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ORIGINAL RESEARCH REPORT

An Accessible, 16-Week Neck Strength Training Program Improves Head Kinematics Following Chest Perturbation in Young Soccer Athletes

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Context: Neck size and strength may be associated with head kinematics and concussion risks. However, there is a paucity of research examining neck strengthening and head kinematics in youths. In addition, neck training is likely lacking in youth sport due to a perceived inadequacy of equipment or time. ***Objective:*** Examine neck training effects with minimal equipment on neck strength and head kinematics following chest perturbations in youth athletes. ***Design:*** Single-group, pretest–posttest case series. ***Setting:*** Athlete training center. ***Participants:*** Twenty-five (14 men and 11 women) youth soccer athletes (9.8 [1.5] y). ***Intervention:*** Sixteen weeks of twice-weekly neck-focused resistance training utilizing bands, body weight, and manual resistance. ***Main Outcome Measures:*** Head kinematics (angular range of motion, peak anterior–posterior linear acceleration, and peak resultant linear acceleration) were measured by an inertial motion unit fixed to the apex of the head during torso perturbations. Neck-flexion and extension strength were assessed using weights placed on the forehead and a plate-loaded neck harness, respectively. Neck length and circumference were measured via measuring tape. ***Results:*** Neck extension (increase in median values for all: +4.5 kg, +100%, $P < .001$; females: +4.5 kg, +100%, $P = .002$; males: +2.2 kg, +36%, $P = .003$) and flexion (all: +3.6 kg, +114%, $P < .001$; females: +3.6 kg, +114%, $P = .004$; males: +3.6 kg, +114%, $P = .001$) strength increased following the intervention. Men and women both experienced reduced perturbation-induced head pitch (all: −84%, $P < .001$). However, peak resultant linear acceleration decreased in the female (−53%, $P = .004$), but not male (−31%, $P = 1.0$) subgroup. Preintervention peak resultant linear acceleration and extension strength ($R^2 = .21$, $P = .033$) were the closest-to-significance associations between head kinematics and strength. ***Conclusions:*** Young athletes can improve neck strength and reduce perturbation-induced head kinematics following a 16-week neck strengthening program. However, further research is needed to determine the effect of improved strength and head stabilization on concussion injury rates.

Keywords: concussion, quasi-isometric, resistance training, youth

Concussions are a growing concern in sport due to the acute and chronic effects of head trauma.[1] It is estimated that between 1.1 and 1.9 million sport and recreation-related concussions occur each year in children 18 years or younger in the United States alone.[2] The cause for concern is especially apparent in adolescence when concussions are more likely[3] and more debilitating during these developmental years.[4] Recently, the repeated head impacts from heading soccer balls have received much attention and led to policy change. In 2015, US Soccer eliminated the heading of soccer balls for players under 10 years and limited exposure for players 11 to 13 years.[5] While this approach may reduce the overall exposure to heading, Peak et al[6] suggest modifying ball mass and pressure, teaching proper technique, and including neck exercises as a more pragmatic approach to concussion reduction.

Researchers typically examine anthropometrics, neck strength, and linear and angular head kinematics in response to impact or perturbation to better understand concussion risks.[7–9] Previous research suggests anthropometric characteristics and neck strength are associated with head kinematics and concussion risk.[10–12] For example, smaller neck circumference, neck to head circumference ratio, and weaker isometric neck strength were significantly associated with concussion rate in 6704 high school athletes.[10] Other studies found that women had less isometric neck strength, neck girth/volume, and stiffness than men, which resulted in greater head kinematics in response to an external force or when heading a soccer ball.[12,13] Finally, a systematic review by Le Flao et al[11] highlighted that high school-aged or younger children display less neck strength and greater head velocity when subjected to head perturbations compared with young and middle-aged adults. A review of heading in young soccer players (≤13 y old) by Wahlquist and Kominsky[14] also found that heading frequency increased with age and that girls sustained higher impact magnitudes than boys, despite heading the ball less frequently. Given the age included by previous reviews[14] and experimental studies,[10] greater research in prepubescent athletes, including heading the ball, are required. Likewise, the suggested importance of neck strength on improving head kinematics and concussion risk warrants further investigation. Given the suggested importance of neck strength in reducing head kinematics and concussion risk, further research examining neck strengthening programs is warranted.

