURE 8),[119,120] and seated with the shoulder elevated to 90° in the scapular plane with the cervical spine maximally rotated towards the dominant shoulder (FIGURE 9). Testing order of positions was randomized for each participant to minimize the potential for fatigue to unevenly impact testing position. The isokinetic dynamometer was set at 60°/s for an arc of 90° (forearm vertical to forearm horizontal). There was a 90-second rest between trials for each cervical position and a short (roughly three minute) wait between humerus positions to allow for recalibration of the dynamometer.

Figure 6. Neutral cervical spine, humerus in frontal plane

Figure 7. Cervical spine in max contralateral rotation with humerus in frontal plane

Figure 8. Cervical spine in neutral with humerus in scapular plane

Figure 9. Ipsilaterally rotated cervical spine with humerus in scapular plane

Following testing, participants received either a thrust spinal manipulation to the upper thoracic spine and cervicothoracic junction (FIGURES 10 & 11), by a licensed physical therapist, or a sham manipulation. The thoracic manipulation required participants to lie supine and link their hands behind their neck with their elbows pointing up. The therapist then positioned his partially closed fist on the participant's back, with the participant's spinous processes running between the therapist's distal phalanges and thenar eminence. The therapist created spinal flexion with his contralateral arm by applying pressure to the participant's forearms. A thrust was then given straight down, manipulating the vertebrae just above the therapist's hand. The sham thoracic manipulation differed from the thrust manipulation in that no thrust was given and the therapist's hand was open, rather than the closed fist with the participant's spinal processes running between the thenar eminence and fingertips. The cervicothoracic manipulation required participants to sit on the edge of the plinth with their hands linked behind their head. The therapist then ran his arms through the openings created by the head, upper arms and forearms to the back of the participant's neck. The therapist then instructed the participant to bring their hands down to where the therapist's were (the therapist picked his hands up off the back of the neck to not apply a lever-like pressure to the back of the participant's neck). A quick thrust with the legs in the vertical direction was given, applying force to the participant through their upper arms. The sham cervicothoracic manipulation was identical to the thrust manipulation with the lone exception of no thrust given.

Figure 10. Thoracic manipulation

Figure 11. Cervicothoracic junction manipulation

Following manipulation or sham manipulation, an identical isokinetic testing protocol was repeated immediately following treatment, and then again, 30 minutes following treatment. During the wait between testing sessions two and three, participants pedaled an upper body ergometer at a comfortable pace to keep warm. Where laboratory based manual therapy studies often find very minimal duration in improvements,[121] this may be due to participants' lack of activity and posture between follow-up testing sessions. In a clinical setting, after receiving manual treatment, patients typically perform therapeutic exercises to capitalize on gains made from manual intervention. This arm bike intervention aimed to mitigate this diminishing effect.

Data Cleaning and Analysis

Isokinetic dynamometry data was collected at 100 Hz. The second of two repetitions was analyzed to allow adjustment to the test, and so all analyzed directions were continued from the opposite direction (rather than analyzing external rotation from rest then internal rotation following external rotation). Peak torque was identified using MATLAB Version R2020a (MathWorks; Natick, MA, USA) for statistical analysis.

To compare all independent variables affecting strength, two multilevel models were implemented for both internal and external rotation. The lowest level of variables included cervical spine position (neutral, contralaterally rotated, ipsilaterally rotated) and time (pre, post and 30 minute follow-up). Both level one variables were treated as fixed effects to discretely determine their effects as categorical variables. Level two variables included individual, sex and treatment group (manipulation vs. sham). Sex and treatment group were treated as fixed effects, as no other variables will impact a participant's sex or group assignment. A summary of variables can be found in TABLE 1. The first model analyzed strength with the humerus in the frontal plane between the cervical spine in neutral and rotated away from the testing arm; the second analyzed strength in the scapular plane with the cervical spine in neutral and rotated towards the testing side. No comparison was made between humeral positions due to the proposed etiology of the deficits created by the cervical position being different in either direction resulting in no meaningful conclusions to be drawn. All model analysis was performed in R Studio (Version 3.6.1; RStudio Inc., Boston, MA, USA).

Table 1. Summary of Variables

Variable Name	Category	Description
Shoulder External Rotation Strength	Dependent; numeric, ratio	Measured in Newtons
Shoulder Internal rotation Strength	Dependent; numeric, ratio	Measured in Newtons
Group	Categorical; nominal. Level 2 fixed effect	Randomly assigned into spinal manipulation and sham manipulation (control)
Cervical Spine Position	Categorical; nominal. Level 1 fixed effect.	Neutral, rotated towards the working side, or rotated away from the working side
Time	Categorical; ordinal. Level 1 fixed effect	Baseline (pre), immediately post intervention and 30 minutes following intervention
Sex	Categorical; nominal. Level 2 fixed effect	Male and Female
Individual	Categorical; nominal. Level 2 fixed effect	Each individual participant

To perform bivariate strength comparisons across different cervical testing positions and within testing position over time, statistical parametric mapping was implemented.[122] This technique allows data from the entire arc of motion to be compared to another arc and check for differences in the wave form.[123,124] This procedure compared data across the entire trial between positions using raw data from the isokinetic dynamometer. All parametric mapping analyses were performed in MATLAB Version R2020a (MathWorks; Natick, MA, USA). The alpha level as set *a priori* at 0.05.

Chapter IV

Results

The purpose of this study was to examine the effects of cervical positioning and thoracic and cervicothoracic junction manipulations on shoulder internal and external rotation strength in healthy, young adults. This chapter outlines and describes the results of this study to each of the following research questions, respectively.

RQ1) Does cervical positioning affect shoulder external rotation strength?

RQ2) Does cervical positioning affect shoulder internal rotation strength?

RQ3) Do spinal manipulations to the thoracic spine and cervicothoracic junction affect shoulder external rotation strength from pre to post manipulation and to a 30-minute follow-up?

RQ4) Do spinal manipulations to the thoracic spine and cervicothoracic junction affect shoulder internal rotation strength from pre to post manipulation and to a 30-minute follow-up?

RQ5) Do spinal manipulations moderate the effect of cervical position on shoulder external rotation strength from pre to post manipulation and to a 30-minute follow-up?

RQ6) Do spinal manipulations moderate the effect of cervical position on shoulder internal rotation strength from pre to post manipulation and to a 30-minute follow-up?

A summary of descriptive statistics of peak shoulder rotation strength can be found below in TABLE 2.

	Frontal Plane Neutral	Frontal Plane Away	Scapular Plane Neutral	Scapular Plane Toward
	External Rotation Strength (Nm)			
Pre	26.74 ± 10.02	25.59 ± 10.85	24.30 ± 9.01	22.64 ± 8.99
Post	25.22 ± 9.44	24.73 ± 9.06	22.34 ± 8.52	19.98 ± 8.83
30-minute Follow-up	24.68 ± 9.49	23.18 ± 8.81	21.54 ± 8.60	19.64 ± 8.32
	Internal Rotation Strength (Nm)			
Pre	42.53 ± 12.48	41.07 ± 11.88	41.90 ± 12.65	37.79 ± 13.53
Post	39.81 ± 10.94	38.62 ± 10.69	38.89 ± 11.64	37.18 ± 11.24
30-minute Follow-up	40.02 ± 12.55	38.32 ± 11.06	38.02 ± 10.91	36.63 ± 11.29

RQ1) Does cervical positioning affect shoulder external rotation strength?

Results from two multilevel linear regression models and two statistical parametric mapping analyses contributed to answering this question. The analyses examined differences between a neutral cervical spine and a maximally rotated cervical spine contralateral to the working shoulder in the frontal plane, and maximally rotated cervical spine ipsilateral to the working shoulder in the scapular plane. Peak strength for external rotation at each time point can be found in FIGURES 12 & 13.

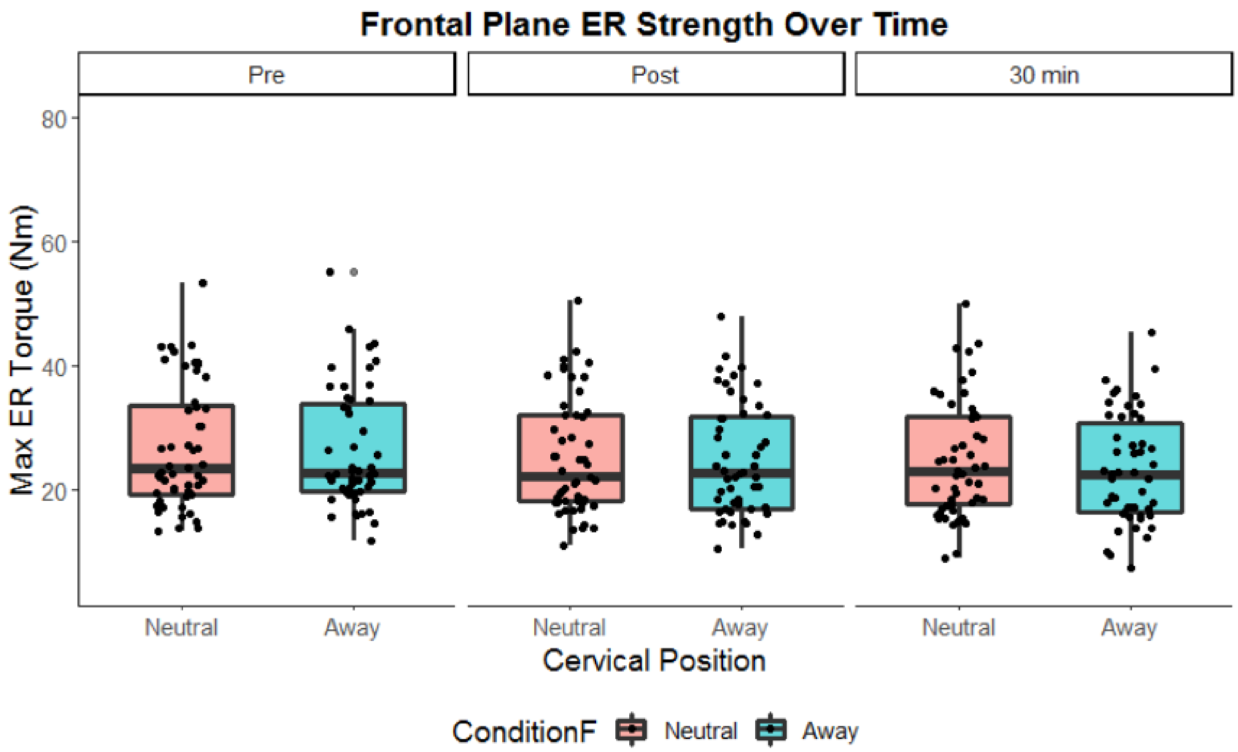


Figure 12. External Rotation Peak Strength in the Frontal Plane

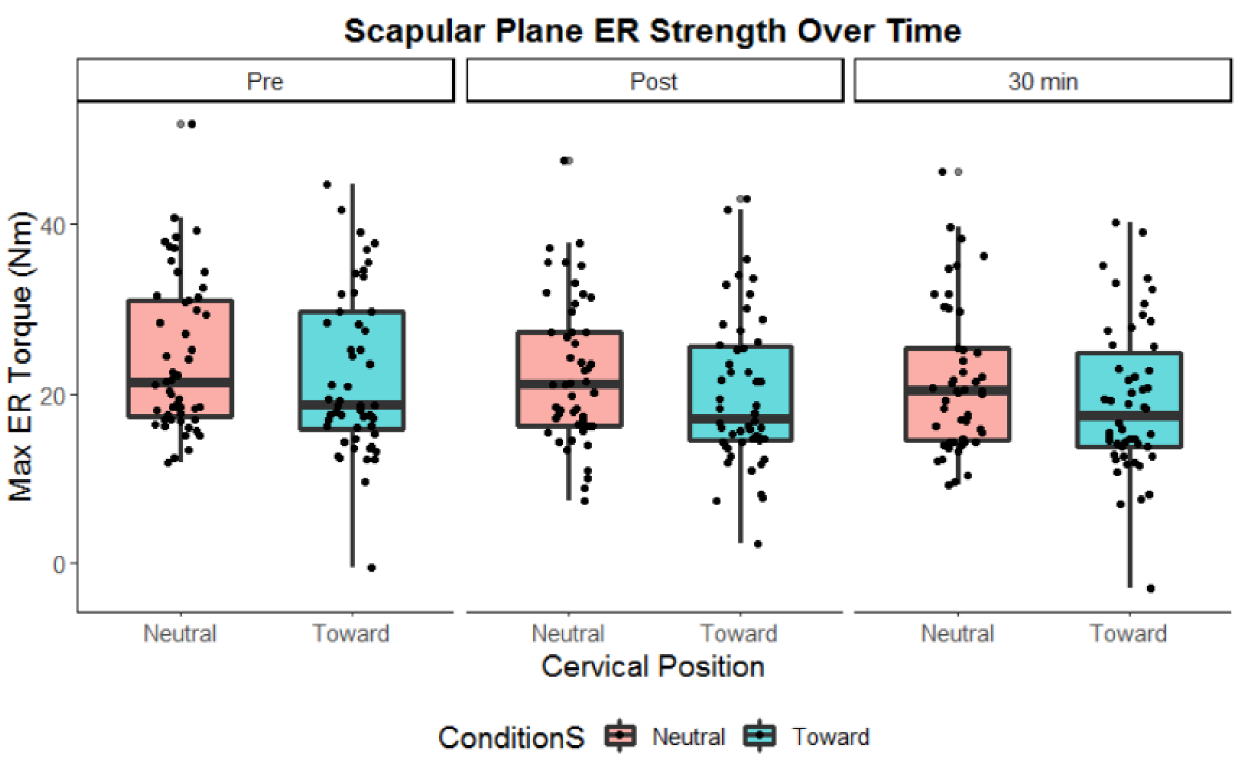


Figure 13. External Rotation Peak Strength in the Scapular Plane

Adding level 1 explanatory variables (cervical position and time) to the intercept only model (individual participants) significantly improved the model by reducing the Akaike information criterion (AIC) and individual variance in both the frontal and scapular planes in both the model for the frontal plane and scapular plane (TABLES 3 & 4). Further, when adding sex as a level two explanatory variable to reduce variance across individuals, cervical position remained an indicator of shoulder external rotation strength. Specifically, cervical spine rotation contralateral to the working arm side in the frontal plane resulted in a small, but significant decrease in external rotation strength (TABLE 3), and cervical spine rotation ipsilateral to the working arm side in the scapular plane resulted in a decrease in external rotation strength about twice that of in the frontal plane (TABLE 4).

