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Injury-Reduction Programs Containing Neuromuscular Neck Exercises and the Incidence of Soccer-Related Head and Neck Injuries

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Context: Concern is growing among soccer players, coaches, and parents regarding head and neck injuries, including concussion, particularly from heading a ball. Thus, we need to explore soccer-specific head injury risk-reduction initiatives. One such initiative is to condition the neck musculature of young players by adding neuromuscular neck exercises to existing injury-reduction exercise programs.

Objective: To investigate the effect of neuromuscular neck exercises completed as part of an injury risk-reduction exercise program on the incidence of soccer-related head and neck injuries in adolescent soccer players.

Design: Prospective cohort study.

Setting: Two sports high schools and 6 soccer clubs during the 2021 soccer season.

Patients or Other Participants: A total of 364 male and female soccer players, aged 12 to 18 years.

Intervention(s): Members of 1 sports high school and 2 soccer clubs performed neuromuscular neck exercises as part of an injury-reduction program during training (neck training group). Members of another sports high school and 4 soccer clubs performed an injury-reduction program but without neck exercises (comparison group).

Main Outcome Measure(s): Self-reported injury data were collected from each player at the end of the season and used to calculate incidence rate ratios (IRRs) with 95% CIs.

Results: In total, 364 players completed the study, including 146 players in the neck training group and 218 players in the comparison group. Despite players in the neck training group being less likely to self-report a concussion (IRR = 0.23; 95% CI = 0.03, 1.04) and pain on heading a ball (IRR = 0.62; 95% CI = 0.34, 1.07), only a lower incidence of possible concussive events (IRR = 0.38; 95% CI = 0.14, 0.90; $P < .05$) was significant.

Conclusions: Integrating neuromuscular neck exercises into injury-reduction exercise programs has the potential to reduce the risk of adolescent soccer players sustaining a possible concussive event, concussion, or pain on heading a ball.

Key Words: heading, football, concussion, youth

Key Points

- Adolescent players who performed neuromuscular neck exercises integrated into injury-reduction programs recounted fewer concussions and possible concussive events as well as less pain on heading a ball than players who did not perform these exercises.
- Compared with players who indicated experiencing more headers per week, those who described <10 headers per week were more likely to note pain on heading a ball, concussion, and a possible concussive event.
- Players who had not received heading technique training were more likely to report a concussion.
- Most players who performed the neuromuscular neck exercises stated that they would like to continue doing so in the future.

Concern is growing among players, coaches, and parents regarding soccer-related head injuries (including sport-related concussion) and their long-term implications.[1,2] Researchers of a 6-year prospective study of head and neck injuries in international soccer players reported an injury incidence rate of 12.5 per 1000 player-hours (men = 12.8, women = 11.5) and 3.7 per 1000 player-hours for time-loss injuries (men = 3.5, women = 4.1), with the most common injury, aside from contusions and lacerations, being concussion (11%).[3] In soccer, concussion or a potential concussive event may be caused by a direct blow to the head (such as from player-player, ball-player, or player-ground contact), as well as from a blow to the player's body causing a whiplash-type motion of the player's head, as both can transmit force to the brain, resulting in the signs and symptoms of a brain injury.[4] In the United States, the concussion incidence among adolescent soccer players is second only to American football,[5] with many of these injury concerns related to heading and where player-player contact occurs during heading duels.[6]

Heading is a movement skill unique to soccer in which the head is used to purposefully strike the ball to redirect it.[4] It is an important and integral skill that can determine the result of a game. In the 2020 European Championships, 25% of all goals scored were from headers.[7] Reported mean heading incidence rates are between 0.24 and 7.16 headers performed per player per game, and rates increase with age.[4,8,9] A similar heading frequency was demonstrated during practice.[10] Although head and neck injuries in soccer are less common than knee and ankle injuries,[11] an additional concern is that frequent ball-head impacts from heading could lead to long-term detrimental effects on brain function.[12–14] During heading, the player's head experiences rapid linear and rotational movement. Using theoretical models, investigators have suggested that rapid acceleration and deceleration (during ball-head contact) can result in brain tissue deformations, such as changes in pressure gradients within the skull, and high shear stresses or strains.[15,16] Given these health concerns, it is important to explore heading-related injury-prevention initiatives.