Several strategies aimed to reduce concussion incidence include protective equipment, rule changes, legislation, and increasing neck strength.[2,10] Coaches often target neck strength due to the relatively low cost and the ease and speed of implementation relative to other strategies. Neck strengthening programs can be effective in increasing isometric strength,[13,15–19] as well as endurance.[20] Geary et al[15] found that elite rugby players significantly improved isometric neck strength than a control group after

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completing a twice-weekly isometric training program for 5 weeks. Another study found that 7 weeks of twice-weekly training improved isometric and rotational neck strength in college American football players.[19] Recently, Müller and Zentgraf[13] found that neck and trunk-focused strength training reduced peak linear acceleration of the head during soccer ball headers. Furthermore, Hislop et al[16] found that a 5-month preactivity resistance training program reduced concussion incidence in schoolboy rugby players, which suggests that even general total body training programs can influence concussion incidence in youth. However, research from Mansell et al[18] and Lisman et al[21] found that improvements in isometric neck strength after 8 weeks of neck training did not improve dynamic stabilization during a head perturbation or football tackle, respectively. Given the contrasting results of previous studies, especially in soccer players,[18,22] it is unclear whether gains in isometric neck strength attenuate head kinematics in response to impacts. Furthermore, much of the existing research has included college or high school-aged athletes, so further investigation examining the effectiveness of neck strengthening programs in younger children is warranted.

Isometric neck muscle strength is typically assessed using hand-held dynamometers,[23] tension scales,[10] or custom-built frames. These passive tests are relatively inexpensive and simple to perform, but do not consider the stabilization characteristics required in response to a perturbation. In addition, the aforementioned strength tests are performed under complete control, highlighting the need to examine the dynamic response to perturbations. Indeed, a review of 13 studies found that short-latency anticipatory strength, rather than peak isometric strength, attenuates postimpact head kinematics[24] and therefore should be assessed accordingly. Recent research by Nazarahari et al[25] used a custom-designed frame to measure head kinematics in response to controlled chest perturbations reliably. However, this custom frame has not yet been used to determine the neck strengthening program's effectiveness in reducing head kinematics. Therefore, the purpose of this study is to examine the effects of a 16-week neck strength training program on head kinematics during controlled chest perturbations in youth soccer players. We hypothesize that the neck strengthening program will significantly reduce the head kinematics of young athletes during controlled chest perturbation.

Methods

The Experimental Approach to the Problem

A single-group pretest–posttest design was implemented to examine the effects of a 16-week neck strengthening resistance program on head kinematics following chest perturbation. Changes in neck extension, flexion strength, and head kinematic characteristics were evaluated before and after 16 weeks of twice-per-week neck training utilizing body mass, resistance bands, and manual resistance.

Participants

Twenty-five youth soccer athletes (9.8 [1.5] y, 147.9 [11.2] cm, 38.7 [11.7] kg), including 14 men (8.8 [0.6] y, 142.3 [9.9] cm, 34 [10.7] kg) and 11 women (11 [1.3] y, 154.9 [8.7] cm, 44.7 [10.3] kg) volunteered to participate. The University of Alberta Research Ethics Board approved this study. All athletes were members of local youth soccer clubs, and the athletes, parents or legal guardians, and coaches were fully briefed on the study procedures and purposes before providing informed consent in the spirit of the Declaration of Helsinki. The study procedures, equipment, data collection, and participant recruitment were provided and completed by (temporarily redacted for peer-review) a private company. The raw data were collected and deidentified per the Personal and Electronic Documents Act and the Health Insurance Portability and Accountability Act before being provided to Auckland University of Technology researchers for processing, analysis, and dissemination. Consultation with the Auckland University of Technology research ethics advisor determined that review by the Auckland University of Technology Ethics Committee was not required.

Testing Procedures

All testing procedures were performed before and after the training period. The initial testing was performed 1 week before the initiation of the training intervention. Likewise, posttesting was performed 1 week following the cessation of the training intervention. All testing procedures were performed at an indoor soccer facility.

Anthropometry

Upon arriving, the participants' height and body mass were recorded using a stadiometer (Seca model 213; Seca, Chino, CA) and a digital scale (Seca model 813). Neck length and circumference were assessed with a retractable measuring tape (Seca model 201) with 1-mm precision. Anterior neck length was defined as the distance between the upper margins of the hyoid bone to the jugular notch.[26] Neck circumference was measured at the midway of the neck, between the mid-cervical spine and mid-anterior neck.[26] Participants were standing and instructed to look straight ahead, with shoulders down.

