International Journal of Sport, Exercise and Health Research

Research Article

IJSEHR 2025; 9(1): 11-16

www.sportscienceresearch.com
Received: 14-01-2025
Accepted: 03-06-2025
Published: 11-09-2025
DOI: 10.31254/sportmed.9103

Relationship Between Sport-Related Concussion and Peak Isometric Cervical Muscle Strength: A Systematic Review and Meta-Analysis

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Abstract

Background: Simulated and actual head impacts have demonstrated that cervical muscle strength (CMS) may alter head kinematics and subsequently mitigate sport-related concussion (SRC) risk. Aims and Objectives: This systematic review and meta-analysis aimed to analyze if CMS serves as a protective factor against SRC in contact-collision sport athletes. Materials and Methods: Five electronic databases (PubMed, CINAHL, SportDiscus, ScienceDirect, and Cochrane) were used. Each search was conducted separately using "Concussion AND" followed by one of 10 keywords: Strength*, Musc*, Postur*, Train*, Core*, Neck*, Flex*, Stab*, Mobi*, and Cervical*. After the initial search, weekly automated searches were conducted using PubMed and the above search terms. After meeting inclusion and exclusion criteria, all articles were assessed using the STROBE checklist. STATA Basic Edition (Version 18.0, StataCorp LLC, College Station, TX) and Microsoft Excel for Mac (Version 16.76, Microsoft Corporation, Redmond, WA) were used for data analysis of the articles. Results: Three articles met inclusion and exclusion criteria, but only two articles examining professional rugby athletes were included in the meta-analysis. Flexion, extension, right side bend, and left side bend CMS all had small or moderate effect sizes. This suggests there is no relationship between CMS and SRC in professional rugby athletes. However, based on the article not included in the meta-analysis, greater CMS significantly ($P<0.001$, unadjusted; $p=.004$, adjusted) reduced SRC risk in high school athletes. Conclusion: More research is needed to clarify the association between CMS and SRC.

Keywords: Head Injury, Injury Prevention, Neck Mechanics, Neck Strength, Mild Traumatic Brain Injury.

INTRODUCTION

Sport participation is an increasingly common way to meet recommended physical activity guidelines.[1] Sport participation comes with inherent risk of injury that includes sport-related concussion (SRC), which has continued to become more prevalent in contact-collision sports such as American football and ice hockey.[2] The definition of SRC has evolved over the past several decades and has resulted in several healthcare governing bodies coining their own definitions.[3] A common thread through all of the definitions is that SRC results in transient and immediate disability in patients that are categorized into 'clinical trajectories' related to their symptomatology.[4] Inadequate treatment of these trajectories may lead to delayed return-to-play and decreased quality-of-life due to persistent post-concussion symptoms.[4] Furthermore, the estimated millions of SRCs that occur each year places additional strain on the already overburdened healthcare systems, especially emergency medical services.[5] These direct outcomes of SRC, in the context of a socioecological framework, highlight the need for effective primary prevention practices.

History of Concussion Prevention

Implementing preventative measures for SRC is not a novel concept in the field of sports medicine, however, most interventions have focused on extrinsic modifications such as helmets, mouthguards, and style of play.[6,7] Helmets and mouthguards have received particular attention due to their widespread use in sports, particularly American football, and their importance in dissipating incoming forces to prevent facial and skull trauma.[6,8–11] However, the preponderance of evidence has demonstrated that neither helmets[6–12] nor mouthguards[7–9,13] play a clinically meaningful role in the prevention of SRC in contact-collision sports. Additionally, add-on helmet devices (i.e., Guardian Caps) designed to reduce head impact

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acceleration fail to significantly reduce peak impact forces.[14]

Ultimately, equipment as an extrinsic modifier does not result in meaningful decreases in SRC risk. This has guided many researchers to evaluate other extrinsic modifiers including rule and play style changes. For example, changes in style of play, such as the "Head Up Football" program have yielded promising results with fewer head impacts[7] and a lower risk of SRC in high school American football players.[15] Furthermore, rule changes that penalize players for purposeful or incidental contact to the head (i.e., "targeting") resulted in fewer SRCs in NFL players[16] but results are mixed in soccer[17,18] and ice hockey.[19] Additionally, moving the kickoff line closer to the end zone resulted in fewer SRCs in collegiate American football players.[20] Simply, these programs suggest changes to play style and rules may reduce the burden of SRC.