Table 3. Frontal Plane Peak External Rotation Strength Model Summaries

	Intercept-only	**Level 1 Explanatory**	**Level 2 Explanatory**
(Intercept)	25.13***	26.69***	20.88***
	(1.28)	(1.31)	(0.84)
Away Cervical Spine Position		-1.04**	-1.04**
		(0.32)	(0.32)
Post Time Point		-0.99*	-0.98*
		(0.39)	(0.39)
30-minute Follow-up		-2.23***	-2.22***
		(0.39)	(0.39)
Male Sex			16.77***
			(1.36)
AIC	1758.25	1724.67	1655.27
BIC	1769.42	1747.01	1681.33
Log Likelihood	-876.12	-856.34	-820.63
Var: Between Subjects	83.83	83.84	20.28
Var: Within Subjects	9.10	7.79	7.79

Coefficient estimates and (standard errors) for each variable. * denotes statistical significance p < .05; ** p < .01; *** p < .001

Coefficient estimates in reference to neutral head position, pre time point, female sex

.

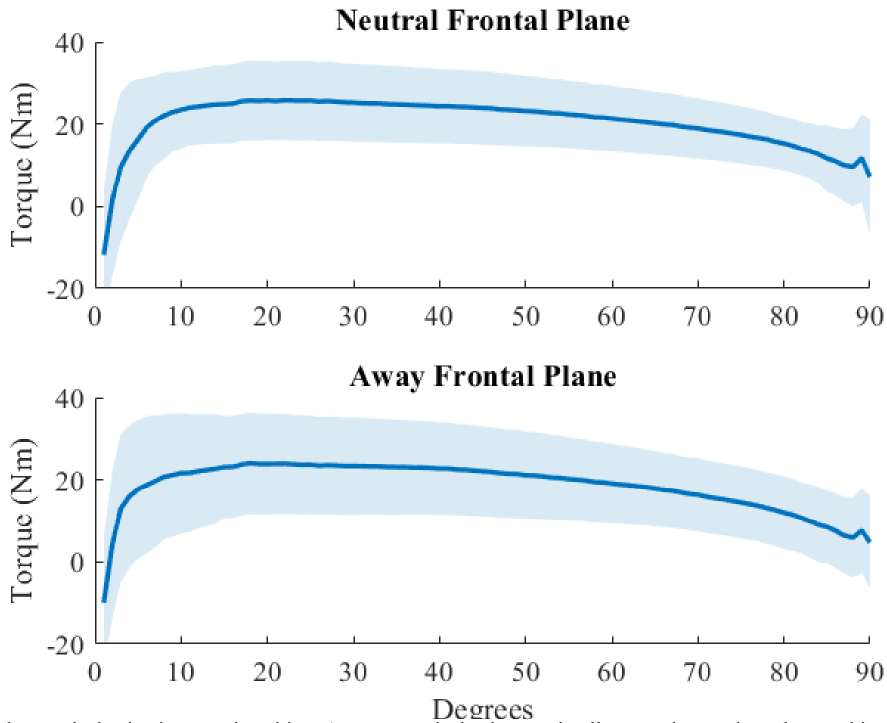
Table 4. Scapular Plane Peak External Rotation Strength Model Summaries

	Intercept-only	**Level 1 Explanatory**	**Level 2 Explanatory**
(Intercept)	21.79***	24.38***	19.14***
	(1.18)	(1.21)	(0.81)
Toward Cervical Spine Position		-2.27***	-2.27***
		(0.35)	(0.35)
Post Time Point		-1.80***	-1.81***
		(0.43)	(0.43)
30-minute Follow-up		-2.68***	-2.69***
		(0.43)	(0.43)
Male Sex			15.14***
			(1.28)
AIC	1826.95	1761.14	1695.21
BIC	1838.12	1783.49	1721.28
Log Likelihood	-910.48	-874.57	-840.61
Var: Between Subjects	69.83	69.69	17.71
Var: Within Subjects	12.35	9.33	9.33

Coefficient estimates and (standard errors) for each variable. * denotes statistical significance p < .05; ** p < .01; *** p < .001

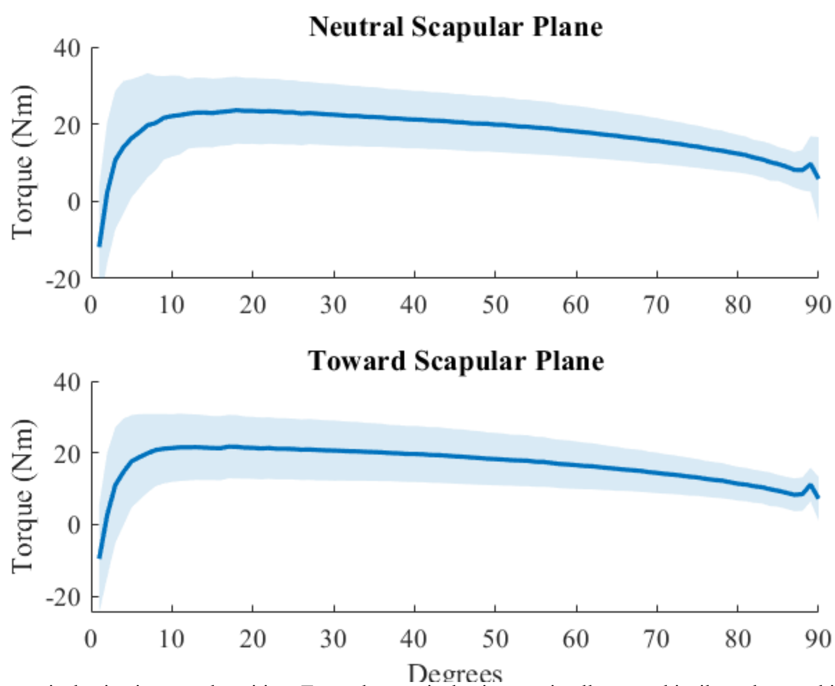
Coefficient estimates in reference to neutral head position, pre time point, female sex.

Parametric mapping analysis revealed significant differences between shoulder external rotation strength in the frontal plane with a neutral cervical spine and a contralaterally rotated cervical spine (df =1,49, F = 16.2, p < 0.001); and in the scapular plane between a neutral cervical spine and ipsilaterally rotated cervical spine (df = 1,48, F = 9.98, p < 0.001) . The distribution of strength values throughout the arc of motion can be found in FIGURES 14 and 15. The statistical parametric mapping results comparing the differences between the two cervical spine positions can be found in FIGURE 16 and 17.



Neutral = cervical spine in neutral position, Away = cervical spine maximally rotated contralateral to working arm side.

Figure 14. Frontal Plane External Rotation Strength



Neutral = cervical spine in neutral position, Toward = cervical spine maximally rotated ipsilateral to working arm side.

Figure 15. Scapular Plane External Rotation Strength

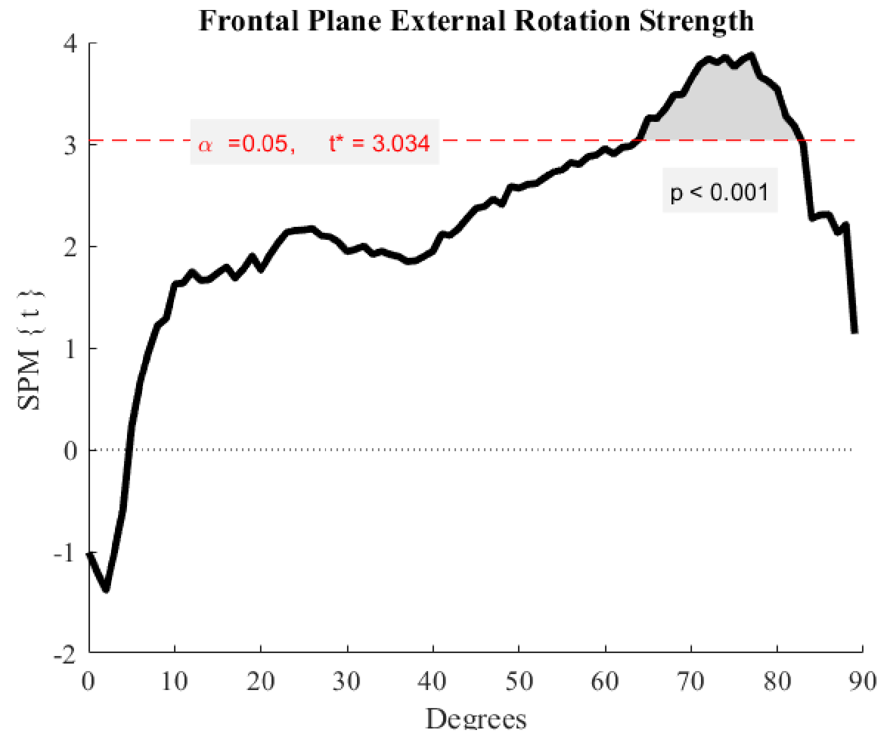


Figure 16. Statistical Parametric Mapping Analysis for Frontal Plane External Rotation Strength

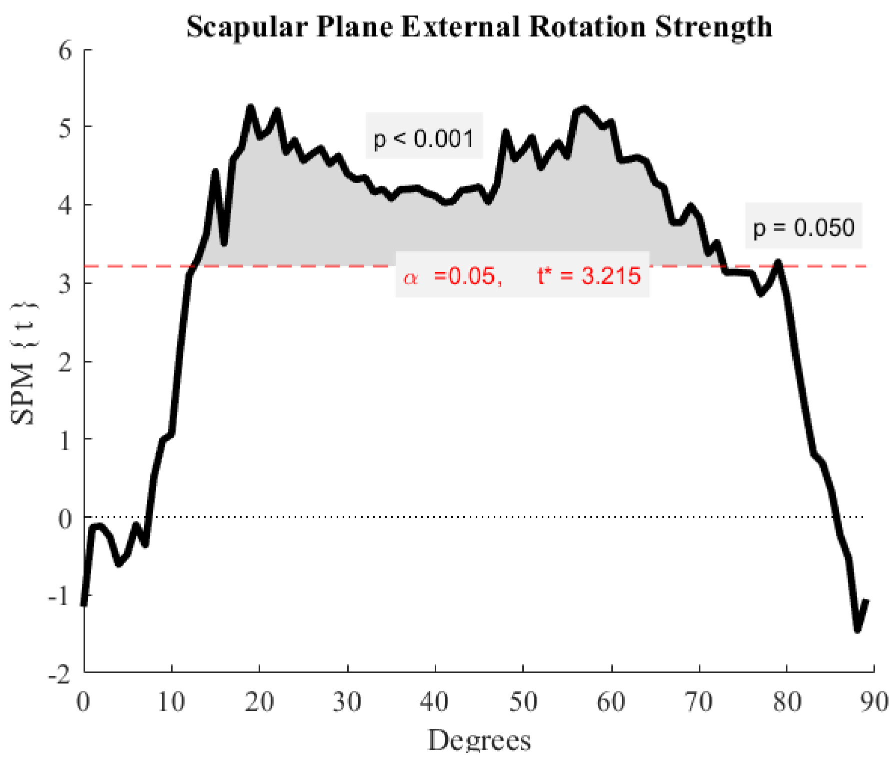


Figure 17. Statistical Parametric Mapping Analysis of Scapular Plane External Rotation Strength

RQ2) Does cervical positioning affect shoulder internal rotation strength?

Results from two multilevel linear regression models and two statistical parametric mapping analyses contributed to answering this question. The analyses examined differences between a neutral cervical spine and a maximally rotated cervical spine contralateral to the working shoulder in the frontal plane, and maximally rotated cervical spine ipsilateral to the working shoulder in the scapular plane. Peak strength for internal rotation at each time point can be found in FIGURES 18 & 19.