Head Kinematics

Head kinematics were measured by a triaxial inertial measurement unit (IMU, MTws; Xsens Technologies, Enschede, The Netherlands) fixed to the apex of the participant's head by a custom harness. The IMU was composed of a triaxial accelerometer (range: ±16 g), and a triaxial gyroscope (range: ±2000 $\text{deg}\cdot\text{s}^{-1}$) and was sampled at 100 Hz.[25] The positive *x*-axis pointed into the anterior direction, the positive *y*-axis pointed in an upward direction, and the positive *z*-axis pointed in a lateral direction to the participant's right. The testing device was designed to replicate a controlled chest impact to simulate a body-to-body contact at a safe magnitude, leading to the transmission of an impulsive force to the head, which is accepted as a mechanism for concussion.[27] A cable attached to a series of weights was connected to a harness wrapped around the participants' chest via a pulley. The participants knelt on a firmly padded platform with another pad positioned just below the sternum to prevent the participant from falling forward after the perturbation. The participants were then instructed to slowly raise the chin until the head position reached 30° from neutral, whereby the IMU emitted a green light (Figure 1B).[25] After maintaining this position for ~3 seconds, the tester pulled a lever and released the load at the end of the cable.[25] No countdown was given; however, the lever was always within the eyesight of the participants. Therefore, some level of anticipation and "bracing for impact" may have occurred. The impulsive impact was then transferred to the participant's chest via the cable and harness. The participants were instructed to

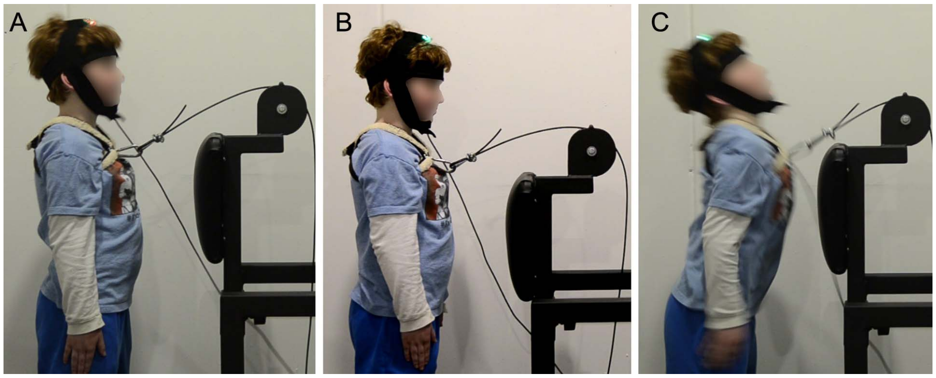

Figure 1 — Participant setup (A) and start position (B) before a controlled chest perturbation (C). Note the light emitted from the inertial measurement unit change from red to green as the participants' head moves to 30° from neutral.

brace for impact and attempt to resist the head and chest movement.[25] Triaxial linear acceleration and triaxial angular rate were recorded by the IMU and saved for future analysis. The drop-load (the amount of weight secured to one end of the cable) was determined during the participants' first visit. Each participant's initial evaluation was loaded to 5 kg. An automatic algorithm determined the change in head pitch and the athlete's time to control and reverse pitch.[25] If little change in pitch was apparent, an additional 5 kg was added to the drop-load and the trials repeated until a substantial change in head pitch was detected. Twenty-one of 25 participants performed a trial with 5 kg, while 4 participants required 10-kg loads before substantial changes in head pitch were apparent. The final load was recorded and matched during posttesting. A single trial was recorded and kept for analysis. The testing apparatus, IMUs, and testing procedures have been previously determined to be highly reliable.[25]