The soccer association in the United States (US Soccer) was the first organization to announce a preventive initiative to address the injury concerns surrounding heading. Their heading guidelines, introduced in 2014, aimed to eliminate purposeful heading in players under 10 years of age and restrict the number of headers performed per week by players aged 11 to 12 years.[17,18] Although taking such a preventive approach may prevent heading-related soccer injury in the early childhood years, it is unlikely to prevent such injury in adolescent players: in particular, those aged 13 years and older who are permitted unrestricted purposeful heading.[6] Coordination and neuromuscular control of the musculoskeletal system continue to develop during maturation, with some transient regression in proprioceptive abilities during the adolescent growth spurt.[19] This adolescent growth spurt occurs earlier in girls and later in boys.[19] When considering the varied stages of maturation in young players as well as biological differences between boys and girls,[20] it seems unlikely that all players will be physically ready to head the ball based purely on chronological age.

A supplementary preventive approach to condition young players before they head the ball could include the addition of neck exercises to existing injury-reduction exercise programs.[21] The idea that increased neck control will reduce head impact magnitudes during heading, thereby reducing the injury risk, is based on the premise that a stronger, stiffer neck may help to stabilize the head on ball contact.[22–24] Absolute neck strength is an important factor, yet heading is a fast, dynamic action that relies not only on strength but also on the ability of players to quickly recruit their neck muscles.[23] Thus, exercises that enhance the neuromuscular responsiveness of the neck muscles can help players generate the maximal amount of tension in the shortest amount of time, which increases the coupling of the head-neck-torso to resist head acceleration on ball impact.[23,24] Neuromuscular neck exercises that focus on the flexors are likely to be the most beneficial ones for soccer players, as most headers originate from a player's forehead.[25] In studies of healthy, uninjured populations (including adolescents), the neck extensors were consistently stronger than the neck flexors (with a flexor-extensor ratio of approximately 0.6).[26–28] However, in an earlier study, authors who explored the relationship between the isometric force and electromyographic output of the neck musculature found that although the neck extensors were the strongest group, observed muscle effort per Newton force was higher in the neck flexors.[29] For example, the neck-flexor muscles require a greater amount of muscle activation than the neck extensors to generate a similar force.[29] Therefore, exercises that focus on the force-producing capacity of the neck flexors[29] and reduce strength imbalances between the flexors and extensors[23,30] may be more likely to reduce whiplash forces to the head on ball contact and potentially reduce the injury risk.[29]

The most common injury-reduction exercise program in soccer is the Fédération Internationale de Football Association (FIFA11+; we will refer to this as *11+*). The 11+ was developed in 2006 by FIFA in collaboration with the Oslo Sports Trauma Research Center and the Santa Monica Orthopaedic and Sports Medicine Center.[31] The 11+ consists of 3 parts: parts 1 and 3 contain running drills, and part 2 focuses on specific strength, plyometric, and balance exercises.[31] Although the 11+ does not currently contain any neck exercises, recent researchers showed that integrating 90 seconds of neuromuscular neck exercises into part 2 of the 11+ improved players' neck strength and reduced head acceleration during heading in adolescent male and female players.[23] However, the effect of these exercises on soccer-related head and neck injuries, including concussion, is yet to be explored.

Aim

Our aim was to investigate the effect of neuromuscular neck exercises performed as part of an injury risk-reduction program on the incidence of self-reported soccer-related head and neck injuries (including concussion and possible concussive events) in male and female adolescent soccer players.

Hypothesis

Players who perform injury-reduction exercise programs that contain neuromuscular neck exercises will demonstrate lower incidences of self-reported soccer-related head and neck injuries than players who do not.

METHODS

Study Design and Recruitment

This prospective cohort study, which involved 2 sports high schools and 6 elite youth soccer clubs, was completed during the 2021 playing season in New South Wales, Australia. All players competed in the highest soccer level for adolescent players in Australia, the National Premier League (NPL). Study procedures were approved by the Human Research Ethics Committee at the University of Sydney.

