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# The Potential Role of the Cervical Spine in Sports-Related Concussion: Clinical Perspectives and Considerations for Risk Reduction

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## SYNOPSIS

Sports-related concussions (SRC) occur due to biomechanical forces to the head or neck that can result in pathophysiological changes in the brain. The musculature of the cervical spine has been identified as one potential factor in reducing SRC risk as well as underlying sex differences in SRC rates. Recent research has demonstrated that linear and rotational head acceleration, as well as the magnitude of force, upon impact is influenced by cervical spine biomechanics. Increased neck strength and girth is associated with reduced linear and rotational head acceleration during impact. Past work has also shown that overall neck strength and girth are lower in athletes with SRC. Additionally, differences in cervical spine biomechanics are hypothesized as a critical factor underlying sex differences in SRC rates. Specifically, compared to males, females tend to have less neck strength and girth which is associated with increased linear and rotational head acceleration. Although our ability to detect SRC has greatly improved, our ability to prevent SRCs from occurring and decrease the severity of clinical outcomes post-injury is limited. However, we suggest, along with others, that cervical spine biomechanics is a modifiable factor in reducing SRC risk. We review the role of the cervical spine in reducing SRC risk, and how this differs dependent on sex. We discuss clinical considerations for the examination of the cervical spine and the potential clinical relevance for SRC prevention. Additionally, we provide suggestions for future research examining cervical spine properties as modifiable factors in reducing SRC risk.

### Keywords

head injury; mild traumatic brain injury; neck

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## INTRODUCTION

According to the most recent consensus statement on concussion in sport, sports-related concussion (SRC) is a traumatic brain injury that results from biomechanical forces to the body including the head and neck[47]. These forces induce pathophysiological changes in the brain, leading to somatic, physical, cognitive, and emotional symptoms, as well as sleep disturbances[47]. Although pathophysiological changes are typically transient, with symptoms often resolving within 10–14 days in adults[47], a percentage of individuals with SRC experience persistent symptoms resulting in prolonged activity and participation limitations[45–47]. Impacts to the head or body can result in linear and rotational head acceleration, which in some cases can lead to damage to brain tissue[21, 25, 41, 63]. The force (g's) and duration of an impact (seconds) influences the magnitude of an impact[25]; however, the magnitude of force associated with SRC is extremely variable, with no consistent findings between impact magnitude and clinical outcomes[26]. Musculoskeletal function, particularly neck strength and activation of neck muscles, may serve as a key mediator of the relationship between impact magnitude and the resulting transfer of energy from the head to the brain[7, 25, 33].

Epidemiological studies have demonstrated higher rates of SRC in female university athletes compared to their male counterparts when competing in comparable sports[13, 15, 17, 49]. Relative to males, females also experience more severe symptoms and longer recovery patterns post-SRC[12, 48]. Sex differences in cervical spine biomechanics are one hypothesis put forth regarding differences in SRC rates and clinical outcomes post-SRC in males and females[12, 14, 66]. This article focuses on the role that cervical spine biomechanics and function play in SRC risk, specifically with regard to neck strength, neck girth, neck strength imbalances, and cervical spine posture. We address how the aforementioned risk factors differ based on sex. Additionally, we provide considerations for clinical examination and clinical relevance to highlight the potential role that physical therapists, athletic trainers, and other sports medicine personnel can play in SRC risk reduction. Since there is limited evidence to support specific recommendations, the goal of this paper is to highlight the importance of assessing the cervical spine with respect to SRC risk, and potential ways of incorporating these measures into clinical practice and future research.