Neck Strength

Neck-flexion and extension strength evaluations were performed following the head kinematic assessment. The athletes warmed up by performing a series of 10 front-to-back and side-to-side neck bends. The athletes then lay supine on the mat with a pad over their forehead. An additional 5 warm-up neck flexions with a 2.27-kg load on the forehead were then performed. Following the warm-up, the tester, a strength, and conditioning coach with ~15 years of experience, prescribed a testing load based on his observations and by receiving feedback from the participants. The participant then performed neck flexions with both the concentric and eccentric portion of the repetition lasting 2 seconds as paced by a metronome. If the athlete demonstrated 5 repetitions with ease at a load, the set was terminated. Following a 1-minute rest period, the test was repeated at a greater load. The maximum load was determined by observing slight difficulty (shaking, difficulty performing the concentric in 2 s) by the fifth repetition. To ensure safety, the set was terminated if the participant completed 10 repetitions, or when the form substantially deteriorated. After 5 minutes of passive rest, the neck extension evaluation was performed in a sequence identical to the flexion evaluation. The participants were lying prone, and the pad was applied on their occiput. At pre-intervention, participants completed an average of 2.4 and 2.7 sets before the final value was determined for neck flexion and extension, respectively. Similarly, 2.0 and 2.5 sets were required to assess neck-flexion and extension strength postintervention.

Training Intervention

A 16-week training program was implemented twice-weekly following soccer practice. The initial 2 sessions were instructed and supervised by a strength and conditioning coach with ~15 years of experience. The coaching staff of each team implemented all subsequent sessions. The exercises were predominantly quasi-isometric and utilized body mass (back bridge and front bridge), resistance bands (neck flexion and extension), or manual resistance (rotational isometrics) (Figure 2). The exercises, sets, repetitions, contraction durations, and rest periods were maintained throughout the training period (Table 1). Band tension was customized during each session based on individual strength levels and feedback. No other resistance training was performed during the 16-week intervention period. All athletes completed at least 85% of the planned training sessions.

Data Processing

Kinematic time series were exported as CSV files and analyzed using custom MATLAB scripts (MATLAB R2019a; MathWorks, Natick, MA). Angular displacement (roll, pitch, and yaw) time series were filtered with a critically damped low-pass filter with a cutoff frequency of 2 Hz. Linear acceleration (x, y, and z) were filtered with a similar filter and a cutoff frequency of 5 Hz. The variables of interest were the pitch, the peak linear acceleration along the antero-posterior axis (PLA-X), and the peak resultant linear acceleration (PLA-R). The pitch (in degrees) was defined as the angular range of head motion about the left–right axis (in the sagittal plane) immediately after the perturbation onset, as the neck first extends due to the head's inertia, then flexes. The PLA-X and PLA-R (in meters per second square) were the negative peak of the head's linear acceleration along the antero-posterior axis, and the resultant linear acceleration sustained as a result of the chest perturbation and the inertia of the head. These 3 variables were semi-automatically identified from the peaks in the time series by the experienced experimenter with the aid of video to identify the perturbation's onset. The participant's body mass also normalized the strength and kinematic data.

Statistical Analysis

Statistical analyses were performed with the 2019 version of RStudio (RStudio, PBC, Boston, MA). Shapiro–Wilk test of normality was conducted on strength and kinematics data. The

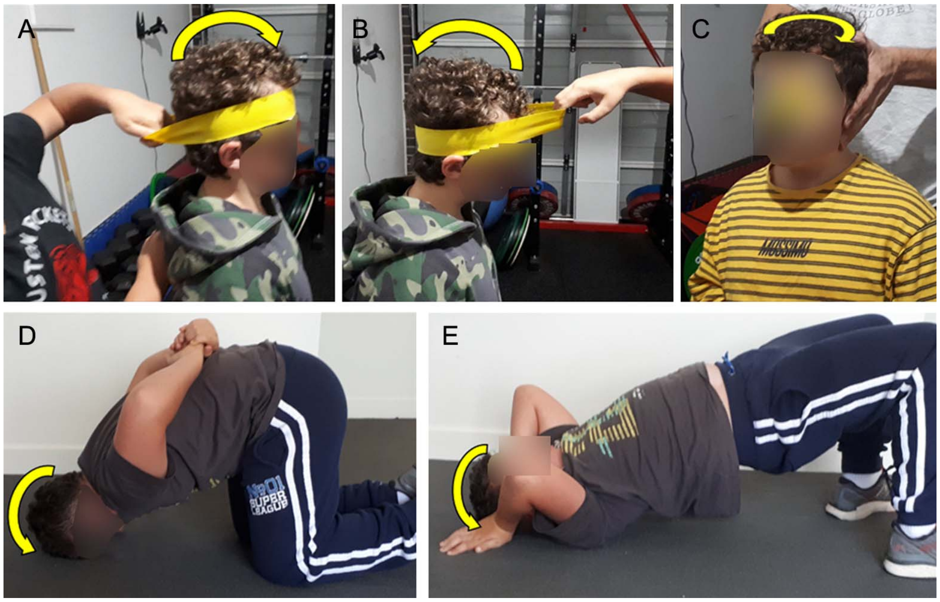

Figure 2 — Neck focused resistance training exercises. (A) Band neck flexion, (B) band neck extension, (C) rotational isometrics, (D) front bridge, and (E) back bridge.