Targeted recruitment of clubs and sports high schools (with specialist soccer development programs) was based, first, on whether each organization already had an established injury-reduction exercise program integrated into routine soccer training and, second, on whether this

Figure. Example of the Versteegh roll and tuck neck-flexor exercise.

exercise program included specific neuromuscular neck exercises (n = 1 sports high school and 2 soccer clubs) or not (n = 1 sports high school and 4 soccer clubs). We specifically recruited the members of the 1 sports high school and 2 soccer clubs who pursued neuromuscular neck exercises integrated into the strength and conditioning component of an injury-reduction exercise program (such as part 2 of the 11+) for this study due to their involvement in an earlier project with the first author (K.P.)[27] and their keen interest in strengthening the existing research relationship. The other school and clubs were then selectively targeted to act as a comparison group, as they were known to us and closely matched the other organizations in age, experience and skill level of the players and number of training sessions and games completed per week, and they performed a similar injury-reduction exercise program but without any additional neck exercises. Male and female adolescent soccer players were then recruited via an invitation email sent by the school or club to each player's parent or guardian. Players were eligible to participate if they were 12 to 18 years old and played soccer for 1 of the targeted organizations during the 2021 soccer season.

Intervention

All players, regardless of organization, pursued an injury-reduction exercise program 2 to 4 times each week as part of their usual training regimen. In addition, 3 of the 8 organizations (n = 1 sports high school and 2 soccer clubs) also performed specific neuromuscular neck exercises we provided to them as part of the strength and conditioning component of the usual injury-reduction exercise program pursued at each training session (and sometimes on match days). The project lead (K.P.) taught these neck exercises to the players and coaching staff before the season commenced. The exercises were supervised during the entire 2021 playing season by either the head physiotherapist (S.V.; n = 1 club) or soccer coaching staff; the project lead (K.P.) followed up with the coaches on a regular basis and conducted several unscheduled visits to monitor adherence (n = 1 club and 1 sports high school). The neuromuscular neck exercises took 90 seconds to complete, were designed to be soccer specific, and were based on the Versteegh roll and tuck (VRT) exercises used in an earlier study.[23] Players were instructed to sit on the ground and hold their knees before rolling backward and forward as fast as they could while keeping their chin tucked in and not allowing their head to touch the ground or floor.[23] They completed one 30-second set of the exercise with their head in the midline (Figure), followed by 30 seconds with their head turned to the left and then 30 seconds with their head turned to the right. These neck exercises reduced head acceleration during heading in adolescent soccer players with an unknown effect on injury incidence.[23]

Effects of COVID-19 Restrictions

Due to the increasing COVID-19 infection rate, the 2021 NPL season ended abruptly in July 2021 after the announcement of stay-at-home orders by the state government with immediate effect for the whole of metropolitan Sydney (an order that remained in force for almost 4 months). These orders meant that the 2021 NPL season consisted of 16 competitive matches played on a weekly basis rather than the planned 22-week season. As a result, the injury data collected via an online self-reported survey were sent directly to players at the end of the playing season.

Main Outcome Measures

All player data were captured and collected using the REDCap application.

Player Characteristics. Player characteristics were whether each player attended a sports high school, which club they played for, the age group they played in, whether they played in a boys' or girls' competition, predominant playing position, frequency of training at school or at a club, average number of games played per week, and how and when they completed the injury-reduction exercise program (training and/or games).

Heading. Specific heading data were (1) whether each player had received training in heading technique at their club or school, (2) whether each player had practiced specific heading drills, and (3) the number of self-reported headers performed during an average training or competition week (including all forms of soccer activity, during both training and games) during the 2021 season.

Injury Incidence. Injury incidence was collected post-season using a self-report online survey sent to each player. Players were asked whether they had sustained a head and neck injury during the 2021 NPL season (training or games). To collect data on possible concussive events, players were asked the following question: "During the 2021 season, have you ever received a blow to your head or body whilst playing soccer which left you with a headache, feeling dizzy, sick, or unwell?" To collect data on concussion, players were asked if they (1) were medically diagnosed with a concussion (by a general practitioner or medical doctor) during the 2021 NPL season; (2) whether they had ever experienced pain or discomfort in their head or neck regions when deliberately heading a ball; and (3) if they had sustained any other type of injury to their head or neck region during soccer training or games during the 2021 NPL season.