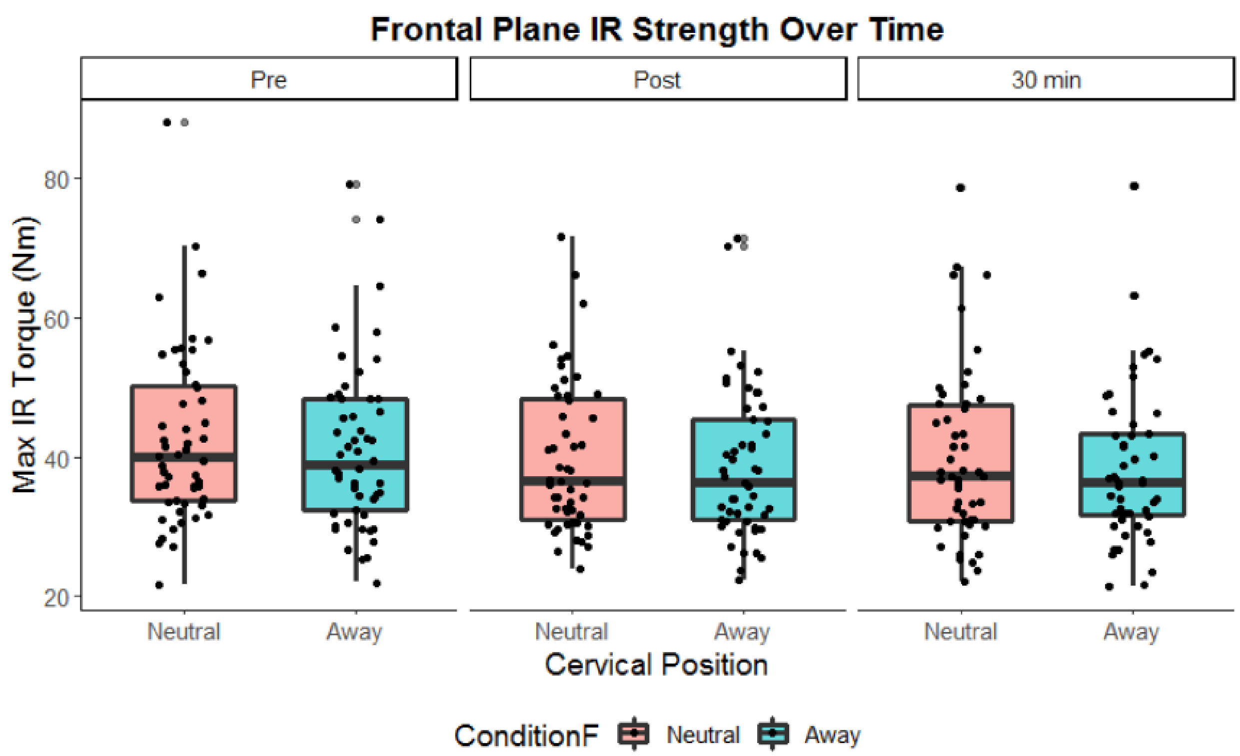


Figure 18. Frontal Plane Internal Rotation Peak Strength

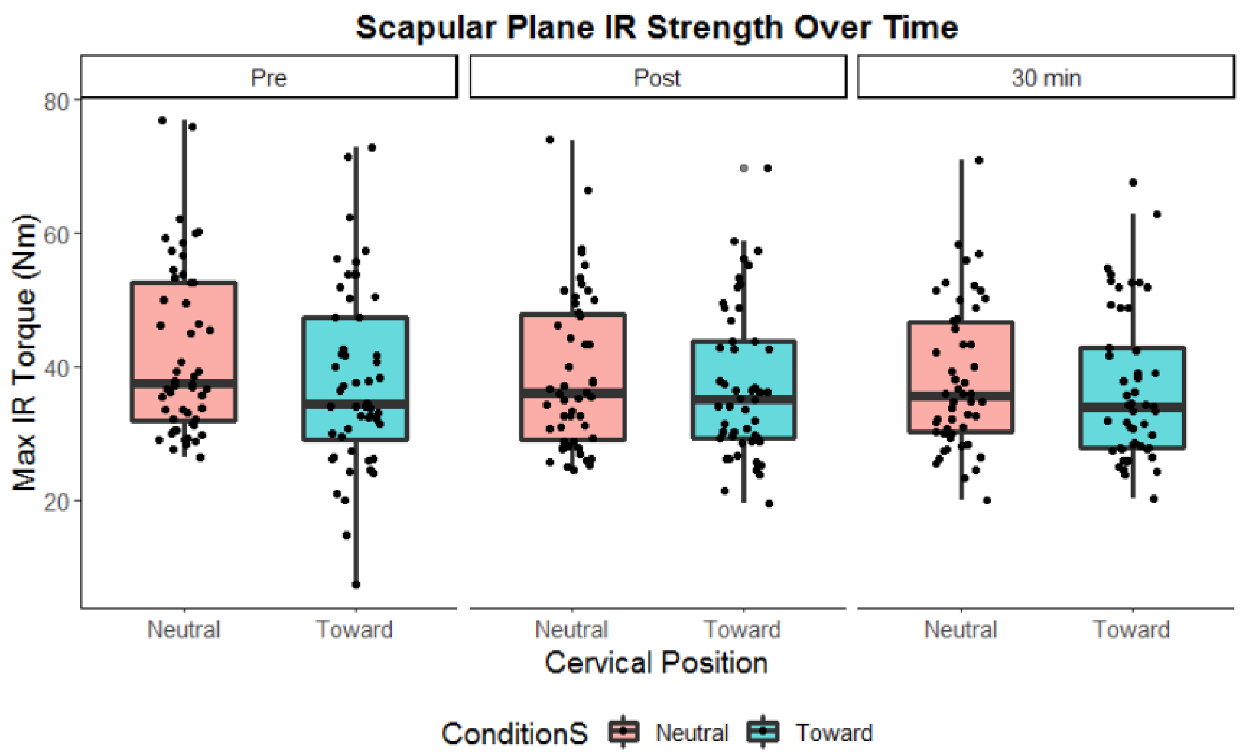


Figure 19. Scapular Plane Internal Rotation Peak Strength

Adding level 1 explanatory variables (cervical position and time) to the intercept only model (individual participants) significantly improved the model by reducing the AIC and individual variance in both the frontal and scapular planes in both the model for the frontal plane and scapular plane (TABLES 5 & 6). Further, when adding sex as a level two explanatory variable to reduce variance across individuals, cervical position remained an indicator of shoulder external rotation strength. Specifically, cervical spine rotation contralateral to the working arm side in the frontal plane resulted in a small, but significant decrease in internal rotation strength (TABLE 5), and cervical spine rotation ipsilateral to the working arm side in the scapular plane, likewise resulted in a small decrease in internal rotation strength (TABLE 6).

Table 5. Frontal Plane Peak Internal Rotation Strength Model Summaries

	Intercept-only	Level 1 Explanatory	Level 2 Explanatory
(Intercept)	40.13***	42.52***	36.04***
	(1.52)	(1.57)	(1.16)
Away Cervical Spine Position		-1.45**	-1.45**
		(0.44)	(0.44)
Post Time Point		-2.40***	-2.38***
		(0.54)	(0.54)
30-minute Follow-up		-2.73***	-2.70***
		(0.55)	(0.55)
Male Sex			18.73***
			(1.87)
AIC	1942.97	1911.53	1857.67
BIC	1954.14	1933.87	1883.73
Log Likelihood	-968.49	-949.76	-921.83
Var: Between Subjects	117.71	117.76	38.54
Var: Within Subjects	17.54	15.15	15.14

Coefficient estimates and (standard errors) for each variable. * denotes statistical significance $p < .05$; ** $p < .01$; *** $p < .001$

Coefficient estimates in reference to neutral head position, pre time point, female sex.

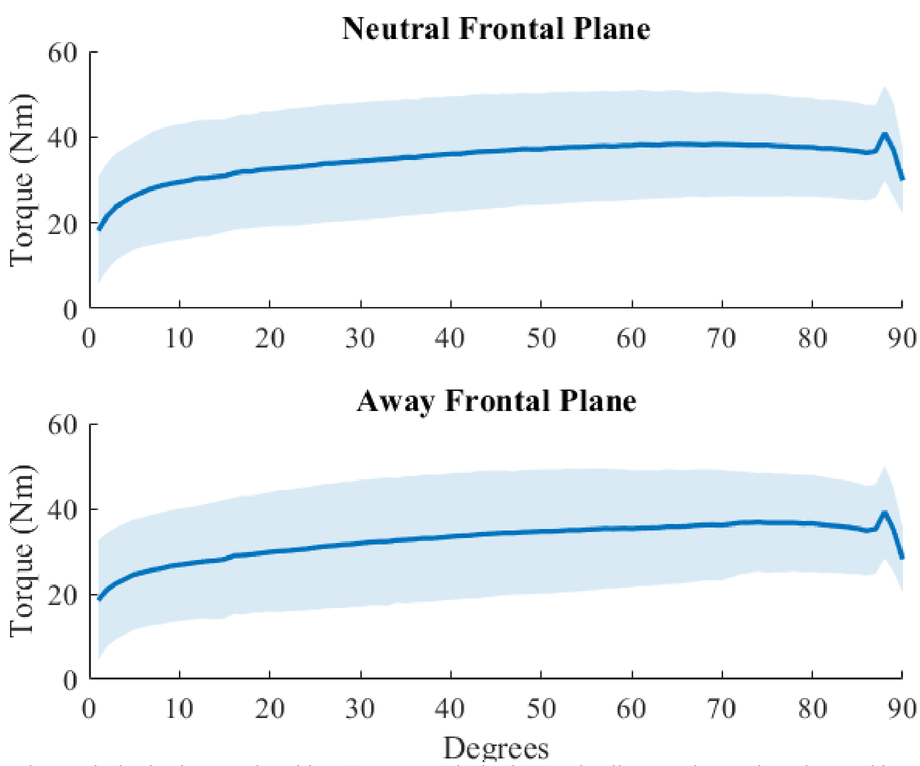
Table 6. Scapular Plane Peak Internal Rotation Strength Model Summaries

	Intercept-only	Level 1 Explanatory	Level 2 Explanatory
(Intercept)	38.44***	41.06***	37.84***
	(0.99)	(1.42)	(1.40)
Toward Cervical Spine Position		-2.42*	-2.42*
		(1.18)	(1.18)
Post Time Point		-1.75	-1.68
		(1.44)	(1.44)
30-minute Follow-up		-2.54	-2.48
		(1.45)	(1.45)
Male Sex			9.29***
			(1.66)
AIC	2364.54	2363.22	2340.48
BIC	2375.71	2385.56	2366.55
Log Likelihood	-1179.27	-1175.61	-1163.24
Var: Between Subjects	32.43	32.90	13.84
Var: Within Subjects	109.85	106.76	106.56

Coefficient estimates and (standard errors) for each variable. * denotes statistical significance $p < .05$; ** $p < .01$; *** $p < .001$

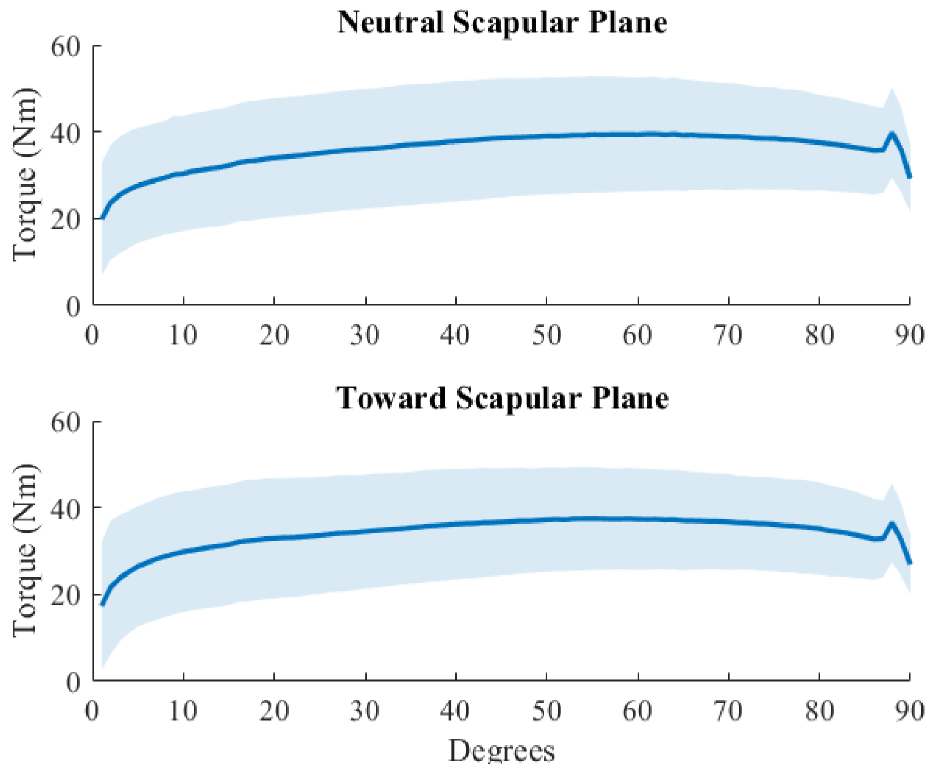
Coefficient estimates in reference to neutral head position, pre time point, female sex.