Table 1 Sixteen-Week Neck Training Program

Exercise	Sets	Repetitions	Tempo, s[a]	Rest, s
Band neck extensions	3	10	2-0-1-2	60
Band neck flexions	3	10	2-0-1-2	60
Front bridge	3	10	2-0-2-0	40
Back bridge	3	10	2-0-2-0	40
Rotational isometrics	3	10	5-s holds	60

[a] Tempo is listed at eccentric, isometric, concentric, and isometric; for instance, a tempo of 2-0-1-2 means that each repetition of the exercise is composed of 2 seconds of eccentric contraction, followed by no isometric hold, then 1 second of concentric contraction, and 2 seconds of isometric hold.

means and SD are reported throughout the manuscript for ease of interpretation; however, the data were not normally distributed over the whole group of participants, and the medians and interquartile ranges are reported in Table 2. Nonparametric tests were utilized: the differences between preintervention and postintervention were assessed using the Wilcoxon signed-rank test for all strength and perturbation measures. A Bonferroni correction was applied to the kinematic variables' tests to adjust for the fact that these variables were measured in one trial. Therefore, the significance levels were set at .05 for the strength measures and .017 for the kinematic variables. Linear regressions were performed to assess the association between extension/flexion strength measures or neck circumference and kinematic measures.

Results

Neck Strength

Neck-extension and flexion strength improved for all but one male participant. The average extension strength increased from 5.6 (1.5) to 8.5 (1.5) kg (+52%) throughout the training period, while flexion strength increased from 3.5 (1.0) to 7.0 (1.5) kg (+100%). These increases in neck strength were significant for both extension and flexion and for men, women, and the full group ($P < .001$, Table 2). The increase in strength when strength was normalized by body mass was similarly significant.

Pitch

Kinematic data were not usable for 3 participants (2 men and 1 woman), where no peak in pitch or linear acceleration was identifiable for the postintervention test. The average pitch (±SD) experienced by the participants ($N = 22$) as a result of the perturbation was 38.2° (22.2°) before the training intervention and 6.0° (8.3°) after the training intervention. At the same load, pitch was reduced from preintervention to postintervention for all but one male participant who showed an increase of 6.8°, with an average decrease of 32.2° (24.4°), or −84%. This decrease was significant ($P < .001$). Results by sex are reported in Table 2. Pitch was generally not associated with any of the strength measures, nor with neck circumference. The normalized pitch postintervention was marginally but nonsignificantly associated with the normalized postintervention flexion strength ($P = .039$, $R^2 = .20$).

Linear Acceleration

The average PLA-X was reduced from preintervention (−6.9 [4.9] $\mathrm{m{\cdot}s^{-2}}$) to postintervention (−3.8 [1.6] $\mathrm{m{\cdot}s^{-2}}$). The mean decrease was 3.2 (4.7) $\mathrm{m{\cdot}s^{-2}}$ or −45%. This decrease was visible for 16 participants (73%). Despite mixed results across participants, the overall decrease was significant ($P = .005$), but sex-specific differences were not ($P = .049$ for females, $P = .052$ for males) (Table 2). The PLA-X measure was not associated with any of the strength measures nor with neck circumference.

Similarly, the average PLA-R was reduced from preintervention (10.7 [6.4] $\mathrm{m{\cdot}s^{-2}}$) to postintervention (7.2 [4.6] $\mathrm{m{\cdot}s^{-2}}$). The mean decrease was 3.5 (7.7) $\mathrm{m{\cdot}s^{-2}}$ or −33%. This decrease was visible for 14 participants (64%) but did not reach significance for the overall group ($P = .05$). Results by sex are reported

Table 2 The Median and [Interquartile Range] for Strength and Perturbation Measures Preintervention and Postintervention