## CERVICAL SPINE BIOMECHANICS AND FUNCTION IN SRC RISK

### Neck Strength and Girth

Neck strength and girth have been described as potential modifiable risk factors in SRC prevention, with research demonstrating a relationship between lower neck strength and neck girth being associated with increased head acceleration during impact[5, 8, 9, 20]. Whereas most studies to date have assessed the relationship between neck strength and girth on linear rotation and acceleration, only one has prospectively assessed this relationship with SRC risk. Collins and colleagues[11] found that neck strength values at baseline were lower in high school athletes who subsequently sustained a SRC relative to those who did not, and further that for every one-pound (approximately 0.45 kilogram) increase in neck strength, SRC risk decreased by 5 percent [11]. The proposed mechanism by which neck strength decreases SRC risk relates to the ability of the neck to decelerate head movement, decreasing the transfer of energy to the brain during impact. A stronger neck can decrease head acceleration[8, 27] and is associated with reduced head velocity, peak acceleration, and displacement during impact in human and simulation studies[9, 20, 33, 71]. Sternocleidomastoid (SCM) muscle strength may be of particular importance in reducing SRC risk, as SCM strength specifically has been shown to be predictive of linear and rotational head acceleration when heading a soccer ball[8].

Furthermore, past work suggests that males have significantly greater neck strength than females in neck extension, flexion, and lateral flexion, even after accounting for differences in body mass[10, 20, 29, 67], and that females have significantly smaller head-neck segment mass and neck girth compared to males[5, 20]. These sex differences in neck muscle strength and girth are thought to contribute to females experiencing increased head acceleration during impact[9, 65]. However, it should be noted that whereas Collins et al[11] found that male athletes who sustained a concussion had lower overall baseline neck strength as compared to the uninjured athletes, this was not significant in female athletes.

Muscle strength imbalances in the cervical spine may also play an important role in head acceleration and SRC risk[16, 29]. Isometric tests demonstrate that cervical extension strength is generally greater than flexion strength[50]. It has been suggested however, that when extension and flexion strength production are similar, the head and neck may be more protected during impact[16, 29]. This suggestion is supported by research showing that, regardless of sex, a flexion-extension strength ratio close to one correlates with lower head acceleration during impact[16].

### Cervical Spine Posture

Cervical spine posture may affect the force generating capacity of neck muscles which could influence SRC risk[29]. A common structural alteration in head positioning is forward head posture (FHP), defined as the external auditory meatus being positioned anterior to the shoulder joint[37]. FHP alters the normal mechanics of the neck[69] and is generally more common in females[54]. FHP also increases activation of the SCM and upper trapezius and subsequently inhibits the deep muscles responsible for segmental stability and neck proprioception[2, 40, 43, 44]. Further, FHP is associated with a decreased flexion-extension strength ratio[3] which, as mentioned previously, has an impact on head acceleration forces[16]. Thus, FHP may result in increased head acceleration during impact due to the muscle imbalances noted in this posture.

## POTENTIAL CLINICAL CONSIDERATIONS FOR SRC PREVENTION

### Neck Strength, Girth, and Endurance

To-date, only one study has linked greater neck strength with decreased SRC risk, and no studies have shown what age- and sex-specific degree of neck strength is critical for risk reduction. However, based on the studies discussed above, it is suggested that head acceleration during impact is affected by head and neck size/girth as well as neck strength[8, 16]. Thus, increasing neck strength and potentially girth, and reducing neck strength imbalances, may in turn reduce SRC risk. Based on this research, we suggest that clinicians consider performing a thorough cervical spine strength assessment for athletes who are at risk for SRC (see TABLE). Where normative strength values exist, clinicians can use these values to identify reduced strength and potential areas of focus[8, 10, 11, 51, 57, 68]. Where normative values do not exist in the literature, clinicians should still consider collecting baseline strength and girth values to identify changes over time or in response to a specific strengthening protocol.