Parametric mapping analysis revealed significant differences between shoulder internal rotation strength in the frontal plane between a neutral cervical spine and a contralaterally rotated cervical spine (df =1,49, F = 15.2, p = 0.023); and in the scapular plane between a neutral cervical spine and ipsilaterally rotated cervical spine (df = 1,49, F = 12.8, p < 0.001) . The distribution of strength values throughout the arc of motion can be found in FIGURES 20 and 21. The statistical parametric mapping results comparing the differences between the two cervical spine positions can be found in FIGURES 22 and 23.



Neutral = cervical spine in neutral position, Away = cervical spine maximally rotated contralateral to working arm side.

Figure 20. Frontal Plane Internal Rotation Strength



Neutral = cervical spine in neutral position, Toward = cervical spine maximally rotated ipsilateral to working arm side.

Figure 21. Scapular Plane Internal Rotation Strength

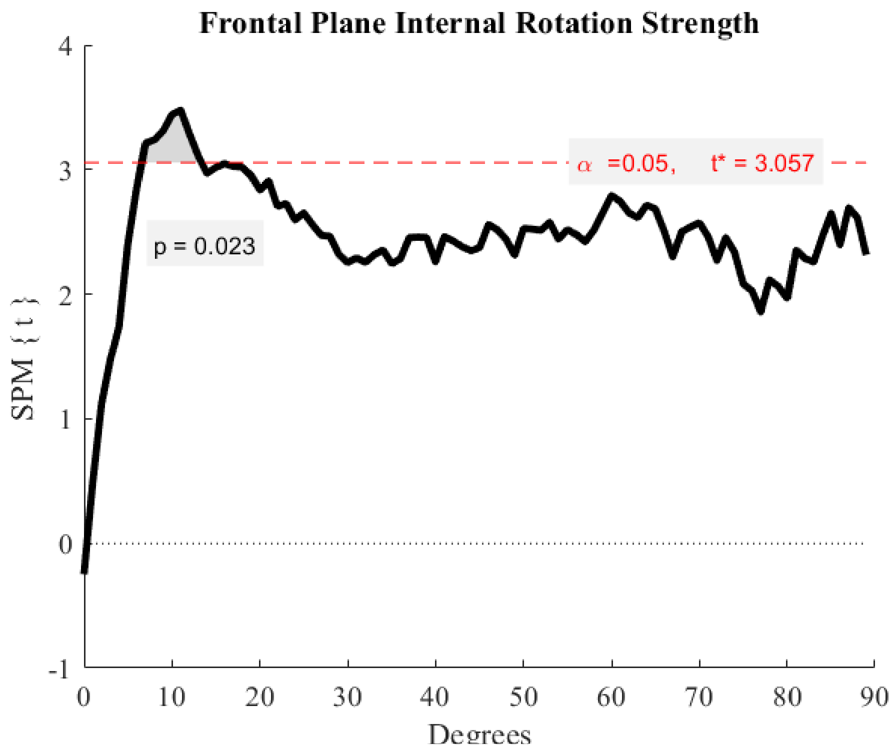


Figure 22. Statistical Parametric Mapping Analysis for Frontal Plane Internal Rotation Strength

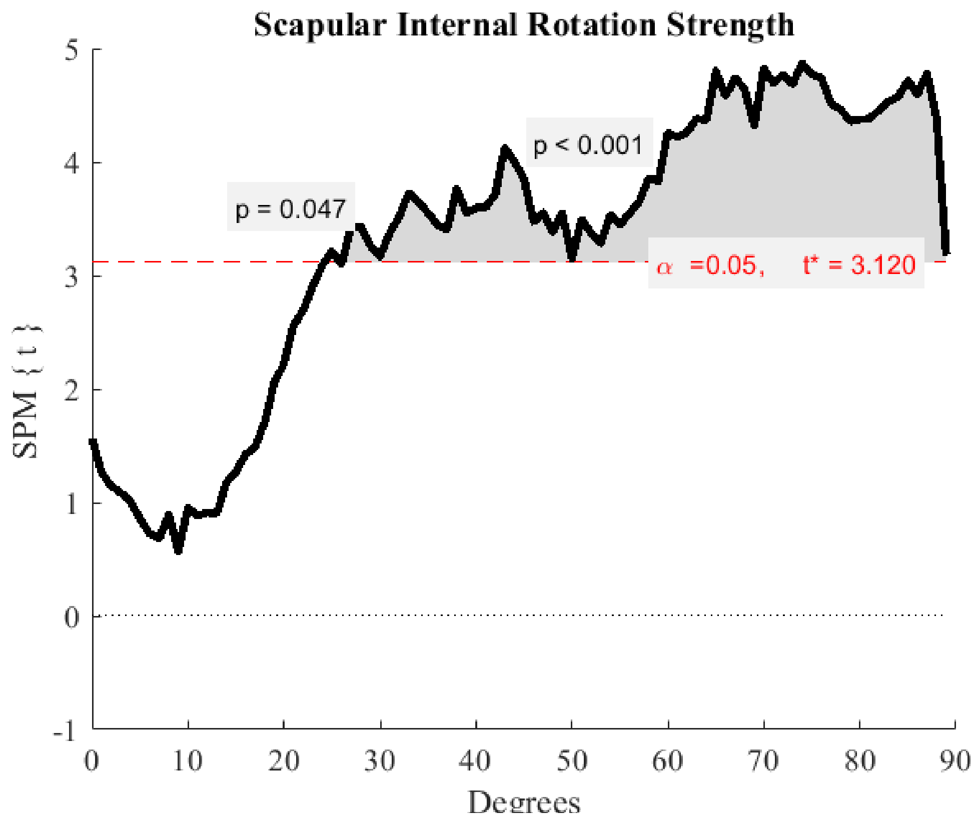


Figure 23. Statistical Parametric Mapping Analysis for Scapular Plane Internal Rotation Strength

RQ3) Do spinal manipulations to the thoracic spine and cervicothoracic junction affect shoulder external rotation strength from pre to post manipulation and to a 30-minute follow-up?

To answer this question, two multilevel regression models – one for the frontal plane and one for the scapular plane – were employed. These models examined peak external rotation strength between a spinal manipulation group and a sham manipulation group across three time points (pre, post and 30-minute follow-up). Peak strength values are displayed in FIGURE 24 for the frontal plane and FIGURE 25 for the scapular plane.

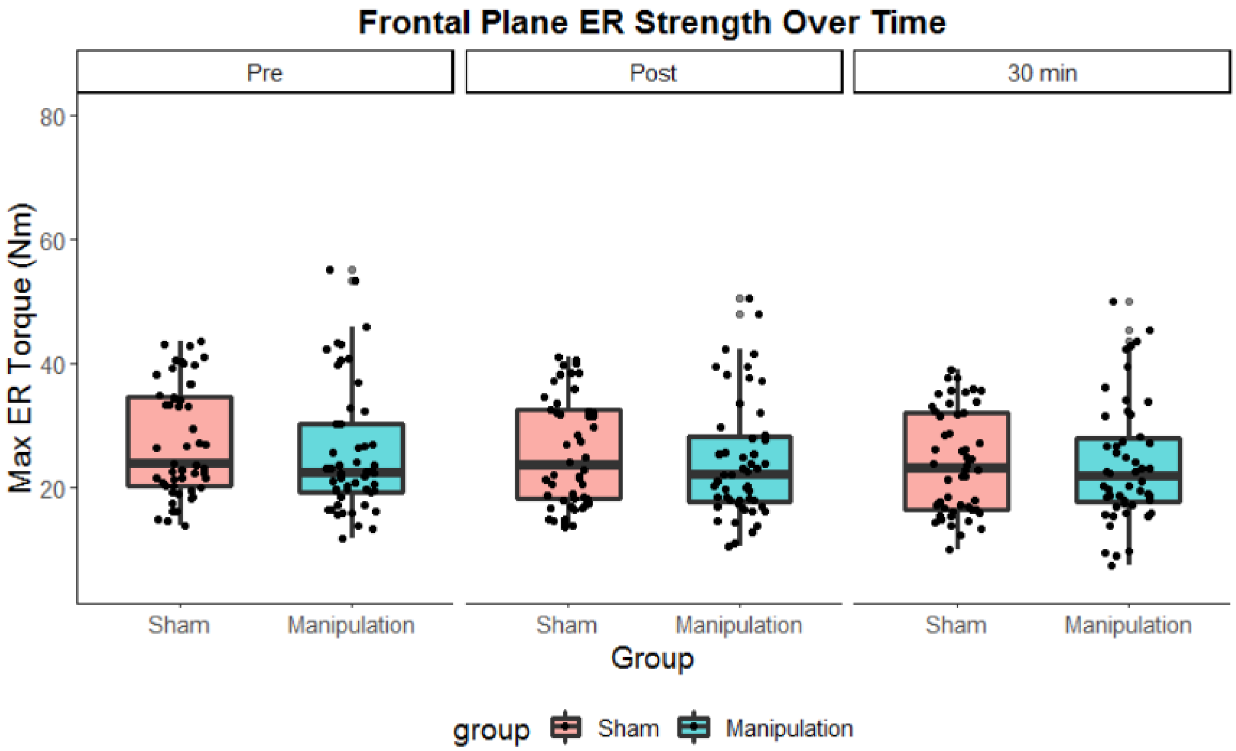


Figure 24. Frontal Plane External Rotation Peak Strength by Group

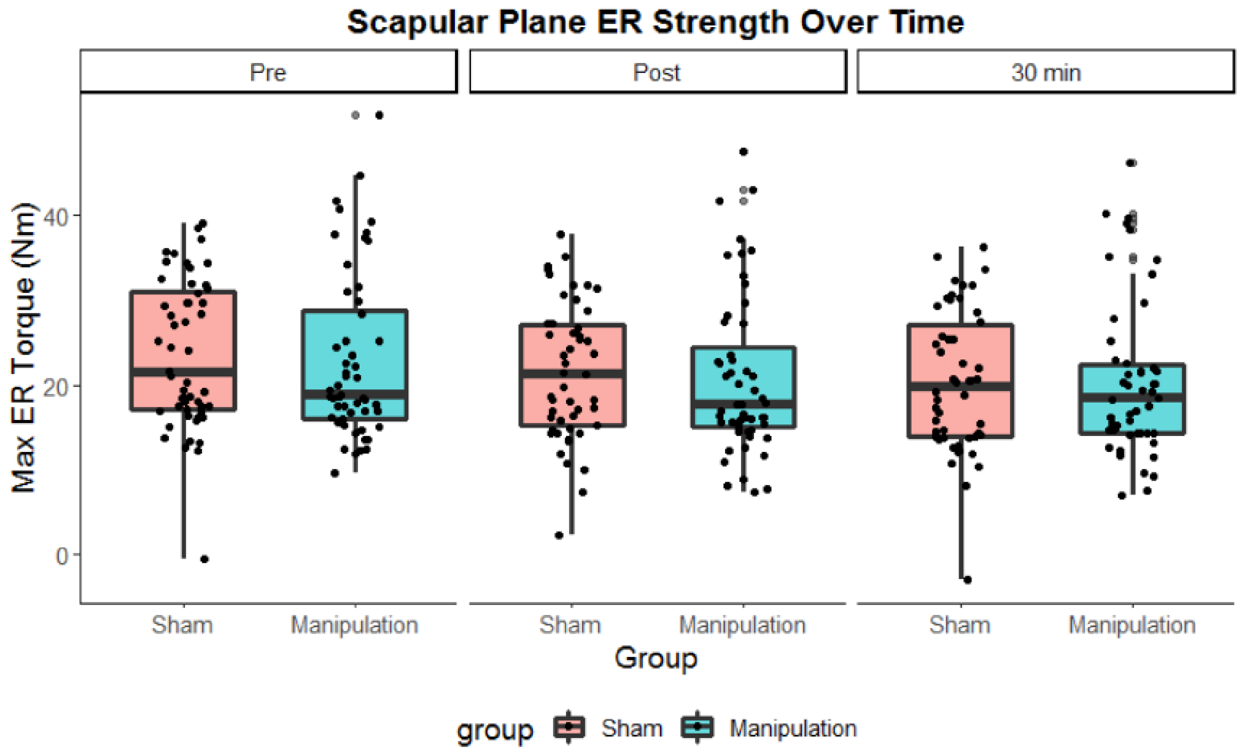


Figure 25. Scapular Plane External Rotation Peak Strength by Group

Adding an interaction for group (sham vs. manipulation) with time did not significantly improve the level 2 explanatory model, indicating no significant effect of spinal manipulation across time in the present study in either the frontal plane (TABLE 7) or the scapular plane (TABLE 8).