	Females			Males			All		
Measurement	**Pre**	**Post**	***P* value**	**Pre**	**Post**	***P* value**	**Pre**	**Post**	***P* value**
Absolute values									
Extension strength, kg	4.5 [4.5 to 4.5]	9.1 [9.1 to 9.1]	.002*	6.1 [5.1 to 7.1]	8.4 [6.8 to 9.1]	.003*	4.5 [4.5 to 6.8]	9.1 [6.8 to 9.1]	<.001*
Flexion strength, kg	3.2 [3.2 to 3.9]	6.8 [6.8 to 7.9]	.004*	3.2 [2.4 to 4.4]	6.8 [4.8 to 7.6]	.001*	3.2 [2.7 to 4.1]	6.8 [6.8 to 7.7]	<.001*
Pitch, deg	43.9 [24.9 to 61.3]	4.6 [1.3 to 7.4]	.002*	25.8 [16.4 to 47.9]	2.4 [1.2 to 3]	<.001*	36.8 [18.6 to 51.5]	2.7 [1.3 to 5.7]	<.001*
PLA-X, $m \cdot s^{-2}$	−6.6 [−13 to −5.7]	−4.7 [−5.7 to −4.1]	.049	−5.1 [−6.5 to −3.8]	−3.3 [−3.6 to −2.6]	.052	−5.7 [−7.9 to −3.9]	−3.6 [−4.7 to −2.8]	.005*
PLA-R, $m \cdot s^{-2}$	12 [7.9 to 19.5]	5.6 [4.8 to 6.7]	.004*	7.9 [5.5 to 9]	5.4 [3.9 to 15]	1	8.6 [7 to 13.9]	5.4 [4.2 to 7.6]	.05
Normalized by body mass									
Extension strength	0.1 [0.1 to 0.1]	0.2 [0.2 to 0.2]	.002*	0.2 [0.2 to 0.2]	0.2 [0.2 to 0.3]	<.001*	0.1 [0.1 to 0.2]	0.2 [0.2 to 0.3]	<.001*
Flexion strength	0.1 [0.1 to 0.1]	0.2 [0.1 to 0.2]	<.001*	0.1 [0.1 to 0.1]	0.2 [0.2 to 0.3]	.001*	0.1 [0.1 to 0.1]	0.2 [0.1 to 0.2]	<.001*
Pitch, $deg \cdot kg^{-1}$	0.9 [0.6 to 1.2]	0.1 [0 to 0.2]	.002*	0.8 [0.5 to 1.6]	0.1 [0 to 0.1]	.001*	0.9 [0.6 to 1.6]	0.1 [0 to 0.2]	<.001*
PLA-X, $m \cdot s^{-2} \cdot kg^{-1}$	−0.1 [−0.3 to −0.1]	−0.1 [−0.1 to −0.1]	.049	−0.1 [−0.2 to −0.1]	−0.1 [−0.1 to −0.1]	.064	−0.1 [−0.3 to −0.1]	−0.1 [−0.1 to −0.1]	.005*
PLA-R, $m \cdot s^{-2} \cdot kg^{-1}$	0.3 [0.2 to 0.4]	0.1 [0.1 to 0.1]	.006*	0.2 [0.2 to 0.3]	0.2 [0.1 to 0.5]	.91	0.2 [0.2 to 0.4]	0.1 [0.1 to 0.2]	.11

Abbreviations: PLA-X, peak linear acceleration along the anterior–posterior axis; PLA-R, peak resultant linear acceleration. Note: Number of participants were 11 females and 14 males for the strength measures, and 10 females and 12 males for the kinematics measures.

*Significant levels of .05 for the neck strength measures and .017 for the kinematic variables following a Bonferroni correction.

in Table 2. The preintervention PLA-R measure was significantly, but poorly associated with the preintervention absolute extension strength ($P = .033$, $R^2 = .21$) as well as the preintervention normalized extension strength ($P = .020$, $R^2 = .24$), in a way that more strength resulted in less acceleration. Contrary to the above results, the pre–post difference in PLA-R was significantly but positively associated with body mass normalized pre–post difference in flexion strength ($P = .026$, $R^2 = .22$) that an increase in flexion strength was associated with an increase in head acceleration.

Discussion

The purpose of this study was to examine the effects of a 16-week neck strengthening program on the head kinematics of youth soccer players. The intervention significantly improved neck flexion and extension strength for men, women, and the entire group over the study period. In addition, pitch and PLA-X significantly decreased for the entire group, whereas only women significantly improved PLA-X and PLA-R between pretest and posttest. This study demonstrates the effectiveness of a neck strengthening program on head kinematics in response to perturbation.