An examination of standard isometric cervical spine strength should be considered in all three planes of movement to quantify flexion/extension, lateral flexion, and rotation. Additionally, isolated SCM strength can be measured by isometrically resisting flexion with the neck rotated to the contralateral side[30]. To measure cervical spine strength, we recommend the use of a hand-held dynamometer (HHD) or other devices that allow for clear quantification of muscle strength and strength imbalances (see TABLE). If the HHD is the device of choice, we further recommend the HHD be strapped to the table to optimize stability and minimize inconsistencies in clinician force[19] (FIGURE). With this strength assessment, we recommend clinicians also consider assessing the flexion-extension strength ratio, as a ratio close to one correlates with lower head acceleration during impact[16]. Additionally, clinicians should consider screening for pain during strength testing, as baseline reports of neck pain have been correlated with increased SRC risk in youth athletes[58]. The type and severity of pain may influence the examination values obtained. We suggest that clinicians consider addressing patients' reports of neck pain or headaches and be cognizant of pain characteristics (e.g. acute versus chronic, radiating versus localized) when determining baseline strength values or prior to implementing a strengthening protocol.

There is evidence that isolated strengthening of the neck may serve to protect against SRC[31] and reduce functional impairments in the cervical spine[4]. Further, isometric neck strengthening has been shown to reduce neck injury and SRC risk in sport[31]. Thus, we recommend clinicians consider implementing a pre-athletic participation strengthening program. This strengthening program should be targeted to increase neck strength in an effort to modify the risk factors associated with SRC. Given the busy nature of a pre-season schedule, clinicians should use their own judgment when determining the volume and intensity of the exercises.

With regard to neck girth, one can hypothesize that since increased neck girth is correlated with lower head linear and rotational accelerations during impact[5, 8], interventions to increase neck girth would create a protective advantage for reducing SRC risk. Some research has sought to create reference values for neck girth[10, 11], however, given the variety of anatomical structures that influence neck circumference (e.g. subcutaneous fat and individual muscle volumes), the best interventions for increasing neck girth are not clear at this time.

We similarly hypothesize that in addition to an isometric protocol for superficial cervical muscles, increasing the endurance capacity of the deep cervical flexors and extensors may be important for reducing SRC risk. Deep cervical flexor activation is thought to enhance stability and improve posture in the cervical spine[22, 39] and when activated properly can help to decrease reliance on superficial muscles for controlled movement of the cervical spine[23]. Additionally, research has suggested that some of the deep muscles of the neck may play a role in decreasing head accelerations[32, 61, 72]. Although the majority of studies have assessed cervical flexor endurance, reliable measures for both cervical flexor endurance[1, 24, 28, 34] and cervical extensor endurance[35, 59] exist. Normative data have been developed for the cervical flexor endurance test[18, 36] and can be utilized for reference values; we are not aware of normative values for neck extensor endurance. While we recommend that cervical spine assessment and strengthening protocols be performed for both sexes, we believe they are of particular importance for the female athlete, given the previously mentioned sex differences in neck muscle strength.

### Cervical Spine Posture

A thorough postural assessment should be considered as part of an athlete's examination. FHP can be observed clinically from the sagittal direction with the athlete in a standing or sitting position. Measuring the craniovertebral angle with a goniometer may further assist with quantifying FHP[56]. Smaller craniovertebral angles have been significantly associated with FHP impairments[73]. Intervening on postural impairments often implies correcting FHP and normalizing associated muscular imbalances. When the postural assessment is complemented by the strength assessment, an individualized intervention plan can be put into place to correct postural imbalances. This plan will vary based on the athlete's individual presentation, however, there are some general practices for reducing FHP that are supported by the literature. Exercises combining cervical retraction and axial extension are commonly prescribed to restore the muscle balances in individuals with FHP[42]. We also recommend taking note of the muscles that are commonly affected by FHP, including the SCM[55], upper trapezius[6], levator scapulae[6], and suboccipital muscles[6].