Feasibility and Acceptability of the Injury-Reduction Exercise Programs With Neck Exercises. To evaluate the acceptability and feasibility of the injury-reduction exercise programs that contained neck exercises, players were asked to rate their level of agreement with statements specifically about the neck exercises using a 5-point Likert scale (*completely agree*, *agree*, *neither agree nor disagree*, *disagree*, or *completely disagree*). They were also asked whether they would like to continue with these exercises next season (*yes* or *no*).

Data Analyses

Analyses were performed using Stata software (version 14.0). Players were divided into 2 groups: the neck training group, which consisted of players who completed the specific Versteegh roll and tuck neuromuscular neck exercises, and the comparison group, which consisted of players who did not complete neck exercises. Descriptive data for player demographics are presented using counts, means, and SDs. Group differences in player characteristics were analyzed using χ^2 tests for categorical data. We also conducted χ^2 tests to explore the relationships between categorical data and the following variables: number of headers per week and injury incidences, as well as heading technique training and injury incidences. The level of significance was set at $\alpha = .05$.

Training and match exposure time was calculated based on the mean number of training sessions and games played per week during the 2021 NPL season for players in each group as provided by the teams. This exposure time was used to calculate the incidence of pain on heading a ball, possible concussive events, diagnosed concussion, and other head or neck injuries per 1000 player-hours, as well as incidence rate ratios (IRRs) to compare reported rates between groups. The IRRs are reported with 95% CIs. The *smallest worthwhile effect*, defined as the smallest intervention effect that justifies the costs, risks, and inconveniences associated with the exercise program, was used to interpret the IRR.[32,33] Based on earlier research,[21,34,35] the smallest worthwhile effect was set at $\leq$0.90 and was further quantified as *certain* or *uncertain* depending on whether the point estimate and the upper level of the 95% CI were both $\leq$0.90.[36]

Sample Size

We calculated an a priori sample size to inform the minimum number of players in each group based on data presented in a review paper on the incidence of concussion in adolescent soccer players[4] and a pre-experimental study in which researchers examined the use of a training module to increase neck and core strength in high school athletes and its effect on concussion incidences.[37] To explore the difference in injury incidence rates between 2 independent groups with a 2-sided confidence level of 95%, power of 80%, and 10% difference in injury incidence between groups, a minimum group size of 134 players (N = 268 players in total) was required.[38,39]

RESULTS

The total number of eligible players was 534. Although no one declined to participate in the study, only 364 players provided consent and completed the online injury incidence survey at the end of the season. A total of 146 players were in the neck training group and 218 were in the comparison group. All schools and clubs in this study completed an injury-reduction exercise program 2 to 4 times each week as part of their usual training; most players (n = 214, 59%; [n = 89, 61% neck training group, n = 125, 57% comparison group]) completed the 11+. The rest performed programs based on the 11+ but with team-based modifications such as adding the Copenhagen hip-adductor exercise to part 2 or additional dynamic stretches to part 1. All players (100%) completed an injury-reduction exercise program during training sessions, with 301 players (83%) reporting that they completed the program during both training sessions and matches (depending on their team or age group). Of the 146 players in the neck training group, 61 players (42%) performed the exercises twice a week; 67 players (46%), 3 times per week; and 18 players (12%), 4 times per week.

In Table 1, we present the baseline characteristics of players who pursued the neck exercises (neck training group) and those who did not (comparison group). Statistically, more girls in the neck training group played in the under-13 and under-16 age groups than those in the comparison group, and more players in the neck training group played in midfield. Furthermore, the numbers of self-reported headers per week differed between groups (P = .001), with 81% of girls self-reporting <10 headers per week in the neck training group versus 70% in the comparison group. Among the boys, 57% in the neck training group self-reported <10 headers per week versus 77% in the comparison group. No other variables were significantly different between groups.