Table 7. Frontal Plane External Rotation Peak Strength Model Summaries

	Level 2 Explanatory	Group Time Interaction
(Intercept)	20.88***	20.07***
	(0.84)	(1.13)
Away Cervical Position	-1.04**	-1.04**
	(0.32)	(0.32)
Post Time Point	-0.98*	-0.64
	(0.39)	(0.56)
30-minute Follow-up	-2.22***	-2.37***
	(0.39)	(0.56)
Male Sex	16.77***	17.00***
	(1.36)	(1.36)
Time Post : Manipulation		-0.68
		(0.78)
30 min : Manipulation		0.31
		(0.78)
AIC	1655.27	1658.53
BIC	1681.33	1695.77
Log Likelihood	-820.63	-819.27
Var: Between Subjects	20.28	19.83
Var: Within Subjects	7.79	7.74

Coefficient estimates and (standard errors) for each variable. * denotes statistical significance $p < .05$; ** $p < .01$; *** $p < .001$

Coefficient estimates in reference to neutral head position, pre time point, female sex and sham manipulation.

Table 8. Scapular Plane External Rotation Peak Strength Model Summaries

	Level 2 Explanatory	**Interactions**
(Intercept)	19.14***	18.17***
	(0.81)	(1.08)
Toward Cervical Position	-2.27***	-2.27***
	(0.35)	(0.35)
Post Time Point	-1.81***	-1.51*
	(0.43)	(0.61)
30-minute Follow-up	-2.69***	-2.69***
	(0.43)	(0.61)
Male Sex	15.14***	15.41***
	(1.28)	(1.28)
Time Post : Manipulation		-0.59
		(0.85)
30 min : Manipulation		0.01
		(0.86)
AIC	1695.21	1698.95
BIC	1721.28	1736.18
Log Likelihood	-840.61	-839.47
Var: Between Subjects	17.71	17.12
Var: Within Subjects	9.33	9.30

Coefficient estimates and (standard errors) for each variable. * denotes statistical significance p < .05; ** p < .01; *** p < .001

Coefficient estimates in reference to neutral head position, pre time point, female sex and sham manipulation.

RQ4) Do spinal manipulations to the thoracic spine and cervicothoracic junction affect shoulder internal rotation strength from pre to post manipulation and to a 30-minute follow-up?

To answer this question, two multilevel regression models – one for the frontal plane and one for the scapular plane – were employed. These models examined peak internal rotation strength between a spinal manipulation group and a sham manipulation group across three time points (pre, post and 30-minute follow-up). Peak strength values are displayed in FIGURE 26 for the frontal plane and FIGURE 27 for the scapular plane.

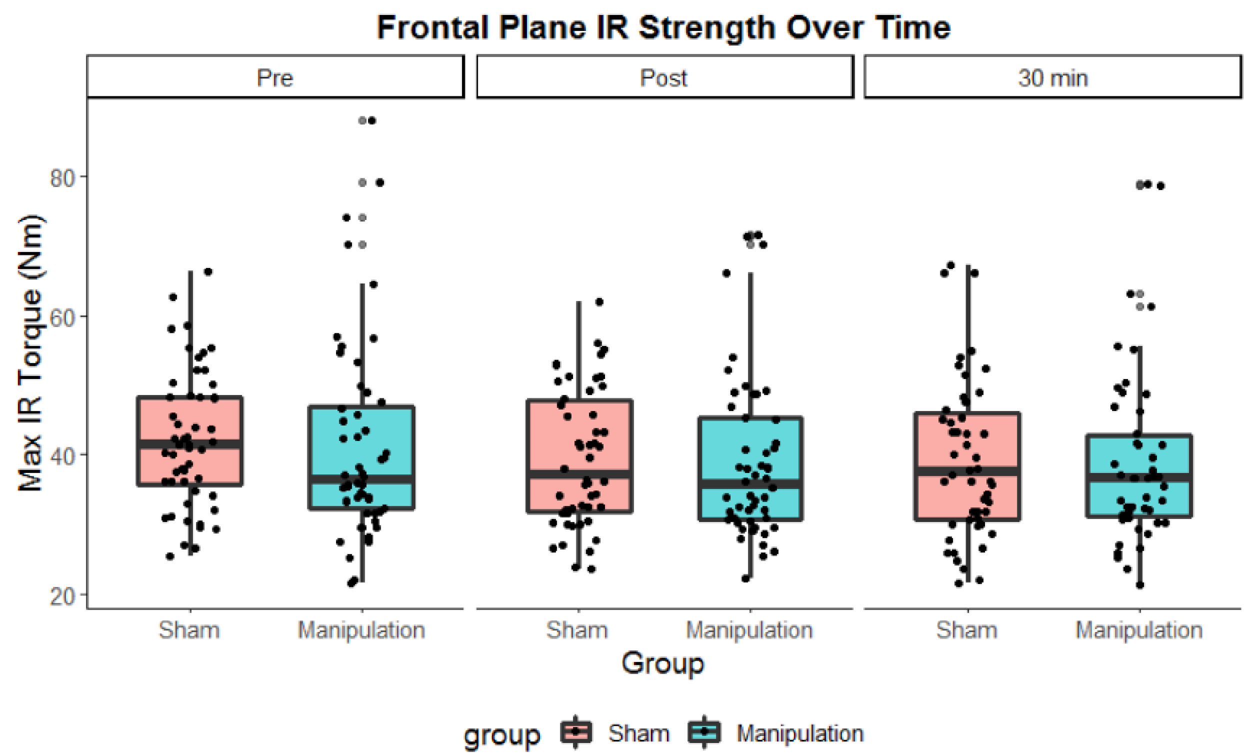


Figure 26. Frontal Plane Peak Internal Rotation Strength by Group

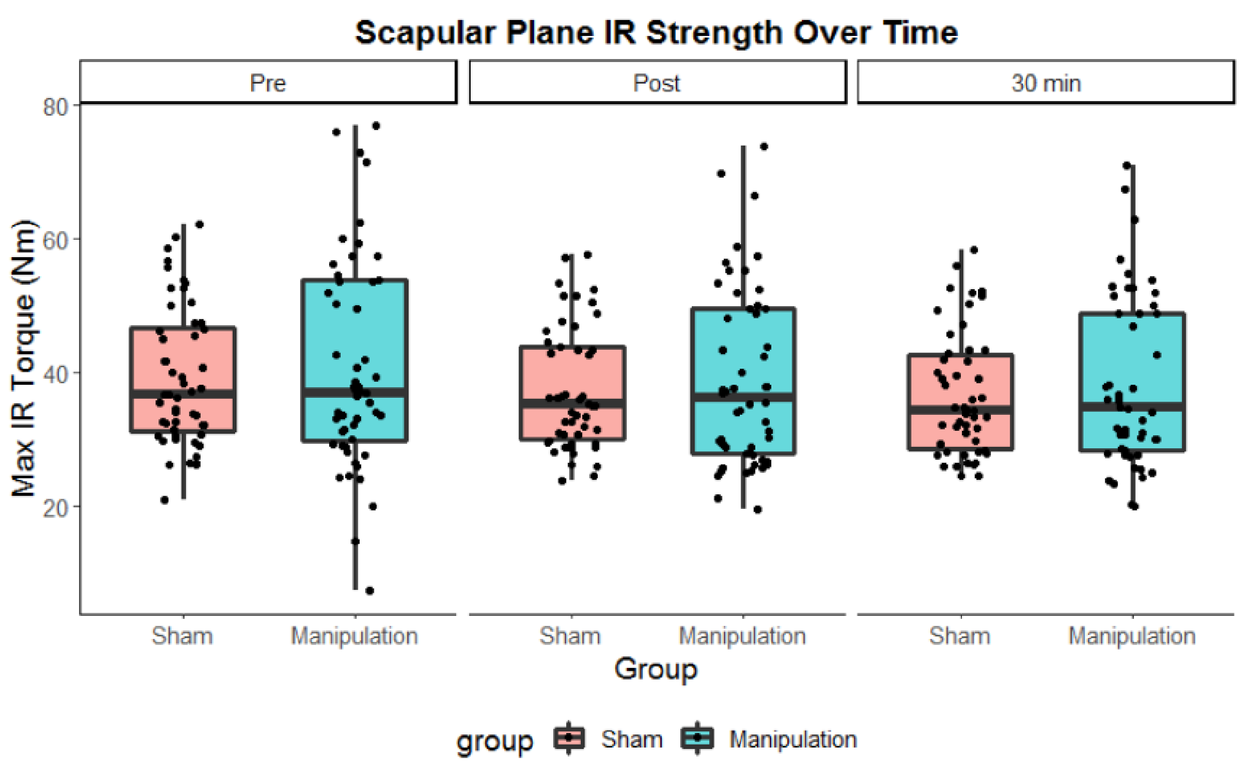


Figure 27. Scapular Plane Peak Internal Rotation Strength by Group

Adding an interaction for group (sham vs. manipulation) with time did not significantly improve the level 2 explanatory model, indicating no significant effect of spinal manipulation across time in the present study in either the frontal plane (TABLE 9) or the scapular plane (TABLE 10).

Table 9. Frontal Plane Peak Internal Rotation Strength Model Summaries

	Level 2 Explanatory	**Interactions**
(Intercept)	36.04***	34.92***
	(1.16)	(1.56)
Away Cervical Position	-1.45**	-1.45**
	(0.44)	(0.44)
Post Time Point	-2.38***	-2.36**
	(0.54)	(0.78)
30-minute Follow-up	-2.70***	-2.52**
	(0.55)	(0.78)
Male Sex	18.73***	19.05***
	(1.87)	(1.88)
Time Post : Manipulation		-0.06
		(1.09)
30 min : Manipulation		-0.36
		(1.10)
AIC	1857.67	1862.44
BIC	1883.73	1899.68
Log Likelihood	-921.83	-921.22
Var: Between Subjects	38.54	37.69
Var: Within Subjects	15.14	15.14

Coefficient estimates and (standard errors) for each variable. * denotes statistical significance $p < .05$; ** $p < .01$; *** $p < .001$

Coefficient estimates in reference to neutral head position, pre time point, female sex and sham manipulation.

Table 10. Scapular Plane Peak Internal Rotation Strength Model Summaries

	Level 2 Explanatory	**Interactions**
(Intercept)	37.84***	36.19***
	(1.40)	(1.82)
Toward Cervical Position	-2.42*	-2.42*
	(1.18)	(1.18)
Post Time Point	-1.68	-1.65
	(1.44)	(2.05)
30-minute Follow-up	-2.48	-2.30
	(1.45)	(2.05)
Male Sex	9.29***	9.73***
	(1.66)	(1.62)
Time Post : Manipulation		-0.11
		(2.88)
30 min : Manipulation		-0.36
		(2.90)
AIC	2340.48	2343.18
BIC	2366.55	2380.41
Log Likelihood	-1163.24	-1161.59
Var: Between Subjects	13.84	11.84
Var: Within Subjects	106.56	106.58

Coefficient estimates and (standard errors) for each variable. * denotes statistical significance $p < .05$; ** $p < .01$; *** $p < .001$
Coefficient estimates in reference to neutral head position, pre time point, female sex and sham manipulation.

RQ5) Do spinal manipulations moderate the effect of cervical position on shoulder external rotation strength from pre to post manipulation and to a 30-minute follow-up?

To answer this question, two multilevel regression models – one for the frontal plane and one for the scapular plane – were employed. These models examined peak external rotation strength between a spinal manipulation group and a sham manipulation group across three time points (pre, post and 30-minute follow-up). No significant three-way interaction was found between group, position and time in either the frontal (TABLE 11) or scapular (TABLE 12) planes. Further, the models including the interactions did not show an improvement over the level 2 explanatory models without. For reference, with the neutral cervical position, pre time point and sham manipulation groups all being coded as 0, a positive three-way interaction term would indicate spinal manipulation works to increase strength in the rotated cervical spine position compared to neutral over time.

Table 11. Frontal Plane Peak External Rotation Strength Model Summaries

	Level 2 Explanatory	**Interactions**
(Intercept)	20.88^{***}	20.46^{***}
	(0.84)	(1.18)
Away Cervical Position	-1.04^{**}	-1.82^{*}
	(0.32)	(0.77)
Post Time Point	-0.98^{*}	-1.41
	(0.39)	(0.78)
30-minute Follow-up	-2.22^{***}	-2.50^{**}
	(0.39)	(0.78)
Male Sex	16.77^{***}	17.00^{***}
	(1.36)	(1.36)
Time Post : Manipulation : Away		-1.75
		(1.54)
30 min : Manipulation : Away		-1.22
		(1.55)
AIC	1655.27	1665.10
BIC	1681.33	1720.96
Log Likelihood	-820.63	-817.55
Var: Between Subjects	20.28	19.85
Var: Within Subjects	7.79	7.63

Coefficient estimates and (standard errors) for each variable. * denotes statistical significance p < .05; ** p < .01; *** p < .001. Away = cervical spine maximally rotated away from working arm side

Coefficient estimates in reference to neutral head position, pre time point, female sex and sham manipulation.

Table 12. Scapular Plane Peak External Rotation Strength Model Summaries

	Level 2 Explanatory	**Interactions**
(Intercept)	19.14***	18.05***
	(0.81)	(1.14)
Toward Cervical Position	-2.27***	-2.04*
	(0.35)	(0.84)
Post Time Point	-1.81***	-1.03
	(0.43)	(0.85)
30-minute Follow-up	-2.69***	-2.23**
	(0.43)	(0.85)
Male Sex	15.14***	15.41***
	(1.28)	(1.28)
Time Post : Manipulation : Toward		1.40
		(1.69)
30 min : Manipulation : Toward		1.37
		(1.70)
AIC	1695.21	1706.70
BIC	1721.28	1762.55
Log Likelihood	-840.61	-838.35
Var: Between Subjects	17.71	17.13
Var: Within Subjects	9.33	9.22

Coefficient estimates and (standard errors) for each variable. * denotes statistical significance p < .05; ** p < .01; *** p < .001.