## QUESTIONS FOR FUTURE RESEARCH

Most studies to date have examined linear and rotational head acceleration in laboratory situations or have related neck strength to a past history of concussion. Given the relationship between neck strength and girth with reduced head acceleration and rotational forces, coupled with Collins and colleagues[11] work demonstrating overall neck strength is lower in those who experience an SRC, the evidence is strong enough to warrant future prospective, highly-powered studies that further examine the role of neck strength as a preventative measure for SRC, as well as a potential intervention for SRC-related symptoms. That is, studies should include measurements of cervical spine characteristics in athletes before SRCs occur to determine whether those with increased neck strength and girth, less neck muscle asymmetry, greater endurance, and neutral alignment of the head and neck, experience fewer SRCs. Furthermore, cervical spine characteristics may impact clinical outcomes post-SRC by reducing the number of symptoms, symptom severity, and recovery timelines. Thus, it is important to collect data on these variables and understand their relationship to clinical outcomes.

Furthermore, although the magnitude of acceleration and rotation forces on impact may be a proxy for expected SRC risk, due to the range of magnitude of forces that result in concussive injuries[25], the amount of force required to cause a SRC is not known. We also do not know if these forces have direct effects on clinical outcome measures post-injury (e.g., symptoms, symptom severity, and recovery timelines) or on the severity of potential brain tissue damage post-impact. Thus, prospective studies are needed that examine for relationships between cervical spine characteristics such as neck strength and endurance, neck girth, and posture as well as biomechanical factors thought to increase SRC risk such as head acceleration and rotation. Baseline biomechanical measures are likely to be of particular importance in contact and collision sports where SRC risk is greater and have the potential to provide additional information about SRC risk and clinical outcomes. Given what is known about differences in head acceleration and rotational forces between males and females, coupled with observations that female athletes incur more SRCs, experience a greater number of symptoms and severity, as well as prolonged recovery timelines, it is important that studies are adequately powered to examine sex differences.

In addition, it is imperative to develop sex-specific norms for neck strength that are associated with reduced risk of SRC. Normative data of isometric strength for cervical flexion, extension, side-bending and rotation have been published for males and females[51, 57] with females having weaker necks compared to men, even when accounting for body weight, body mass index, height and neck length[51, 57, 68]. However, what is not known is whether there are specific strength values in male and female athletes that are associated with fewer SRCs, or maybe more importantly, fewer clinical symptoms, reduced symptom severity, and reduced recovery timelines. Additionally, the influence of innate anatomical variations of the cervical spine between males and females warrants further investigation[62]. Specifically, females tend to have increased ligamentous laxity[52, 53, 60], smaller vertebral body width[64] and less consistent vertebral coupling[64] which have been suggested to decrease dynamic stability of the cervical spine[62]. These geometric differences between male and female necks[68] along with factors such as the ratio of muscle strength around the cervical spine also needs further investigation with respect to their roles in SRC risk or prevention. If sex-specific strength targets and muscle strength balance goals can be identified, then pre-activity training programs can be designed to meet those targets.

Finally, future research examining the relationship between cervical spine characteristics and SRC risk should consider sport-specific factors and level of competition. That is, greater neck strength and girth, reduced muscle asymmetries, and neutral alignment of the head and neck may be of greater importance for athletes participating in high-impact sports associated with greater magnitude of impacts to the head and body. Athletes participating in sports with no, or limited, contact may not need to incorporate these protocols in pre-athletic participation assessments. Nonetheless, we believe it is still important to collect normative values and understand differences in cervical spine characteristics in athletes who compete in collision, contact, limited, and non-contact sports.