Current Research on Neck Mechanics

With some extrinsic modifications failing to adequately address SRC risk reduction, researchers are pivoting towards intrinsic modifications to prevent SRC.[6,8] The relationship between cervical muscle strength (CMS) and SRC risk reduction is of particular interest currently.[6] This interest is driven by the theory that head kinematics that would otherwise lead to SRC (particularly shear forces across the brain[21]) may be reduced by increasing CMS.[6] To address this theory, researchers have completed several simulated and laboratory studies. However, neither simulated[22–24] nor laboratory studies[25–31] came to a consensus on the relationship between CMS and SRC. For example, simulation studies to determine forces exerted on the head and brain had highly variable conclusions.[22–24] Some models[22,23] found simulated CMS was not sufficient to attenuate forces responsible for SRC, whereas a separate study[24] suggests that CMS supersedes all conditions in attenuating incoming forces responsible for SRC.

The Present Review

SRC is a common injury occurring in all age groups that often causes immediate and delayed symptoms that impact an athlete's ability to participate in normal daily activities and sport. [32] There is a growing body of research investigating extrinsic and intrinsic strategies to reduce SRC risk.[33] Research suggests, at best, there is inconclusive evidence to support the effectiveness of extrinsic modifications, and, at worst, these methods provide no protection against SRC.[6–14] Focus has shifted towards intrinsic and modifiable protective factors, such as cervical muscle strength and endurance, posture, and biomechanics.[33] Due to the recency of this shift, little research related to CMS and SRC risk has been synthesized for clinicians to take immediate action in improving patient care and reducing SRC risk. Therefore, this article aims to provide an appraisal of the role of CMS in reducing SRC risk in contact-collision sport athletes.

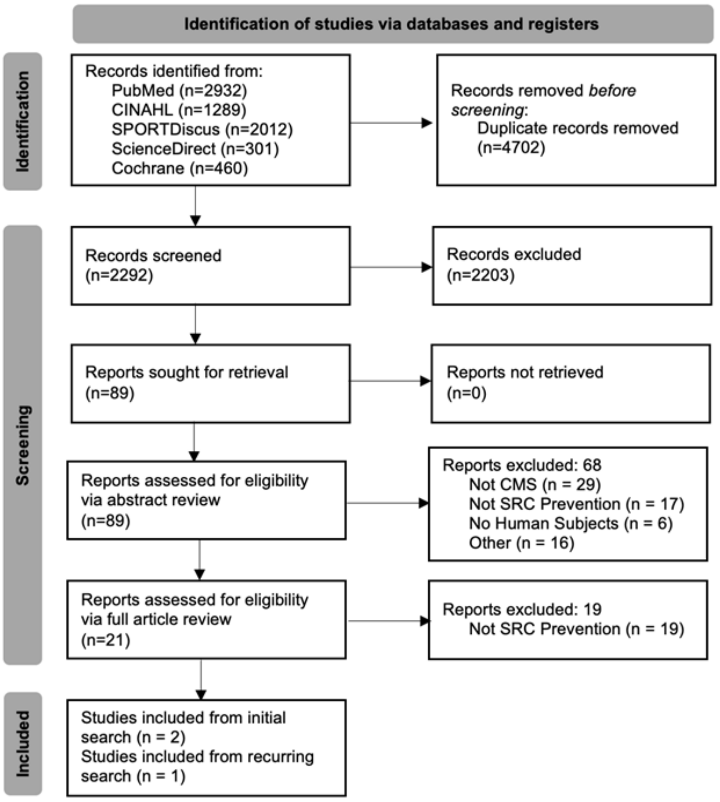
MATERIAL AND METHODS

We conducted a systematic review and meta-analysis to address our clinical question. Studies were identified from five electronic databases (PubMed, CINAHL, SportDiscus, ScienceDirect, and Cochrane). Each search was conducted separately using "*Concussion AND"* followed by ten keywords: *Strength*, Musc*, Postur*, Train*, Core*, Neck*, Flex*, Stab*, Mobi*,* and *Cervical**. These search terms were slightly modified depending on limitations within each database. After the initial search was completed on June 30, 2022, a weekly automated search was created in PubMed using the above search terms. The weekly automated search concluded on December 13, 2024. All authors were involved in the review process. Author 1 and Author 2 initially screened all articles for inclusion. If a conflict occurred concerning article inclusion, Author 3 reviewed the article of concern to make the final determination. Studies were included for title review if they were 1.) published within the last 10 years, 2.) peer-reviewed journal articles, 3.) prospective, 4.) human subjects, and 5.) available in English. Included articles were then screened for exclusion criteria which included removing systematic reviews and any irrelevant articles. A reference list hand search was also conducted on all articles that underwent full-text review. All articles were assessed concurrently by Author 1 and Author 2 using the STROBE checklist to determine methodological quality.[34] Cohen's *d* effect size classification was set at small ($d = 0.2$), medium ($d = 0.5$), and large ($d = 0.8$).[35]