Toward = cervical spine maximally rotated toward from working arm side

Coefficient estimates in reference to neutral head position, pre time point, female sex and sham manipulation.

RQ6) Do spinal manipulations moderate the effect of cervical position on shoulder internal rotation strength from pre to post manipulation and to a 30-minute follow-up?

To answer this question, two multilevel regression models – one for the frontal plane and one for the scapular plane – were employed. These models examined peak internal rotation strength between a spinal manipulation group and a sham manipulation group across three time points (pre, post and 30-minute follow-up). No significant three-way interaction was found between group, position and time in either the frontal (TABLE 13) or scapular (TABLE 14) planes. Further, the models including the interactions did not show an improvement over the level 2 explanatory models without. For reference, with the neutral cervical position, pre time point and sham manipulation groups all being coded as 0, a positive three-way interaction term would indicate spinal manipulation works to increase strength in the rotated cervical spine position compared to neutral over time.

Table 13. Frontal Plane Peak Internal Rotation Strength Model Summaries

	Level 2 Explanatory	**Interactions**
(Intercept)	36.04***	34.92***
	(1.16)	(1.63)
Away Cervical Position	-1.45**	-1.46
	(0.44)	(1.08)
Post Time Point	-2.38***	-2.58*
	(0.54)	(1.09)
30-minute Follow-up	-2.70***	-1.96
	(0.55)	(1.09)
Male Sex	18.73***	19.05***
	(1.87)	(1.88)
Time Post : Manipulation : Away		-0.35
		(2.16)
30 min : Manipulation : Away		1.75
		(2.17)
AIC	1857.67	1870.89
BIC	1883.73	1926.75
Log Likelihood	-921.83	-920.45
Var: Between Subjects	38.54	37.71
Var: Within Subjects	15.14	15.04

Coefficient estimates and (standard errors) for each variable. * denotes statistical significance $p < .05$; ** $p < .01$; *** $p < .001$. Away = cervical spine maximally rotated away from working arm side

Coefficient estimates in reference to neutral head position, pre time point, female sex and sham manipulation.

Table 14. Scapular Plane Peak Internal Rotation Strength Model Summaries

	Level 2 Explanatory	Interactions
(Intercept)	37.84***	38.54***
	(1.40)	(2.20)
Toward Cervical Position	-2.42*	-7.11*
	(1.18)	(2.79)
Post Time Point	-1.68	-2.13
	(1.44)	(2.82)
30-minute Follow-up	-2.48	-2.81
	(1.45)	(2.82)
Male Sex	9.29***	9.74***
	(1.66)	(1.62)
Time Post : Manipulation : Toward		2.69
		(5.61)
30 min : Manipulation : Toward		3.44
		(5.63)
AIC	2340.48	2339.84
BIC	2366.55	2395.69
Log Likelihood	-1163.24	-1154.92
Var: Between Subjects	13.84	12.74
Var: Within Subjects	106.56	101.15

Coefficient estimates and (standard errors) for each variable. * denotes statistical significance $p < .05$; ** $p < .01$; *** $p < .001$.

Toward = cervical spine maximally rotated toward from working arm side

Coefficient estimates in reference to neutral head position, pre time point, female sex and sham manipulation.

Chapter V

Discussion

The purpose of this study was to examine the effects of cervical positioning and thoracic and cervicothoracic junction manipulations on shoulder internal and external rotation strength in healthy, young adults. This chapter discusses the results as they pertain to each research question and how they are applicable to populations at risk for shoulder injury, such as overhead athletes and manual trades workers.[4,5,73]

RQ 1-2) Does Cervical Spine Position Affect Shoulder Rotation Strength?

The results of this study support the hypothesis that cervical spine position does affect shoulder rotation strength. Specifically, rotating the cervical spine away from the working side with the shoulder abducted in the frontal plane resulted in just over a 1 Nm decrease in shoulder external rotation strength compared to holding the cervical spine in a neutral position (26.74 ± 10.02 vs. 25.59 ± 10.85 Nm). This roughly 4% decrease between changes in position may be due to biomechanical alterations of cervicoscapular musculature,[7] as described in chapter 2, or neurologic alterations from stretching and/or compressing the motor nerves running to the working musculature.[31-34,63]

Internal rotation strength was stronger than external rotation strength in the frontal plane with the head in neutral, with a peak torque of 42.53 ± 12.48 vs. 26.74 ± 10.02 Nm respectively, however, the effect of rotating the cervical spine away from the working side had a similar proportionate decrease in strength, about 4%, to that of external rotation (42.53 ± 12.48 vs. 41.07 ± 11.88 Nm). Similar to external rotation, this strength decrease could be to biomechanical or neurologic alterations.

Interestingly, the decrease in peak strength resulting from contralateral cervical spine rotation was proportionate between external and internal rotation, but the potential biomechanical mechanism is not. Shoulder external rotators are located on the posterior side of the body and most commonly have an attachment on the scapula.[14] The scapula receives attachments from the trapezius and levator scapulae,[14] which are lengthened during maximal contralateral cervical rotation and shortened by elevating the humerus.[7] As the cervicoscapulo muscles are altered, the length-tension relationships of the scapulohumeral muscles are altered. This would affect the posterior deltoid, infraspinatus and teres minor, which collectively account for almost all shoulder external rotation.[7] In contrast, the shoulder internal rotators are not as largely affected by the scapula. While the teres major and subscapularis attach to the scapula, the pectoralis major does not rely on the scapula for the support, and while the latissimus dorsi attaches to the scapula in a portion of the population,[125] its attachment to the axial skeleton is much more expansive.[14,125] Therefore, there is reason to conclude altered length-tension relationships of scapular musculature would affect shoulder external rotation more than internal rotation.

Proximal motor neuroanatomy, however, is similar to both internal and external rotators, with both groups innervated by the brachial plexus.[14] Afferent fibers of the brachial plexus to both muscle groups remain relatively approximate to each other through the shoulder.[7,14] All fibers run through the scalenes, between the 1st rib and clavicle and underneath the pectoralis minor.[36,39,40,61,62] A few exceptions are the suprascapular nerve, which innervates the supraspinatus and infraspinatus, and the upper and lower subscapular nerves, which innervate the subscapularis.[14] These nerves branch off the brachial plexus proximal to the pectoralis minor and would not be subject to compression underneath the pectoralis minor during scapular elevation during testing.[47] However, they would still be subject to compression between the anterior and middle scalenes along with between the 1st rib and clavicle.[40,61,62] Therefore, maximally rotating the cervical spine contralateral to the working arm side would biomechanically affect the nerves (see Chapter II – Biomechanics of Altered Testing Positions) to both internal and external rotation musculature in a similar fashion.

The similar 4% decrease in both internal and external rotation from contralateral cervical spine rotation lends itself to the conclusion that the deficit is due to neural affects over muscle biomechanics. However, the data in the present study did not directly have a way of measuring where the deficit came from. Future research should incorporate measures of muscle activation, such as electromyography, and neural drive, such as F-wave,[126] H-reflex[127] or transcranial magnetic stimulation.[128]

The findings of decreased shoulder rotation strength in the frontal plane from rotating the cervical spine contralaterally to the working side are most applicable to overhead athletes. Baseball pitchers,[129] tennis players serving[130] and volleyball players spiking[130] all reach a position of maximum external rotation with their cervical spine rotated (and often extended) to the contralateral side. All three of these overhead motions place tremendous rotary stress on the shoulder,[131-133] and therefore, require an appropriate amount of strength to prevent injury.[134] If this weakness is caused by neural compression, similar to that of shoulder weakness in thoracic outlet syndrome,[40] it would be exacerbated by end range cervical spine rotation while in a shoulder abduction and external rotation.

Where in the arc of motion the weakness lies is also noteworthy. In the frontal plane, significant differences in both shoulder internal and external rotation strength occurred while the shoulder was around 70-80° of external rotation (close to the forearm being vertical – FIGURES

16 & 22). Further, as the strength test approached end range (end of external rotation trial and start of internal rotation trial), the statistical parametric mapping analysis became non-significant as strength started to diminish, likely due to it being the very beginning or very end of the repetition. Therefore, it is likely that strength would remain diminished by contralateral cervical spine rotation as the humerus continues to externally rotate. This is important, particularly for overhead athletes because "maximum external rotation"[6,129-131] is the most demanding position of the overhead action. Decreased external rotation strength in an externally rotated position could impede the rotator cuff's ability to stabilize the shoulder,[135] while decreased internal strength could inhibit active support to the overhead motion, placing more stress on non-contractile tissue. This is of further concern as the shoulder musculature exhibit decreased ability to control glenohumeral translation in this position.[136] It is known that decreased shoulder rotation strength is an injury risk factor for overhead athletes,[134] and these results add to the literature in identifying where the weakness occurs, and how the cervical spine position overhead athletes operate in may contribute to shoulder pathology.

Further, in cases of shoulder pathology, bigger muscles tend to compensate for smaller muscles.[78,119] Future research is required to determine which muscles were less active, but if the trend of smaller muscles shutting off and bigger muscles taking over holds true, this could mean decreased contribution from the rotator cuff muscles could be a driving force in the decreased strength found in the altered testing position. Because the rotator cuff plays a key role in shoulder stabilization and injury prevention,[135] further research is warranted to determine if the position athletes are placing themselves in is contributing to decreased rotator cuff activation, and therefore, injury susceptibility.

Because these data come from a healthy population, it provides valuable proof of concept insight for how overhead athletes may be impacted. Findings should be validated in overhead athletes by future studies. If the pattern from these data hold true, this lends itself to better examination techniques and potential treatment. Currently, all shoulder strength testing is performed with the cervical spine in a neutral position, and all therapeutic/strength and conditioning exercises are performed in a neutral cervical spine position. If athletes can be trained to maintain their strength and shoulder activation in altered cervical spine positions, it may prove beneficial in injury prevention.

The results from this study indicate ipsilateral rotation toward the working side affects both internal and external shoulder rotation strength with the arm elevated 90° in the scapular plane. In the level 2 explanatory model, there was a significant effect of rotating the cervical spine to the working side decreased shoulder external rotation strength by an estimated 2.27 Nm (24.30 ± 9.01 vs. 22.64 ± 8.99). This roughly 10% decrease between changes in position may be due to biomechanical alterations of cervicoscapular musculature,[7] as described in chapter 2, or neurologic alterations from stretching and/or compressing the motor nerves running to the working musculature.[40,62]

Internal rotation also showed a similar magnitude in effect of a rotated cervical spine ipsilateral to the working arm side with a significant estimate of 2.42 Nm decrease in strength (41.90 ± 12.65 vs. 37.79 ± 13.53 Nm). However, due to internal rotation being substantially stronger than external rotation in the scapular plane (41.90 ± 12.65 vs. 24.30 ± 9.01 Nm), this decrease in strength was proportionately less than external rotation at roughly 6%. Further, the model for external rotation showed a smaller standard error (0.35 vs. 1.18 Nm), indicating stronger evidence for an increased impact on external rotation strength than internal.

While there may be some of the neurologic component explained in Chapter II, there is a key biomechanical difference when discussing the scapular plane. The act of horizontally adducting the humerus 45° anterior to the frontal plane is accompanied with shoulder protraction.[7] Shoulder protraction lengthens many of the scapular stabilizers, such as the rhomboids, middle and lower fibers of the trapezius.[7] These muscles retract the scapula, which counters the pull of many of the shoulder external rotators due to their attachments on the scapula and posterolateral humerus.[7,14] Additionally, when horizontal adduction occurs at the glenohumeral joint while in an elevated position, it places the posterior scapulohumeral musculature on stretch. Therefore, the scapular stabilizers used in shoulder external rotation along with the external rotators, themselves, are both operating in a lengthened position, which is not ideal for tension generation.[137] In contrast, the shoulder internal rotators would not be as affected. The pectoralis major is in a stronger position than in the frontal plane, where abduction and external rotation lengthens it past its resting position.[14] The latissimus dorsi, teres major and subscapularis all pass anterior to the shoulder vertical axis of rotation and would not be lengthened like other posterior shoulder musculature.[7]

When rotating the cervical spine ipsilateral to the working arm side, extra tension is not created to pull the scapula in any particular direction. Rather, slack is placed in the upper trapezius and levator scapulae muscles.[7] This may affect participants' ability to stabilize the upper scapula which may affect the tendency of participants to use scapular elevation as a compensation to increase force output.[47] Another factor that should be considered is outcome-based behavior. Participants were instructed to look as far as they could to the side, like they were trying to look over their dominant shoulder. In some participants, this may have resulted in additional spinal rotation, increasing the horizontal adduction angle of the shoulder, placing them at a less advantageous position during the start of their external rotation repetition.

