Prevention of sport-related concussions through neuromuscular and neck strengthening programs: A review and synthesis of the literature

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Introduction

A sport-related concussion (SRC) is defined as a brain injury resulting from a blow to the head, neck, or body, transmitting an impulsive force to the brain during sports or exercise (Patricios et al., 2023). As emphasized in the latest Consensus Statement for Concussion in Sport, the prevention of SRCs is pivotal to alleviate the impact of the injury and the potential lingering symptoms that can adversely affect athletes' daily lives and performance (Patricios et al., 2023). In recent years, numerous studies have explored strategies for SRC prevention, including policy and rule changes (for example, restricting body checking), employment of protective equipment (for example, mouthguards, helmets), SRC management (for example, implementation of laws and protocols), and training approaches (for example, neuromuscular and neck training; Patricios et al., 2023). The following review is focused on neuromuscular training (NMT),

NMT, encompassing elements of balance, agility, and strength training, has emerged as a promising strategy to mitigate the risk of SRC (Emery et al., 2015). Neck strengthening has, however, gained most of the attention for its potential efficacy in reducing SRC risk (Collins et al., 2014; Eckner et al., 2014; Elliot et al., 2021; Honda et al., 2018; Hrysomallis, 2016). In fact, neck strengthening may be particularly important for people who are at an increased risk of suffering from a SRC, such as children and youth, females, and individuals with forward head posture (FHP; Cheng et al., 2019; Striefer et al., 2019; Halstead et al., 2018). Incorporating NMT and/or neck strengthening into an athlete's routine may be a feasible and inexpensive way to reduce injury risk (Collins et al., 2014; Hrysomallis, 2016).

Purpose and Objectives

The purpose of this review is to describe the role of neck strength in reducing SRC risk, as it is a major focus in the literature. This review will also provide sports organizations and clinicians with information that can help them promote and develop neck as well as NMT programs for athletes that could help reduce the risk of SRC.

The objectives of the review are to:

1) Highlight the role of neck strength in supporting the head during an impact;
2) Identify at-risk populations for reduced neck strength and;
3) Explore NMT and neck strengthening programs found in the literature.

Search Strategy

This review was first conducted in May 2020. To explore the literature surrounding the benefits of neck strengthening on SRC risk reduction, three databases (PubMed, DOAJ, and Elsevier Science Direct) were searched using the terms "Neck Strength" OR "Cervical Musculature" AND "Concussion" AND "Risk Reduction" OR "Prevention" OR "Gender Differences". Studies were included in the review if they were peer-reviewed, published in English between 2014 and 2020. An additional search was performed on Google Scholar using the same search terms to

supplement the findings from the original searches. Additional articles were identified through a manual search of the reference lists of key articles included within the review. In November 2023, this review was updated by searching through PubMed and Google Scholar using the terms above in addition to “neuromuscular training” OR “balance training” OR “strength training” OR “agility training”. A total of 35 articles were included in this review.

Summary of Findings

The role of the neck during an impact

Even though more research is needed, it has been suggested that increased neck strength may be an effective way to reduce SRC risk (Peek et al., 2020; Striefer et al., 2019). This rationale stems from the notion that a stronger neck can contribute to enhancing the stability of the head and cervical spine, consequently augmenting the neck's capacity to absorb forces associated with impacts (Elliot et al., 2021; Gillies et al., 2022). It is also hypothesized that individuals with increased neck strength can diffuse the forces of a hit through their muscles and thus experience less head motion (meaning, velocity, acceleration, and displacement) following an impact compared to those who have weaker neck muscles, which could lead to a reduced SRC risk (Ennis et al., 2018; Eckner et al., 2014; Collins et al., 2014; Striefer et al., 2019; Peek et al., 2020; Honda et al., 2018).

In fact, while research in this area is still in its early stages, researchers have found a relationship between SRC risk and neck strength. For example, Collins and colleagues (2014) identified a direct relationship between neck strength and SRC risk where lower SRC risk tends to occur with greater neck strength. In their study, Collins and colleagues (2014) measured SRC occurrence in 6,662 male and female soccer, basketball and lacrosse players over a two-year timeframe. The researchers found that there was a five per cent decrease in SRC risk for every one pound of additional neck strength (Collins et al. 2014). Eckener et al. (2014) further supported the protective effects of neck strength by noting that increased neck strength reduced the head's angular and linear velocity (meaning, speed) following an impact. Recent research by Farley et al. (2022) has further deepened our understanding, revealing a significant association between neck extension strength and SRC risk. According to their findings, a 10% increase in neck extension strength corresponds to a 13% reduction in SRC rate (Farley et al., 2022). These studies demonstrate the potential benefits of neck strengthening programs (Ennis et al., 2018; Waltzman & Sarmiento, 2018).