## CONCLUSION

Significant advancements have been made in the diagnosis and management of SRC, yet we are still falling short in preventing and reducing the risk of these injuries occurring. As such, an important focus moving forward is to determine ways to prevent SRC and reduce the severity of their impact when they do occur. Neck strength, girth, and cervical spine posture have been identified as potential factors that reduce SRC risk by decreasing linear and rotational head acceleration and the magnitude of force upon impact. Further, it is speculated that biomechanical differences in the cervical spine between males and females may impact sex differences in SRC rates. Thus, we suggest that focusing on biomechanical properties of the cervical spine are important as they may represent a modifiable factor in reducing SRC risk. Clinically, it is important to comprehensively assess the cervical spine, including strength, girth, and postural assessments, prior to engagement in sport, and particularly in those where there is a high risk of impact, to determine who would benefit from pre-activity cervical spine interventions. Established normative values and baseline measurements would be helpful to in implementing intervention and preventative measures. Furthermore, future research is needed which focuses on: how cervical spine biomechanics influence SRC risk, sex differences in SRC rates, and whether reductions in head acceleration and rotation forces directly impact SRC outcomes.

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**FIGURE 1.**

In the supine position the athlete is performing isometric cervical flexion at mid-range cervical flexion. The clinician is able to quantify the athlete's strength by using the hand-held dynamometer, which is strapped to the table to optimize stability and minimize inconsistencies in clinician force.

**TABLE 1.**

Potential Cervical Spine Examinations and Clinical Considerations in Reducing SRC Risk.

| Factor of Interest | Potential Examinations to Consider | Measurements to Consider | Clinical Relevance | Avenues for Future Research |
|---|---|---|---|---|
| Neck Strength and Girth | Isometric neck strength measures in all three planes of motion to quantify flexion, extension, lateral flexion, rotation, and flexion in rotation (sternocleidomastoid). | Isometric strength measurements with a:<br>• Hand-held dynamometer[5, 10, 19, 68, 70].<br>• Fixed dynamometer[16, 19, 51, 57].<br>• Hand-held tension scale[11]. | Lower neck strength is associated with increased head linear and rotational accelerations during impact[5, 8, 9, 20] as well as increased SRC risk[11]. Additionally, every one-pound (approximately 0.45 kilogram) increase in neck strength, decreased concussion risk by 5 percent[11]. | • Development of age- and sex-specific strength normative values.<br>• Relationship between neck strength and SRC risk, including reducing linear and rotational head acceleration.<br>• Relationship between neck strength and clinical outcomes post-SRC. |
| | Neck circumference measurement. | Circumference measurement above[10] or below[11] the thyroid cartilage. | Lower neck girth is associated with increased head linear and rotational accelerations during impact[5, 8] as well as increased SRC risk[11]. | • Relationship between girth and SRC risk, including reducing linear and rotational head acceleration.<br>• Relationship between girth and isometric neck strength. |
| Neck Endurance | Neck muscle endurance measures. | Cervical flexor[24, 28, 34] and extensor[35, 59] endurance tests. | Since increased activation of the deep cervical flexors is thought to enhance stability and posture in the cervical spine[22, 39] and possibly play a role in controlling head accelerations[32, 61, 72], there is potential for increases in neck endurance in these muscles to be associated with decreased risk of SRC. | • Relationship between deep muscle endurance and SRC risk.<br>• Relationship between deep muscle endurance and clinical outcomes post-SRC. |
| Strength Imbalances | Asymmetry in neck strength measures across the three | Calculation of a strength imbalance score | A flexion-extension ratio that is close to one correlates with lower | • Relationship between neck muscle |

| Factor of Interest | Potential Examinations to Consider | Measurements to Consider | Clinical Relevance | Avenues for Future Research |
|---|---|---|---|---|
| | planes of motion. | within planes of motion[16]. | head accelerations during impact[16] which may allow for more neck protection[16, 29]. | asymmetries and SRC risk. |
| Posture | Observation for forward head posture (FHP). | Craniovertebral angle measurement[56]. | It is speculated that since FHP is associated with a decreased flexion-extension strength ratio[3], more extreme postural impairments may be associated with SRC risk. Obtaining this specific measure may be important as smaller craniovertebral angles are associated with FHP impairments[73]. | • Relationship between head-neck posture and linear and rotational head acceleration.<br>• Relationship between head-neck posture and severity of clinical outcomes post-SRC. |