Similar to the frontal plane, future studies should examine muscle activation via electromyography and neural drive via F-wave, H-reflex and transcranial magnetic stimulation to determine the origin of strength deficits in this rotated cervical spine position. This could be of greater importance with the shoulder elevated in the scapular plane with ipsilateral rotation as the magnitude of strength deficit was greater than in the frontal plane.

The scapular plane position with ipsilateral cervical spine rotation is applicable to both overhead athletes and manual trades workers. Shoulder demands are required with the cervical spine in ipsilateral rotation when an overhead athlete's follow through phase,[129,130,133] or when a manual trades worker is working overhead. External rotation strength was weaker in the scapular plane with the cervical spine ipsilaterally rotated for just about the entire arc of motion outside of force development and relaxation regions, but specifically, greater differences were noticed at peaks around 20° and 60° of shoulder external rotation (FIGURE 17). The peak external rotation strength deficit around 20° of external rotation is applicable to overhead athletes during the deceleration phase, where a large amount of energy must be absorbed by the posterior shoulder musculature to eccentrically control shoulder internal rotation and horizontal adduction after ball release/strike.[138] The second external rotation strength deficit peak at 60° is highly applicable to trades workers working overhead. With the shoulder elevated in the scapular plane, to reach overhead, the forearm will be relatively vertical, likely with about 60° of external rotation, as further external rotation approaches the close-packed position of the joint[7] and is less comfortable. An electrician, for example, to look at what he is manipulating with his hand would work in this position of an elevated and externally rotated shoulder with an ipsilaterally rotated cervical spine, which may contribute to higher shoulder injury rates in trades workers.[4,5]

Internal rotation strength in the scapular plane with the cervical spine ipsilaterally rotated was weaker for roughly the last 60° arc of the internal rotation trial (last 60° as the forearm approached horizontal – FIGURE 23). This is highly applicable to manual trades workers. A plumber, for example, often has to use active shoulder internal rotation to apply force as he turns a valve overhead. Not only may weakness in this position affect the task, but forceful tasks overhead require high amounts of shoulder stabilization from the rotator cuff.[135] This is of particular importance, as those with cervical root impingement have less activation of the supraspinatus, a key shoulder stabilizer.[81] The supraspinatus' job is to stabilize the shoulder during dynamic tasks, so with decreased strength or activation, this could indicate insufficiency during the task, potentially partially explaining why trades workers and overhead athletes commonly injure their shoulders.[4,5,139] Further studies should also examine this potential mechanism in these populations due to the high incidence of proximal neural involvement in cases of shoulder impingement/supraspinatus tendinopathy.[80,81]

Also, of potential impact to overhead athletes and trades workers is the effects of an ipsilaterally rotated cervical spine greater impacting the strength of the shoulder external rotators vs. the internal rotators. For overhead athletes – pitchers, for example – when the cervical spine is ipsilaterally rotated during follow through[129,130] to look at home plate, a high demand is placed on the posterior shoulder external rotators to absorb energy as the pitching arm decelerates.[138] Due to the high incidence of injury to the supraspinatus, infraspinatus and teres minor in pitchers, the inability of the shoulder external rotators to fully function in this rotated cervical spine position may help explain injury mechanisms. Further, infraspinatus atrophy is commonly seen in tennis players,[84] which is suspect because of the high activity of the posterior shoulder musculature during follow through.[8] This warrants further investigation into factors leading to injury, as repeated stimulation typically leads to muscle hypertrophy.[140]

In trades workers working overhead, such as electricians and plumbers, the posterior shoulder muscles must activate to hold the shoulder in elevation and manipulate the work site with the hands. Decreased strength with a rotated cervical spine during work will result in compensation for fatigue more quickly than in a neutral position, likely resulting in elevating the shoulder girdle,[47] which may be a more vulnerable position for supraspinatus injury.[70,72]

The data to answer research questions 1 and 2 support the hypotheses that altering the cervical spine position does influence shoulder rotation strength. These results should be a platform for future research to guide health professionals in their assessment of populations that require regular use of their shoulders in altered cervical spine positions. Currently, shoulder strength testing is taught with the cervical spine in a neutral position.[2] There may be reason to consider strength testing patients' shoulders in altered cervical spine positions to match their functional need. If future research establishes a mechanism for this positional effect of shoulder weakness, it would open the door for intervention studies to see if training in altered positions can reduce rates of shoulder injury in populations such as overhead athletes and manual trades workers. Because this dissertation offers theory to a mechanism increasing shoulder pathology in given populations by using a general, active population, further research should establish baseline strength data in at risk populations.

RQ 3-4) Do Spinal Manipulations to the Cervical and Cervicothoracic Spine Affect Shoulder Rotation Strength After Manipulation and 30 Minutes Following Spinal Manipulation?

The results of this study do not support the hypothesis that spinal manipulation increases shoulder rotation strength after manipulation and 30 minutes following manipulation. There was no significant estimate for the interaction of time and being in the spinal manipulation group vs. sham in the models for both internal and external rotation, in the frontal and scapular planes. Further, the models that included the interaction terms in the analysis were weaker models according to the AIC and BIC in comparison with the level two explanatory models.

These results are surprising because spinal manipulation has been shown to acutely increase strength and muscle activation.[104-106] This is thought to be accomplished through neuroexcitation and increased neural drive.[104,106] However, this study did include a few key limitations that may explain some of the differing results. In the author's opinion, the repeated nature of the tests may have resulted in both physical and mental fatigue. To prevent physical fatigue, 90 seconds of rest were allotted between sets (each set consisted of two repetitions of both concentric and eccentric shoulder rotation). Some of the stronger participants still reported some fatigue, although they reported they did not feel it was affecting their performance. However, with the 90 second rest between each set and the repeated nature of the study collection, participants may have lost motivation to continue providing maximum effort in the same task. This may be shown by the negative main effect estimate for time in all models, most of which reached statistical significance. The effect of time seemed to affect both groups similarly, with almost all group by time interaction estimates being very close to zero.

Last, the effect of joint cavitation[141,142] is not well defined in the literature.[142-144] The therapeutic effect of joint cavitation is also conflicting in the literature, with some studies showing improvement without the cavitation and others showing patients associating it with a therapeutic effect.[143-145] In the present study, two members of the spinal manipulation group did not achieve a joint cavitation during manipulation and three of the members in the sham manipulation group cavitated from the set up. However, when adjusting the models to account for joint cavitation rather than group assignment, the interaction of joint cavitation with time and the main effect of time did not change. Future research should investigate the effects of spinal manipulation and joint cavitation on muscle strength and activation in a design with less repeated maximum effort tests.

RQ 5-6) Do Spinal Manipulations Moderate the Effect of Cervical Position on Shoulder Rotation Strength from Pre to Post Manipulation and to a 30-Minute Follow-up?

The results of this study do not support the hypothesis that spinal manipulations moderate the effect of cervical spine position on shoulder rotation strength, specifically by decreasing the deleterious effect of a rotated cervical spine on peak shoulder rotation strength. In the multilevel models, the neutral cervical spine position, sham manipulation and pre time point were all dummy coded as 0. Therefore, a positive three-way interaction of group, time and cervical spine position would indicate that strength in the rotated spinal position increased across time in the manipulation group compared to the sham manipulation group. In this dissertation's models for both internal and external rotation in both the frontal and scapular planes, none of them showed a significant three-way interaction term between manipulation group, time and cervical spine position. Further, the models including the three-way interactions did not improve the AIC or BIC over the level two explanatory models, indicating including the interaction did not improve the models' ability to predict shoulder peak rotation strength.

To the author's knowledge, this question has never been assessed in the literature. It is known that spinal manipulations do increase cervical rotation range of motion.[12] Therefore, the hypothesized deleterious effects of cervical rotation position on shoulder rotation strength may have been lost by cueing participants to turn their head as far as possible. Participants may have accessed increased spinal rotation from receiving the manipulation (TABLE 15) and negated the effect, whereas there may have been an interaction had they stayed at the same rotation angle as prior to manipulation. This does bring to light a key limitation of this study in there was no reliable way to measure how far each participant rotated their cervical spine during each trial – information that would have allowed for a mixed effects model, allowing cervical rotation angle to vary across trials.

Table 15. Total Cervical Rotation (Left + Right) Range of Motion Between Groups

	Control (Sham)	**Manipulation**
Baseline (Pre)	144 ± 19°	144 ± 14°
Post	149 ± 19°	156 ± 14°
30-Minute Follow-up	151 ± 19°	158 ± 16°

Similar to the previous section, the effects of joint cavitation are not fully established. Studies that have analyzed joint cavitation vs. no cavitation have mostly measured pain and patient [143-145], whereas to the author's knowledge no study to this point has examined the effect of a high-velocity, low-amplitude thrust causing cavitation vs. no cavitation on strength and/or range of motion. Given the effects of the frontal plane surrounded mimicking the signs and symptoms of thoracic outlet syndrome rather than a cervical spine pathology, it is not as surprising that when replacing the sham vs. manipulation group term with whether or not participants experienced a joint cavitation, it did not change the three-way interaction in the frontal plane. The model performed equal to the level two explanatory model in AIC, BIC and log likelihood (note: it did not perform worse, as the interactions model split by group did).

In contrast to the frontal plane, however, the scapular plane with ipsilateral cervical spine rotation was theorized to affect shoulder rotation strength by mimicking cervical radiculopathy, where the spinal nerves may be compressed by the position of the intervertebral foramen. Due to the known mechanical effects of spinal manipulation on the cervical spine[99,101,109,110] in addition to the neural drive theory,[104,106] there was stronger theory for spinal manipulation improving the interaction between cervical spine rotation and shoulder rotation strength in the ipsilateral cervical spine rotation and scapular shoulder elevation position. When replacing the group variable with cavitation in the scapular plane rotation strength models, there was improvement in the models (TABLES 16 and 17). In addition, all three-way interaction terms for cavitation by position by time had positive coefficient estimates. Despite none of them reaching significance, the addition of the interaction terms was enough to significantly reduce within subjects variance and improve the overall models over the previously best, level two explanatory models. Further, the power analysis for this study was performed using main effects effect sizes from a previous study of less complexity (Giordano, in review). A three-way interaction requires greater samples sizes to obtain the same power,[146] which may mean sample size was a limiting factor in the interaction term, itself, reaching statistical significance. Nonetheless, this provides sufficient foundation to warrant future investigation into this research question

Table 16. Scapular Plane External Rotation Model Summaries

	Level 2 Explanatory	**Interaction by Group**	**Interaction by Cavitation**
(Intercept)	19.14***	18.05***	18.06***
	(0.81)	(1.14)	(1.12)
Toward Cervical Position	-2.27***	-2.04*	-1.20
	(0.35)	(0.84)	(0.85)
Time Post	-1.81***	-1.03	-1.29
	(0.43)	(0.85)	(0.84)
30-minute Follow-up	-2.69***	-2.23**	-2.41**
	(0.43)	(0.85)	(0.85)
Male Sex	15.14***	15.41***	14.77***
	(1.28)	(1.28)	(1.25)
Time Post: Manipulation		-1.29	
		(1.20)	
30 min : Manipulation		-0.68	
		(1.21)	
Time Post : Manipulation : Toward		1.40	
		(1.69)	
30 min : Manipulation : Toward		1.37	
		(1.70)	
Time Post : Cavitation			-0.70
			(1.13)
30 min : Cavitation			-0.30
			(1.14)
Time Post : Cavitation : Toward			2.19
			(1.61)
30 min: Cavitation : Toward			1.42
			(1.62)
AIC	1695.21	1706.70	1649.24
BIC	1721.28	1762.55	1704.90
Log Likelihood	-840.61	-838.35	-809.62
Var: Between Subjects	17.71	17.13	16.30
Var: Within Subjects	9.33	9.22	8.10

Coefficient estimates and (standard errors) for each variable. * denotes statistical significance $p < .05$; ** $p < .01$; *** $p < .001$.

Toward = cervical spine maximally rotated toward from working arm side

Coefficient estimates in reference to neutral head position, pre time point, female sex and sham manipulation.

Table 17. Scapular Plane Internal Rotation Model Summaries

	Level 2 Explanatory	Interaction by Group	Interaction by Cavitation
(Intercept)	37.84***	38.54***	37.83***
	(1.40)	(2.20)	(2.34)
Toward Cervical Position	-2.42*	-7.11*	-3.88
	(1.18)	(2.79)	(3.01)
Time Post	-1.68	-2.13	-1.88
	(1.44)	(2.82)	(3.01)
30-minute Follow-up	-2.48	-2.81	-2.09
	(1.45)	(2.82)	(3.05)
Male Sex	9.29***	9.74***	9.31***
	(1.66)	(1.62)	(1.67)
Time Post: Manipulation		-1.46	
		(3.97)	
30 min : Manipulation		-2.09	
		(3.99)	
Time Post : Manipulation : Toward		2.69	
		(5.61)	
30 min : Manipulation : Toward		3.44	
		(5.63)	
Time Post : Cavitation			-1.41
			(4.07)
30 min : Cavitation			-2.74
			(4.10)
Time Post : Cavitation : Toward			3.82
			(5.75)
30 min: Cavitation : Toward			5.38
			(5.79)
AIC	2340.48	2339.84	2335.92
BIC	2366.55	2395.69	2391.68
Log Likelihood	-1163.24	-1154.92	-1152.96
Var: Between Subjects	13.84	12.74	13.97
Var: Within Subjects	106.56	101.15	104.49

Coefficient estimates and (standard errors) for each variable. * denotes statistical significance $p < .05$; ** $p < .01$; *** $p < .001$.