Risk factors for low neck strength

Provided that low neck strength may increase a person’s risk of SRC, identifying *who* is likely to have low neck strength may help in protecting against SRC. This review identified three at-risk groups for low neck strength: (1) Children and youth, (2) females, and (3) individuals with forward head posture (FHP).

1) Children and youth

Research exploring the correlation between neck strength and SRC risk in the youth population is limited; however, preliminary evidence suggests that low neck strength may be a contributing factor to youth athletes' risk of SRC (Engelman et al., 2021; Peek et al., 2020; Caswell et al., 2014). Youth have lower neck strength and a greater head-to-neck mass ratio compared to adults, and as such, they are unable to decrease the forces applied to their body during an impact, which results in greater head acceleration (Peek et al., 2020; Caswell et al., 2014). Clinicians should be aware of youth athletes' increased vulnerability to SRC and prescribe neck strengthening programs as appropriate.

2) Females

Female athletes appear to be at an increased risk of sustaining a SRC compared to males. This increased SRC risk may be partially due to females having lower neck strength, neck girth, and neck muscle mass than their male counterparts (Esopenko et al., 2020; Gallo et al., 2022; Striefer et al., 2019; Koerte et al., 2020; Lin et al., 2018; Mollayeva et al., 2018). As a result of lower neck strength, females often experience more significant angular acceleration and displacement of their heads during an impact, which could increase the risk of SRC (Peek et al., 2020). While few studies have examined the role of strength training on SRC reduction among females, the research that has been done suggests that females with increased neck strength are at a decreased risk of SRC (Cheng et al., 2019, Halstead et al., 2018; Engleman et al., 2021, Koerte et al., 2020; Lin et al., 2018; Mollayeva et al., 2018). For example, Honda et al. (2018) noted that female soccer players with stronger necks had a lower SRC risk than those who had weaker necks. As such, it is possible that female athletes may particularly benefit from a neck strengthening program.

3) Individuals with FHP

An individual's posture may contribute to their SRC risk. Research suggests that greater FHP, when individuals hold their head out in front of their body out of the neutral alignment with their spine while using computer or phone for example, reduces head-neck segment stability (Striefer et al., 2019). This reduced stability occurs in part because FHP activates the superficial neck muscles rather than the deep neck muscles responsible for cervical support (Striefer et al., 2019). Additionally, FHP causes an imbalance between neck flexor and extensor strength ratio, which has been associated with increased head acceleration following an impact (Peek et al., 2020; Striefer et al., 2019). FHP is more often seen in the female population and may contribute to females' having a more significant risk of sustaining an SRC (Striefer et al., 2019). In general, clinicians should assess neck strength when screening for SRC risk and recommend neck exercises as needed.

While perhaps not a risk factor, it is also important to consider how an athlete’s sport may impact their neck strength. In a recent investigation conducted by Nutt and colleagues (2022),

the authors indicate a sport-dependent relationship with neck strength. Specifically, rugby athletes exhibited greater neck musculature strength compared to their football counterparts (Nutt et al., 2022). While additional research is essential to deepen our understanding, this observed disparity may be attributed to distinct physical demands inherent to each sport. Consequently, this suggests the necessity for customized training programs tailored to the specific requirements of each sport as athletes participating in certain sports may have lower neck strength than others.

Neck and neuromuscular training programs

The first portion of this section will center around neck strengthening programs given the predominant focus of existing research on this subject while the subsequent portion will delve into neuromuscular training programs.

A variety of equipment can be used for neck strengthening, including resistance and virtual reality devices (Hrysomallis, 2018). However, Hyrosommalis (2018) and Caswell et al. (2014) both recommend that neck strength programs use limited or inexpensive equipment to make these programs available to a larger portion of the population. Regardless of what equipment is used for these strengthening programs, athletes should be trained on proper techniques by a certified individual to avoid injury (Hrysomallis, 2018; Caswell et al., 2014).

While neck strength programs of varying frequencies, intensities, and durations were examined, programs with a higher frequency (i.e., more than twice per week) and intensity typically resulted in more muscle gains than those with lower frequencies and intensities (Hrysomallis, 2018). This body of research also demonstrated that neck strength can increase in as little as six weeks (for example, Hamlin et al., 2020), highlighting the potential for neck strengthening to have protective effects in a short time frame.

Neck training should include exercises that promote symmetrical muscular development (Peek et al., 2020; Hrysomallis, 2016; Caswell et al., 2014). This is because muscle symmetry is vital to neck stability (Peek et al., 2020). Athletes with strength imbalances between their neck flexors and neck extensors are likely to experience increased head acceleration following an impact (Peek et al., 2020; Hrysomallis, 2016).