In Table 2, we provide the injury incidence data collected at the end of the season for boys and girls combined, with boys (n = 76) indicating more injury incidences than girls (n = 50) in terms of raw numbers. For example, 35 (53%) of the 66 players who described pain on heading a ball were boys (6 boys in the neck training group and 29 in the comparison group). Nineteen (54%) of the 35 players who recounted a possible concussive event were boys (2 in the neck training group and 17 in the comparison group). Twelve (80%) of the 15 players who noted a concussion were also boys (1 in the neck training group and 11 in the comparison group). All players (n = 10) who reported any other type of head or neck injury were boys, with injuries including neck pain (n = 1), cut or laceration to the head (n = 2), or bumps or bruising (n = 7). However, when reviewing injury incidences as a percentage of the total number of participants per sex, we found that 34% of boys described an injury incidence compared with 36% of girls, which was not a statistically significant difference.

Interestingly, players who performed fewer headers per week (regardless of group) were more likely to indicate pain on heading a ball (P = .003), a possible concussive event (P = .001), a concussion ($P \leq .001$), and other head or neck injury (P = .017), with more than 73% of players who

Table 1. Player Characteristics

Characteristic	Neck Training Group Combined (n = 146)	Neck Training Group Boys (n = 102)	Neck Training Group Girls (n = 44)	Comparison Group Combined (n = 218)	Comparison Group Boys (n = 124)	Comparison Group Girls (n = 94)
Age group, No. (%)						
Under 13	80 (55)	52 (51)	28 (64)[a]	83 (38)	56 (45)	27 (29)[a]
Under 14	27 (18)	25 (25)	2 (5)[a]	53 (24)	31 (25)	23 (24)[a]
Under 15	24 (16)	20 (20)	4 (9)	52 (24)	25 (20)	27 (29)
Under 16	9 (6)	3 (3)	6 (14)[a]	13 (6)	13 (10)	0 (0)[a]
Under 17	4 (3)	0 (0)	4 (9)	15 (7)	1 (1)	17 (18)
Under 18	2 (2)	2 (2)	0 (0)	2 (1)	2 (2)	0 (0)
Position, No. (%)						
Goalkeeper	6 (5)	4 (4)	2 (5)	22 (10)	15 (12)	7 (8)
Central defender	15 (10)	11 (11)	4 (9)	27 (12)	17 (14)	10 (11)
Full back	11 (8)	10 (10)	1 (1)	40 (18)	23 (19)	17 (18)
Midfielder	67 (46)[a]	47 (46)	20 (45)	64 (29)[a]	35 (28)	29 (31)
Winger	25 (17)	13 (13)	12 (27)	42 (19)	26 (20)	16 (17)
Striker	22 (14)	17 (17)	5 (12)	23 (12)	12 (9)	11 (12)
Training sessions per week, mean ± SD						
School	2.96 ± 0.85	2.83 ± 0.99	3.27 ± 1.22	2.92 ± 0.87	2.83 ± 0.99	3.01 ± 0.82
Club	2.83 ± 0.71	2.93 ± 0.63	2.59 ± 0.84	3.04 ± 0.61	3.07 ± 0.59	2.98 ± 0.64
Games per week, mean ± SD						
School	0.93 ± 0.04	0.96 ± 0.60	0.91 ± 0.52	0.88 ± 0.03	1.01 ± 0.86	0.93 ± 0.36
Club	1.05 ± 0.03	1.08 ± 0.39	1.00 ± 0.00	1.04 ± 0.02	1.07 ± 0.33	1.00 ± 0.00
Heading technique training, No. (%)	65 (45)	41 (41)	24 (55)	94 (43)	60 (48)	34 (36)
Heading drills completed, No. (%)	92 (63)	53 (52)	39 (89)	144 (66)	88 (71)	56 (60)
Headers per week (self-reported), No. (%)						
0	3 (2)	2 (2)	1 (2)	17 (8)	9 (7)	8 (9)
1–5	54 (37)[a]	27 (27)	27 (61)[a]	48 (22)[a]	43 (35)	5 (5)[a]
6–10	36 (25)[a]	28 (28)	8 (18)[a]	96 (44)[a]	43 (35)	53 (56)[a]
11–15	31 (21)	23 (23)	8 (18)	32 (15)	17 (14)	15 (16)
16–20	12 (8)	12 (12)	0 (0)	15 (7)	8 (6)	7 (7)
21+	10 (7)	10 (10)	0 (0)	12 (6)	6 (35)	6 (6)