Toward = cervical spine maximally rotated toward from working arm side

Coefficient estimates in reference to neutral head position, pre time point, female sex and sham manipulation.

Summary

This chapter discusses the results of Chapter III as they relate to the research questions of this dissertation. Hypotheses to Research Questions 1 and 2 were supported that cervical spine rotation does negatively influence shoulder rotation strength. This is important for populations such as overhead athletes and trades workers that are at risk for shoulder injury,[4,5,139] as part of their injury mechanism may be related to the functional position of their cervical spine while using their shoulders. Hypotheses to Research Questions 3 and 4 were not supported in that spinal manipulation did not improve shoulder rotation strength after manipulation and 30 minutes following manipulation, which is contradictory to current literature. However, this could have been due to the repetitive nature of the strength testing in this study protocol. Hypothesis to research questions 5 and 6 were also not supported in that spinal manipulation was not found to moderate the effect of cervical position on shoulder rotation strength. However, there was some evidence to warrant investigation into the effects of joint cavitation during spinal manipulation moderating the effect of cervical spine position on shoulder rotation strength.

This study lays groundwork for future investigations into the spine's position on extremity strength and function. In clinic, strength is tested in a neutral cervical spine position.[2] However, in daily activities, populations prone to shoulder injury such as overhead athletes and trades workers often require strenuous use of their shoulders in altered cervical spine positions. Therefore, there may be reason to assess shoulder strength in altered positions and potentially strengthen/work on muscle activation in altered cervical spine positions. Future studies should analyze muscle activation and neural measures during shoulder strength testing in altered cervical spine positions. Further investigation into the role of spinal manipulation and its ability to mitigate the deleterious effects of a rotated cervical spine position on shoulder rotation strength is warranted.

This project is the first to the author's knowledge to examine the effects of a rotated cervical spine on shoulder strength, which lends itself to several limitations. First, participants were instructed to turn their heads as far as they could like they were looking over their shoulder. This could have impacted some participants that used spinal rotation to accomplish this while their shoulder was locked in place on the isokinetic dynamometer. Second, the researchers had no reliable way, such as an accelerometer, to measure the amount of cervical spine rotation each participant had during each trial. Trials were repeated if they fell out of the testing position, but an objective number to introduce cervical spine rotation as a random effect into the multilevel models would be an improvement. Third, this study was performed in healthy, active young adults as a proof of concept. Jumping straight to pathologic populations would not be ideal in case they already show limitations in neutral cervical spine positions. However, this does limit the generalizability of the findings where it may not be extrapolated to the population they are most targeted to help. Further, perhaps the intervention would have a more therapeutic effect in a pathologic population. Last, the sample size may not have been adequate to perform a three-way interaction inside a multilevel model, which could have resulted in spinal manipulations not moderating the effects of cervical spine rotation on shoulder rotation strength.

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Appendix A

Participant Recruitment Email/Script

Greetings,

The Sports Medicine & Movement Lab is currently conducting a research study to examine active (active in 30 minutes of physical activity 4 or more days of the week) individuals 18-35 years of age. You must be injury free to the cervical and thoracic spine and shoulder for the last 6 months, with no history of shoulder surgery in the last 12 months or spinal surgery at any point.

Upon arrival, you will have electromyography sensors placed on 8 of your shoulder and neck muscles. Your cervical range of motion and shoulder strength will then be tested before, after, and 30 minutes after a spinal manual therapy technique performed by a licensed physical therapist in the state of Alabama. You will receive $10 in compensation for completing the study.

Please wear loose fitting athletic attire to testing. If you, or anyone you know, is interested in participating in this study, please let me know. All procedures are non-invasive, and discomforts may include headache or back stiffness in about 20% of cases. Other potential risks are those associated with exercise. Included are muscle strain, muscle soreness, ligament and tendon damage.

If you have any questions about the study, please contact me at KAG0070@auburn.edu.

Thank you,

Kevin Giordano

Appendix B

AUBURN UNIVERSITY

The Effect of Cervical Spine Position and Spinal Manual Therapy on Shoulder Strength

This study is being conducted by the Sports Medicine and Movement Laboratory at Auburn University under the supervision of Dr. Gretchen Oliver.

IRB Approval #:

Purpose:

- To examine the influence of cervical spine position and thoracic spinal manual therapy on shoulder rotation strength in active individuals 18- 35 years of age

Who:

- Main inclusion criteria
    - 18-35 years of age
    - Active in 30 min of physical activity 4 or more days of the week
    - Free of shoulder and spine injury for the past 6 months
    - Dominant upper extremity surgery free for past 12 months
    - No history of cervical or thoracic spine surgery
    - No history of spine or shoulder joint disease

You may be excluded from participation in this study if you fail to meet any of the inclusion criteria listed above

What:

- Electromyography sensors will be placed on 8 muscles around your shoulder and neck
- Shoulder strength and cervical spine range of motion will be measured pre, post and 30 minutes after a spinal manual therapy technique (pictured below)
- A physical therapist licensed in the State of Alabama will perform all manual therapy techniques
- Approximately 60 minute requirement
- You will receive $10 for completing the study

Where:

- Sports Medicine and Movement Laboratory at Auburn University, Auburn, AL
    - 301 Wire Rd. Auburn, AL 36849
- Parking is available, free of charge, if coming from off campus

For more information, please contact Kevin Giordano (KAG0070@auburn.edu)

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Appendix C

SCHOOL OF
KINESIOLOGY
301 Wire Road
Auburn, AL 36849
(334) 884-4483

AUBURN UNIVERSITY

COLLEGE OF EDUCATION

(NOTE: DO NOT SIGN THIS DOCUMENT UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)

Auburn University
CONSENT TO PARTICIPATE IN RESEARCH
Title: The Effect of Cervical Spine Position and Spinal Manual Therapy on Shoulder Strength

General

You are being asked to participate in a research study for the Sports Medicine &Movement Lab. This research study is voluntary, meaning you do not have to participate. The procedures, risks and benefits are fully described in this form. The purpose of this study is to determine how the position of your neck impacts your shoulder strength. Another purpose is to study how a spinal manual physical therapy technique affects shoulder strength. This study will require you to make one visit to the lab, which should last approximately one hour. You will arrive on the day of testing in a loose fitting athletic top. We will place sensors on eight muscles around your neck and shoulders, then measure how far you can turn your head. You will then complete the testing protocol, which will have you push as hard as you can into a machine for a couple seconds with your head straight and your head turned. You will then have a manual physical therapy technique performed on your back by a licensed physical therapist. We will then repeat the testing protocol. There will then be a wait and we will repeat the testing again a half hour following the manual technique. The most likely risks include muscle soreness from strength testing and headache and/or back stiffness occurs roughly 20% of the time following the manual technique. A serious injury to the spinal cord or lungs can occur between 1 in 120,000 and 1 in 250,000,000 times. You do also have the alternative of not participating in this study.

Who May Participate?

This study is designed to examine the effects of a rotated neck position and a spinal manual therapy treatment on shoulder rotation strength in healthy, active individuals ages 18-35. Active is defined as participating in exercise for at least 30 minutes at the rigor of at least a light jog for 4 or more days of the week. Participants must be without shoulder injury for the past 6 months, without shoulder surgery for the past 12 months, with no history of cervicothoracic spinal fusion (bones in your mid and upper back sealed together by surgery), spinal joint disease or shoulder joint disease. Participants must not currently be experiencing any ailment which would prevent them from performing maximum effort strength testing or from rotating their neck fully to either side.

Research Procedures

To be considered for this study, you physically active 30 minutes most days of the week. You should be cervical spine and shoulder injury free for at least the past 6 months. Additionally, you should have no history of cervical fusion, cervical joint disease or shoulder joint disease. Testing for this research will require you to be dressed in a loose fitting athletic top and a mask. Your height, body mass, and age will be documented. Height and mass will be measured with a common Standiometer (scale with height ruler) and will be recorded to the nearest tenth of a kilogram and centimeter. Age will be determined from this consent form and will be recorded to the nearest month. Electromyography (EMG) sensors will be placed on 8 muscles in the

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shoulder and neck region to record your muscle activity. Cervical rotation range of motion (how far you can turn your head) will be measured with a *CROM* device (headset with attached inclinometers and a magnetic necklace to account for torso movement – this means a tool like a compass that shows direction based on a magnet). Together, this procedures will require 3 minutes of close contact with one of the researchers.

Shoulder internal and external rotation strength will then be measured on an isokinetic dynamometer (device that moves at constant speed that you will push against). Following these measurements, you will receive a spinal manual therapy treatment technique from a licensed physical therapist. This will involve two movements. The first, you will lay on your back with your hands behind your neck and the therapist's hand will go behind your back, on your spine, between your shoulder blades (left). For the other, you will be sitting with your hands on the back of your head and the therapist will be behind you and place his arms around your arms and behind your neck without pushing into your head or neck (right). These two techniques will take about one minute total. The strength and neck range of motion measurements will then be repeated, then again, 30 minutes after the treatment. This results in four different strength tests in two directions, lasting 1.5 seconds each, at each time point for a total of 12 tests requiring 36 total seconds of maximal effort. Testing will take approximately 60 minutes to complete.

Cervicothoracic technique

Thoracic technique

Potential Risks

As with any movement research, certain risks and discomforts may arise. The possible risks and discomforts associated with this study are no greater than those involved in daily physical activity and may include: muscle strain, muscle soreness, ligament and tendon damage. Every effort will be made to minimize these risks and discomforts. It is your responsibility, as a participant, to inform the investigators if you notice any indications of injury or fatigue or feel symptoms of any other possible complications that might occur during testing.

The manual therapy procedure does have a very small possibility of severe injury to the spinal cord or lungs, ranging from 1 in 120,000 to 1 in 250,000,000, with better studies showing the risk is on the safer end of that range. There may be some side effects from the manual therapy technique with the most common being a headache or back stiffness, occurring about 20% of

Participant Initials __________

the time. You will also be asked to remain laying down to give blood pressure an extra minute to renormalize before standing – most of the headaches are theorized to be due to some people having quick drops in blood pressure after manual therapy and standing up to quickly.

To reduce the risk of injury, certain precautions will be taken. During data collection, a board certified athletic trainer and physical therapist will be present. Water will be provided to you as needed, and ice will be made available after testing. The researcher will try to prevent any problem that could happen because of this research. If at any time, there is a problem you should let the researcher know and she will help you. Should an emergency arise, we will call 911 and follow our Emergency Action Plan. In the unlikely event that you sustain an injury from participation in this study, the investigators and Auburn University have no current plans to provide funds for any medical expenses or other costs you may incur.

Due to the need for your physical presence at the research site, face to face interaction with the researcher or others, etc., there is a risk for exposure to COVID-19 and the possibility that you may contract the virus. For most people, COVID-19 causes only mild or moderate symptoms. For some, especially older adults and people with existing health problems, it can cause more severe illness. Current information suggests that about 1-3% of people who are infected with COVID-19 might die as a result. You will need to review the Information on COVID-19 for Research Participants that is attached to this consent document. To minimize your risk of exposure, any investigator who needs to come closer than 6 feet in contact with the participant will wear the appropriate personal protective equipment (PPE) of a face mask, eye protection, gloves (discarded after each participant), and lab coat (discarded after each participant). The manual treatment will require roughly 60 seconds of close contact, sensor placement will require roughly 3 minutes of close contact and testing how far you can turn your head will take approximately 1 minute. Additionally, all research equipment that will come in contact with the participant will be decontaminated BEFORE and AFTER each participant with EPA approved disinfectant. Participants will be required to wear a cloth mask while researchers are within 6 feet. These procedures will be enforced while the Human Research Protection Program requires additional safety measures due to COVID-19.

Confidentiality
All information gathered in completing this study will remain confidential. Your individual performance will not be made available for public use and will not be disclosed to any person(s) outside of the research team. The results of this study may be published as scientific research. Your name or identity shall not be revealed should such publication occur.

Participation and Benefits
Participation in this research is strictly voluntary and refusal to participate will result in no penalty. If you change your mind about participating, you can withdraw at any time during the study. Your participation is completely voluntary. If you choose to withdraw, your data can be withdrawn as long as it is identifiable. Your decision whether or not to participate or to stop participating will not jeopardize your future relations with Auburn University or the School of Kinesiology.

You will receive $10 for completing this study.

Questions Regarding the Study
If you have questions about this study, please ask them now. If you have questions later you may contact Kevin Giordano by phone (719)352-9647, or email at kag0070@auburn.edu.

Participant Initials _________

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Appendix C (cont.)

If you have any questions about your rights as a research participant, you may contact the Auburn University Office of Research Compliance or the Institutional Review Board by phone (334)-844-5966 or email at irbadmin@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO PARTICIPATE.

__________________________________ ____________
Printed Name of Participant Date of Birth

__________________________________ ____________
Signature of Participant Date

The above consent form was read, discussed, and signed in my presence. In my opinion, the person signing said consent form did so freely and with full knowledge of its contents.

__________________________________ ____________
Signature of Investigator Date

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