Several studies have explored the effectiveness of strength training protocols for improving neck strength in athletes. For instance, a review of the literature performed by Hrysomallis (2016) noted that significant increases in strength were seen in healthy athletes who underwent neck training programs. These programs included various dynamic and isometric exercises, including dumbbell shrugs and lateral neck flexion and extension exercises (Hrysomallis, 2016; Caswell et al., 2014; Hamlin et al., 2020; Rotto et al., 2020). General exercises such as deadlifts that require some degree of isometric neck contraction were not found to improve neck strength (Hrysomallis, 2016). Similarly, in a 12-week intervention program that involved isometric neck strength training for the extensors, flexors, lateral flexors, and rotators, no significant enhancements in neck strength were observed compared to the control group (Deng et al.,

2022). Notably, this was the first study conducted exclusively with female athletes, underscoring the need for further research to pinpoint the ideal duration and frequency of a neck strengthening program as well as specific exercises tailored for females to improve neck strength and therefore possibly reduce SRC risk. On the other hand, in a randomized controlled trial by Attwood and colleagues (2022), participants engaged in either isometric neck training three times per week for eight weeks (intervention group) or maintained their regular training routine without specific neck muscle strengthening (control group). Results demonstrated a substantial (24%) enhancement in neck strength within the intervention group as opposed to the control group, suggesting a potential reduction of SRC risk. Similarly, the 7-week training protocol from Versteegh and colleagues (2020) was found to improve isometric neck strength. However, it is not clear if this program would help decrease SRC risk (Versteegh et al., 2020).

In fact, it is crucial to mention that very few studies have explored the link between neck strength training and head biomechanics such as head acceleration. For instance, not all neck strengthening programs have proven effective in reducing head acceleration. As reported by Waring and colleagues (2022), a program of neck strengthening exercises conducted twice a week over six weeks yielded positive outcomes, demonstrating increased strength in the anterior and anterolateral (meaning, both right and left) neck muscles. However, this intervention did not yield a statistically significant difference in heading biomechanics, indicating no discernible reduction in head acceleration during impact. Therefore, while an increase in neck strength is observed following neck strengthening programs, drawing definitive conclusions regarding SRC risk remains challenging. Consequently, further research on the subject is warranted to provide a more comprehensive understanding.

Moreover, it is worth noting that there might be challenges in implementing neck strengthening programs in sport. In a study conducted by Jeffries and colleagues (2020), even though a significant majority of athletic trainers (70%) expressed confidence in the effectiveness of neck strength and stability programs for SRC prevention, only 15% were actively engaged with teams that had integrated such initiatives. This emphasizes the necessity for additional research to systematically identify and address potential challenges or drawbacks linked to the implementation of these training strategies.

Although the majority of research focuses on neck strengthening programs, some studies examine the effectiveness of NMT programs. For example, Howell and colleagues (2022) randomized athletes into a NMT training program or standard care after receiving clearance from a physician to return to sport following SRC. The NMT intervention was adapted from existing programs that focused on plyometric (meaning short and intense bursts of activity), strength (for example, lifting weights), technique, and balance training. At the end of the training program, the authors made athletes perform a dual task, which consisted of a motor progressions (for example, standing, walking, hopping, ball catching, side-to-side ball catching) combined with cognitive progressions (for example, animal naming, digits backward, immediate memory recall; Howell et al., 2022). The aim of this study was to evaluate the effectiveness of a NMT intervention in reducing acute sport-related time-loss injury over the subsequent year compared to standard care. The results revealed a difference between the two groups,

indicating a higher incidence of injuries in the standard care group following SRC clearance (Howell et al., 2022), which means that those who did NMT were less likely to be injured after they returned to play. This suggests a potential protective effect of NMT against other types of injuries. Another study found that engaging in NMT warm-up programs (for example, balance training, resistance training and plyometric training) three times per week was correlated with a reduced rate of SRC in rugby players across all age groups (Hislop et al., 2017).

Conclusion

This review provides sports organizations and clinicians with information that can help them promote and develop neck strengthening and NMT programs for athletes. Specifically, this review highlighted the neck's role in supporting the head during an impact, the populations at risk of low neck strength, and various programs found in the literature.

According to the research, athletes with lower neck strength are more susceptible to SRC. This is because lower neck strength reduces an athlete's ability to mitigate the forces applied during an impact. Thus, athletes with poor neck strength experience greater head motion than athletes with stronger neck musculature. Children and youth, females, and individuals with a forward head posture tend to exhibit low neck strength and may benefit the most from neck strengthening programs to reduce SRC risk.

While there is evidence showing that neck strengthening programs can increase neck strength, researchers must explore if there is a definitive relationship between neck strengthening programs and SRC risk. That said, few studies have shown that SRC risk tends to be lower when neck strength is greater. Some NMT programs also showed benefits in reducing SRC and other injuries. However, more research is needed to explore a direct link between neck strengthening as well as NMT programs and SRC risk reduction.

Take-Home Points
• Most of the research has focused on neck strengthening programs compared to neuromuscular training to reduce SRC risk. • Children and youth, females, and individuals with forward head posture are at an increased risk of SRC. • More research is needed to draw a definitive conclusion regarding neck and neuromuscular training programs in reducing SRC risk.

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