[a] Denotes a statistically significant ($P \leq .05$) difference in player characteristics for combined data or data stratified by sex.

self-reported an injury also stating that they performed fewer than 10 headers per week. Players who had received heading technique training were less likely to recount a concussion ($P = .007$). Players who self-reported pain on heading a ball were more likely to also relate a possible concussive event ($P \leq .001$) or concussion ($P \leq .001$). A player who noted a possible concussive event was more likely to acknowledge being diagnosed with a concussion ($P \leq .001$).

In terms of the effectiveness of the neuromuscular neck exercises, we observed a worthwhile effect regarding possible concussive events (IRR = 0.38; 95% CI = 0.14, 0.90; $P \leq .05$) as both the point estimate and upper level of the 95% CI for the IRR were ≤0.90, whereas the evidence for concussion (IRR = 0.23; 95% CI = 0.03, 1.04) and pain (IRR = 0.62; 95% CI = 0.34, 1.07) on heading a ball was uncertain (point estimate was ≤0.90, but the upper 95% CI was ≥0.90; $P \leq .05$).

In Table 3, we demonstrate the acceptability and feasibility results for the neck exercises in the neck training group. In addition, using a *yes* or *no* response, 127/146 players (87%) who performed neck exercises commented that they would like to continue doing so.

DISCUSSION

A potential, viable, and low-cost strategy to decrease concussions and potential concussive events in soccer is adding neuromuscular neck exercises to injury-reduction exercise programs.[21] These neck exercises have been shown to reduce head acceleration during heading in a similar cohort of adolescent players.[23] We determined that players in the neck training group were less likely to identify pain on heading a ball as well as fewer possible concussive events, although the results were significant only for the latter. These findings add support to an earlier systematic review outcome that injury-reduction exercise programs involving neck exercises may reduce sport-related head and neck injuries, including concussion in contact-sport athletes.[21] Although the specific role that the neck musculature may play in reducing the head and neck injury risk is still being debated, the ability of a player to actively recruit the neck muscles to reduce the magnitude of head acceleration on contact provides the most likely explanation. This ability is particularly important for reducing injuries caused by whiplash-type motions, in which the head rapidly accelerates and decelerates, which can occur via ball-head impacts and player-player and player-ground contacts. Mitigating the magnitude of head acceleration and deceleration is more likely to reduce the risk of injury when the impact is anticipated, rather than unanticipated (such as a blind-sided tackle or unintentional ball impact to the back of the head).

To further decrease the risk of sustaining a concussion in soccer, multifaceted strategies that include both extrinsic and intrinsic factors should be considered. Extrinsic injury-prevention strategies have shown success: for example, the 2006 implementation of a rule change to permanently remove athletes from play (red card) for deliberate elbow-to-head

Table 2. Injury Incidence (IR[a]) and Injury Incidence Rate Ratio (IRR) for the Neck Training and Comparison Groups

Group	Players, No.	Exposure Hours	Pain on Heading a Ball, No. (%, IR)	IRR	Potential Concussive Event, No. (%, IR)	IRR	Concussion, No. (%, IR)	IRR	Other Head or Neck Injury, No. (%, IR)	IRR
Neck training	146	18 011	19 (13, 1.05)	0.62[b] (0.34–1.07)	7 (5, 0.38)	0.38[c] (0.14–0.90)	2 (1, 0.11)	0.23[b] (0.03–1.04)	4 (3, 0.22)	1.01 (0.21–4.29)
Comparison	218	27 485	47 (22, 1.71)		28 (12, 0.94)		13 (6, 0.47)		6 (3, 0.22)	

[a] Per 1000 player-hours.
[b] Uncertain evidence of a worthwhile effect.
[c] Certain evidence of a worthwhile effect ($P \leq .05$).