STATA Basic Edition (Version 18.0, StataCorp LLC, College Station, TX) was used to conduct the meta-analysis. Before analysis, Microsoft Excel for Mac (Version 16.76, Microsoft Corporation, Redmond, WA) was used by Author 1 and Author 2 to conduct unit conversions and calculations of geometric mean and geometric standard deviation for CMS values. The sample size, geometric mean, and geometric standard deviation for two groups (athletes with and athletes without SRC) were used to conduct the meta-analysis. Each variable was modeled as a two-group (SRC or No SRC) continuous outcome using random effects. Effect sizes were reported as Cohen's *d* with a 95% confidence interval. Heterogeneity was reported using the I-squared (I^2) statistic.

RESULTS

Our initial literature searches returned 6,994 articles. Ultimately, 89 articles met our inclusion criteria that resulted in further evaluation. Abstract and full-text reviews were conducted to assess for exclusion criteria. Three articles (see Figure 1) were included in the final systematic review. All articles reported similar anthropometric and CMS data. Only Farley et al.[36] and Liston et al.[37] were included in the meta-analysis due to similar participant demographics and methods. Article summaries and STROBE scores for these articles are presented in Table 1.



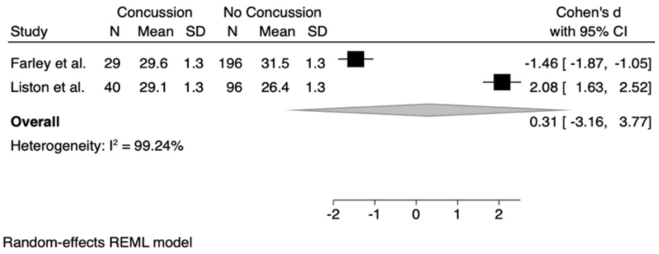
SRC- Sports-Related Concussion; CMS- Cervical Muscle Strength

Figure 1: PRISMA flowchart of included studies

Table 1: Overview of included studies

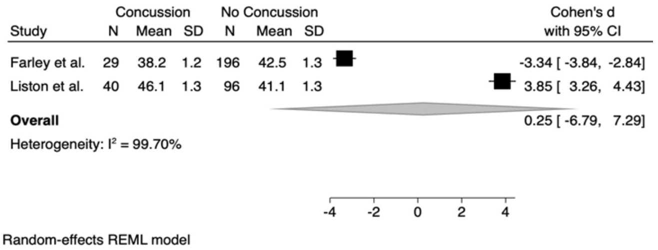
Article	Study Design	STROBE Score	Inclusion Criteria	Participants	Outcome Measures	Results
Collins et al. (2014)	Prospective Cohort	18	Participation in HS RIO M/F lacrosse, basketball, soccer HS athletes	2011; 32 HS 2012; 40 HS Total; 6704 athletes Total SRC; 179	Head girth Neck length & girth Peak isometric CMS in frontal & sagittal planes	Greater CMS in flexion, extension, and R/L lateral flexion reduced SRC incidence 1 pound increase in CMS decreased SRC risk by 5%
Farley et al. (2022)	Prospective Cohort	17	18-35 year old, male, Georgian professional rugby athletes No cervical or glenohumeral pain during ROM assessment	10 professional teams 225 total adult athletes Total SRC; 29	Peak isometric CMS in frontal, sagittal, & transverse planes	Greater CMS in extension decreased SRC risk 10% increase in extension CMS reduced SRC risk by 13% Highest SRC risk occurs when extension CMS is below 41 kilograms
Liston et al. (2023)	Prospective Cohort	18	Male, professional rugby players 18 years or older No current cervical injuries and no cervical surgeries in the past 3 months	136 total adult athletes Total SRC; 40	Peak isometric CMS in frontal & sagittal planes Isometric cervical muscle endurance in the sagittal plane	Greater CMS in extension increased SRC risk Previous SRC is the greatest predictor of future SRC risk

CMS- Cervical Muscle Strength; SRC- Sport-Related Concussion; ROM- Range of Motion; HS RIO- High School Reporting Information Online; M/F- Male/Female; HS- High School