contact led to a 29% reduction in head injuries in men's professional soccer.[40] Rule changes such as this one could be complemented by intrinsic strategies, such as teaching heading technique proficiency so players learn how to position the body to safely contest aerial balls and heading duels as well as how to track a ball and receive it on the forehead (as opposed to the top or side of the head). Players in our study who indicated receiving heading technique training were less likely to note concussions. However, this relationship requires further exploration given that we did not collect mechanism-of-injury data. Recent researchers demonstrated that a behavioral-skills training program was an effective method of teaching correct heading technique to youth soccer players based on coach evaluation using a 14-item checklist, although injury data were not collected.[41]

The inverse relationship between heading exposure and injury (including postconcussion symptoms, depression symptoms, anxiety, and sleep disorders) has been identified in professional football players.[42] Our results supported this relationship as our adolescent players who cited an injury were more likely to complete <10 headers per week. Symptoms among players with low-level heading exposure might be explained by a low level of resilience, possibly associated with an inferior heading technique or heading-avoidant behavior.[42] Given that approximately 55% of our players had not received any formal training on heading technique, educating athletes on how to head a ball may be a valuable injury-prevention strategy. This lack of formal training along with the relationship between pain on heading a ball and a possible concussive event or concussion may have meant that some players actively reduced the numbers of headers they performed due to pain, fear-avoidant behavior, or both, which may then have increased their risk of injury when they did head the ball. Caution is warranted for heading guidelines that restrict or prohibit heading in certain age groups, as this may inadvertently increase players' injury risks due to a lack of motor skill development in all components required for heading (which involves more than just ball-head contact). For example, in the only known study to evaluate US Soccer's heading guidelines, investigators described an increase in players aged 10 to 13 years who presented to the emergency room with a soccer-related concussion from 2013 to 2014 (pre-guidelines) versus 2016 to 2017 (post-guidelines; $P \leq .05$).[43] Future heading guidelines must outline the motor learning development framework with which to teach heading technique. The relationship among heading technique training, the number of headers per week, and injury risk should be explored further.

Future heading guidelines could also include a complementary injury-prevention strategy to incorporate neuromuscular neck exercises into routine training and existing injury risk-reduction programs, particularly in young players before they start to head the ball. These exercises will assist in physically preparing players for the head acceleration and deceleration during heading technique training, which will not only improve their heading performance but also potentially reduce their injury risk by decreasing the whiplash-type motion of the player's head-on head or body contact that is associated with some mechanisms of head and neck injury.[23]

Table 3. Player Acceptability and Feasibility of the Neck Exercises: Players Who Agreed or Completely Agreed With Each Statement

Statement	Neck Training Group, No. (%)		
	Combined (n = 146)	Boys (n = 102)	Girls (n = 44)
1. The neck exercise program was easy to complete.	134 (92)	90 (88)	44 (100)
2. The neck exercise program did not take too long for me to complete.	146 (100)	102 (100)	44 (100)
3. I feel that I benefitted from neck exercises.	132 (90)	88 (86)	44 (100)
4. I feel our team benefitted from completing neck exercises.	131 (90)	88 (86)	43 (97)

The inverse relationship between greater neck strength and fewer head and neck injuries, including concussion, has been purported for many years.[44,45] Exercises that enhance the neuromuscular responsiveness of the neck muscles (particularly the neck flexors) enable them to generate the maximal amount of tension in the shortest amount of time (ie, rate of force development or contractile impulse) and will likely provide the most benefit.[44] However, published research in this area is scarce, particularly with soccer players. We know of only 1 study on the effects of an injury-reduction exercise program that involved soccer players (as well as athletes from other sports), and this was a pre-experimental study.[37] The authors explored the effects of a 10-week, preseason exercise program aimed at increasing mobility, agility, stability, flexibility, and general strengthening and included core and neck exercises.[37] They recruited 119 male and female high school soccer, American football, and volleyball athletes and showed a reduction in concussion incidence among athletes who completed the intervention (risk ratio [RR] = 0.15).[37] A similar effect was also seen in 2 cluster randomized controlled trials, involving a combined total of 3807 rugby union players, of a pre-activity movement control exercise program (which included neck exercises) compared with a dynamic stretching and nontargeted exercise program (which did not include neck exercises).[34,35] The RRs and IRRs calculated for these studies revealed a reduction in head and neck injuries for players completing the intervention (RR = 0.34, IRR = 0.33[35] and RR = 0.81, IRR = 0.82[34]). Our results compare favorably with these earlier findings in that players who completed neuromuscular neck exercises as part of their usual injury-reduction exercise program had less self-reported pain on heading a ball (IRR = 0.62) and fewer self-reported possible concussive events (IRR = 0.38) and concussive events (IRR = 0.23) despite only possible concussive events being significant.