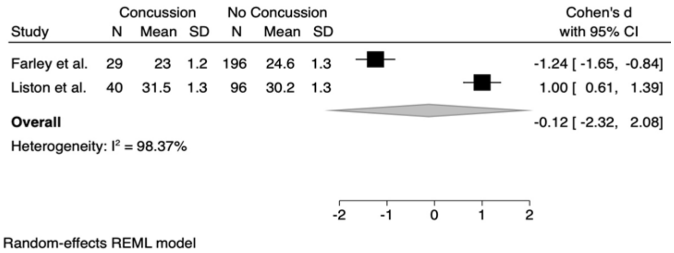
Effect sizes and 95% confidence intervals

Figure 2: Forest plot of meta-analysis for cervical flexion strength in athletes with and without a concussion



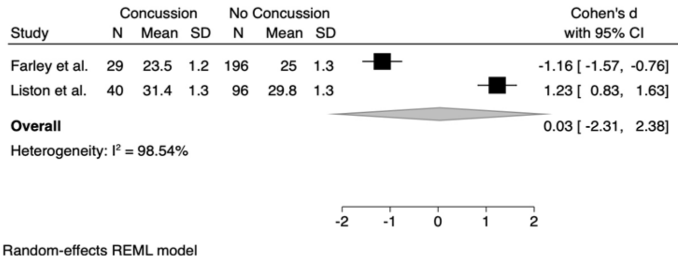
Effect sizes and 95% confidence intervals

Figure 3: Forest plot of meta-analysis for cervical extension strength in athletes with and without a concussion



Effect sizes and 95% confidence intervals

Figure 4: Forest plot of meta-analysis for cervical right side bend strength in athletes with and without a concussion



Effect sizes and 95% confidence intervals

Figure 5: Forest plot of meta-analysis for cervical left side bend strength in athletes with and without a concussion

Collins et al.[38] collected data in coronal and sagittal planes from approximately 6,700 high school student-athletes, of which 179 were diagnosed with an SRC during the trial period. CMS was significantly lower (*p*<0.001, unadjusted; *p*=0.004, adjusted) in all planes for those diagnosed with an SRC.[38] The authors also reported that risk for SRC was reduced by 5% for every 1-pound increase in CMS.[38]

Farley et al.[36] examined linear and rotational CMS of 225 professional rugby players. A total of 30 diagnosed SRCs occurred to 29 players during the study period.[36] Only extension CMS was significantly associated with decreased SRC incidence (*p*=0.044, unadjusted; *p*=0.019, adjusted).[36] For every 1% increase in extension CMS, SRC incidence decreased by 1.3%.[36] Furthermore, Farley et al.[36] determined that 41 kg of extension CMS was a sufficient cutoff value for elevated SRC risk. Extension CMS of less than 41 kg was recorded in 71% of the athletes diagnosed with SRC and only 46% of those without a diagnosed SRC.[36]

Liston et al.[37] also assessed the CMS of professional rugby athletes. Of the 136 study participants, there were 51 SRCs reported from 40 of the players.[37] Both flexion (*p*=0.04, OR=1.01, 95% CI: 1.00-1.01) and extension (*p*=0.01, OR=1.0, 95% CI: 1.00-1.01) CMS were associated with increased SRC risk.[37] When adjusted for body weight, only extension CMS was associated with increased SRC risk (*p*=0.01, OR=1.88, 95% CI: 1.15-3.09).[37]

None of the meta-analyses yielded statistically significant results and all had a very high degree of heterogeneity. Isometric peak flexion strength (Figure 2) had substantial heterogeneity (I^2=99.2%) and a moderate effect size (*r*=0.31, 95% CI: -3.16-3.77). Isometric peak extension strength (Figure 3) also had substantial heterogeneity (I^2=99.7%) and a small effect size (*r*=0.25, 95% CI: -6.79-7.29). Isometric peak right side bend (Figure 4) had substantial heterogeneity (I^2=98.4%) and a small effect size (*r*=-0.12, 95% CI: -2.32-2.08). Lastly, isometric peak left side bend (Figure 5) had substantial heterogeneity (I^2=98.5%) and a small effect size (*r*=0.03, 95% CI: -2.31-2.38).