Concern is increasing that repeatedly heading a ball, even when it does not lead to immediate signs or symptoms of a head injury, could be detrimental to brain functioning in later life.[12–14] The neck exercises in this study likely had an effect in reducing the injury incidence due to their ability to increase the stability of the head-neck-torso complex. In an earlier study, male and female adolescent players who performed the same neck exercises displayed a reduction in head acceleration during heading compared with players who did not perform these exercises.[23] A larger follow-up study in which researchers look at the effect of these neuromuscular exercises on head acceleration as well as brain functioning and injury incidence would make an important addition to this research area.

Our encouraging findings should be considered with caution in light of a number of limitations. First, the injury data were self-reported. Although the self-reported concussion incidence has been used in earlier investigations of adolescent soccer players,[27,46] it might be subject to recall and other biases. The confounding of recall bias was assumed to be similar between groups, but this may not have been the case. Furthermore, the survey questions pertained only to the most recent playing season to reduce the influence of recall bias, yet we were not able to verify the injury data reported. Currently, no standardized injury-surveillance system exists in Australian sub-elite soccer, and injury statistics are collected ad hoc by different clubs, often using their own injury definitions, making comparisons difficult. Also, we recognized a priori that incidences of concussion in soccer are much lower than those in other contact sports such as rugby, with underreporting or less recognition of concussion in sport being common.[47,48] Thus, the injury incidence was expanded to include possible concussive events and pain on heading a ball. These data can only be collected subjectively via player self-report, and they do not appear in any team's injury system, making verification challenging regardless of when these data were collected. Players may have under- or overreported the number of concussions, possible concussive events, and other head and neck injuries, but the overall concussion rate in our study was comparable with that in earlier epidemiologic studies.[49] The concussion rate of 0.47 per 1000 player-hours in our comparison group was very similar to the 0.36 per 1000 player-hours for boys and 0.82 per 1000 player-hours for girls via an injury-surveillance system.[50]

Another important limitation was that the comparison group was larger than the neck training group. We decided to include more comparison players to mitigate any risk from a potential dropout of comparison clubs and lower participation rates of comparison players. To limit the influence of these sample size differences, we calculated IRRs using soccer exposure hours; however, it is possible that higher incidences of concussion would have been reported in the neck training group if the group was larger and if more eligible players had completed the study. Additionally, we did not recruit adolescent soccer players who had not engaged in an injury-reduction exercise program; therefore, the effect of the neuromuscular neck exercises in isolation cannot be determined from these results. The schools and soccer clubs involved in the study included only adolescent players who were competing at the highest level for their age group, and as such, the findings may not be generalizable to the greater adolescent soccer player population with a lower skill level. Note that the teams and coaches were known to the research team and had already demonstrated good "buy-in" regarding injury risk-reduction exercise programming, which would have contributed greatly to their willingness to integrate neck exercises into their usual training routine. Given that exercise interventions rely on the support and adherence of teams, coaches, and players, our results may not translate to players without this high level of organizational support. Also, the outcomes may have been influenced by the different demographics of the groups, particularly the higher percentage of boys in the training group. Still, this influence may have been balanced by the fact that boys were more likely to self-report pain on heading and concussive and possible concussive events than girls. Finally, whether the shortened season had any influence on the findings is unknown.

CONCLUSIONS

Integrating neuromuscular neck exercises into injury-reduction exercise programs has the potential to reduce the risk of sustaining a possible concussive event or concussion and to reduce pain on heading the ball in adolescent soccer players.

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