DISCUSSION

After reviewing nearly 7,000 articles from our original search, we identified only three articles that met our inclusion and exclusion criteria. Two articles[36,38]reported a significant, negative association between increased CMS and decreased risk of SRC. Collins et al.[38] found that CMS in the coronal and sagittal planes mitigated SRC risk, while Farley et al.[36] reported that only extension CMS mitigated SRC incidence. Therefore, both studies agreed that SRC risk is mitigated in individuals with greater extension strength. However, the most recently published article concluded that there was a statistically significant, but non-clinically meaningful association between CMS and risk of SRC.[37] While we are unsure of the reasons behind these conflicting results in professional rugby athletes, we suspect a possible ceiling effect regarding CMS and its ability to mitigate SRC in more physically intense environments. Younger athletes are likely to have less CMS[39] and, therefore, may experience a greater benefit from CMS improvements to prevent SRC.

Connections to Related Literature

The findings from the included articles in our systematic review were not surprising given the inconsistency of results in related literature. For example, lab-based simulation studies that used similar Hybrid III neck models and accompanying computer software to determine forces exerted on the head and brain had highly variable conclusions.[22–24] Simulated values of CMS using the humanoid models were reported to result in limited changes in force attenuation that were also found to not be clinically meaningful.[22,23] Furthermore, simulated increases in CMS did not result in force attenuation significant enough to reduce SRC risk.[23] However, there was a significant difference in some cervical stiffness conditions but the difference was not clinically meaningful in reducing SRC.[22] Unlike others, Jin et al.,[24] suggests that quicker activation of cervical muscles in a simulated setting reduces peak strain and acceleration forces. They also found that cervical strength superseded all conditions in attenuating simulated forces.[24]

Similar studies conducted with human subjects have provided more consistent results, but the findings from these studies are still mixed. One specific variable of interest is the timing of neuromuscular activation. In a laboratory setting, the anticipation of an incoming perturbation and pre-loading of cervical muscles decreased neuromuscular response time and subsequent muscle activation latency in response to head perturbations.[25,28–30,40] Neuromuscular activation of neck musculature (such as the sternocleidomastoid) by clenching the jaw (such as around a mouthguard) before impact further has been demonstrated to significantly decrease head kinematics.[28,29] CMS may also play a role in the reduction of head kinematics following impacts and perturbations; however, findings are inconsistent. Some evidence suggests that isometric strength significantly reduces head kinematics following an impact,[25,26,31] while other studies have reported that isometric strength does not affect head kinematics.[27,30] Interestingly, CMS may increase head kinematics in some scenarios while in others it may not. For example, those who more quickly develop torque in extensor muscles in response to perturbation may experience greater head kinematics while those who develop flexor torque more quickly may experience lesser forces.[30]

Limitations & Strengths

From an inclusion perspective, while all authors participated in article review and selection, there is still a possibility for selection bias. However, we believe this is unlikely since Farley et al.[36] identified Collins et al.[38] as the only article related to the relationship between SRC and CMS, and Liston et al.[37] identified Farley et al.[36] as the only other professional rugby study identifying this potential relationship. This systematic review and meta-analysis is limited by the availability of evidence related to the variables of interest. However, we conducted over 50 searches across multiple databases to ensure that we collected as many articles as possible for review, which ultimately yielded nearly 7,000 articles. Additionally, all three articles that were included in the final review and analyses displayed a high degree of robusticity as they are classified as Level 2 evidence[41] with a Strength of Recommendation classification of “B”. The small sample size of articles for review and the inconsistency of the results makes it difficult to draw meaningful conclusions from these articles. This is exemplified by a high degree of heterogeneity. However, to some extent, this was unavoidable since the I^2 statistic skews high in studies with limited articles for inclusion.[42] This small sample size also limits the generalizability of this review to groups outside of males participating in contact-collision sports. Lastly, this study was not prospectively registered since the review was already conducted prior to considering online registration databases, such as PROSPERO.

CONCLUSION

Our systematic review and meta-analysis, like most literature in the field of SRC risk mitigation through CMS, provided mixed results concerning the relationship between CMS and risk of SRC. In professional rugby athletes, our meta-analysis, because of mixed findings among the included articles, suggests that there is no relationship between CMS in any plane of motion and risk for SRC. While the article regarding high school athletes was not included in the meta-analysis, the authors suggest greater CMS may result in lower risk of SRC in those who are still physically maturing. Clinicians should consider screening CMS in high school athletes and, if necessary, implementing a cervical strength training program to help mitigate risk of SRC. Further research from a more heterogeneous sample, including athletes participating in other contact-collision sports and female athletes in general, would provide greater clarity of the relationship between CMS and future risk of SRC.

Acknowledgments

Author 1 would like to acknowledge the considerable support of Dr. Michelle Gamber throughout this project.

Conflicts of interest

None declared.

Financial Support

None declared.

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