This study found that a 16-week neck strengthening intervention significantly improved extension (+3.0 [1.8] kg on average) and flexion (3.6 [1.5] kg) strength for all participants. Like Fisher et al's[28] study on high school-aged participants, the female's extension and flexion strength increased more than the males after an 8-week neck strengthening intervention. At the college level, Mansell et al[18] also found increases in neck circumference and extensor strength in women but not men after an 8-week training program.

We observed that, along with an increase in strength measures, the kinematic measures also improved after a chest perturbation following training. Pitch improved (ie, decreased) in boys, girls, and the entire group after the training intervention but was not associated with strength or neck circumference. As head kinematics improved but were not associated with neck strength measures, a learning effect and neurological priming may have been present.[29] To our knowledge, this is the only study to measure changes in head pitch in response to perturbation after a training intervention. In addition, the average of all participants PLA-X decreased after the training program, but only the female group decreased PLA-X and PLA-R (the male group did not). This contradicts other studies reporting increased isometric neck strength without improvements in head kinematics in college athletes after 8 weeks of training.[17,18] In addition, isometric strength training did not mitigate head accelerations sustained by adolescent boys throughout a hockey season.[23] However, isometric neck strength significantly reduced head kinematics during soccer ball headings in high-school ages soccer players,[13] and was a significant predictor for concussion in high school basketball, soccer, and lacrosse athletes.[10] The increase in dynamic neck strength may have helped reduce head kinematics, but we cannot be sure it is a cause-and-effect relationship. In addition, this relationship was reversed when normalizing with body mass; however, it is unlikely that body mass changes would substantially manifest themselves in the head or neck, especially compared with larger body segments such as the legs or torso. While participant dynamic neck strength improved and head kinematics decreased in the current study, the significance of these findings must be kept in context given the controlled setting and progressive loading moderated by the researchers. Future research is still needed to examine how these performance improvements impact the ball's actual heading and, more importantly, concussion rates during sport.

Female participants improved both neck extension strength and kinematic measures more than male participants. These differences between sexes may be partially explained by the females' greater kinematic values (more head movement) and lower strength values at baseline, per other studies.[12,13] For instance, even after training, the male group still had lower pitch, PLA-X, and PLA-R values, despite being 2 years younger on average. The female deficits in strength and stabilization may be associated with increased concussion rates in women than men of the same or similar sports (baseball/softball).[30,31] However, these aspects have rarely been investigated below the high school level.

In addition to strength, early muscle activation can help stabilize the neck.[32] High school-aged and younger participants experience greater muscle latencies compared with young and middle-aged adults.[11] However, our study did not use electromyography to assess muscle activity. The training program involved primarily slow and controlled exercises that likely did not require a fast contraction to stabilize the neck. So, it is unclear whether the training program increased muscle activity or decreased latency. Improving muscle latency times (more rapid reaction to impact) could reduce the risk of concussions and high acceleration impacts and improve soccer players' heading performance.[33] Further research utilizing electromyography and a training program with higher velocity exercises or rapid muscle contractions may provide greater insight into how muscle latency changes with training.

Limitations

There are several limitations in our study that should be considered in future research. First, this study had no control group that completed the pretest and posttest without completing an intervention, so it is unclear whether the gains in neck strength and reduced kinematics are due to the training program, maturation, or a learning effect from repeated testing. Several 8-week neck strengthening studies with adults have not used control groups but reported significant gains in isometric neck strength (15% flexion, 22.5% extension[18]; 7% flexion[17]). Another study with adolescent athletes (age 16.9–17.6 y) found 94% to 191% improvements in predicted one repetition maximum flexion and extension after 8 weeks of 4-way neck machine training,[28] but used no control group. Eckner et al[34] also found larger improvements in a neck training group than a control group (age 14.8 [1.8] y) after 8 weeks of training, suggesting that as little as 2 months of training can be effective in improving neck strength and reducing angular velocity. No other study has examined neck strengthening programs in subjects as young as the current study, so there are no values in the literature to compare directly. However, the age of participants in the present study suggests they were likely prepubertal, so it is more likely that gains in strength were due to training, as opposed to increases in motor function due to maturation. Another methodological limitation is the number of trials potentially performed by different dynamic strength tests. As load progression was subjectively determined by the research in collaboration with the participant, some participants may have conducted fewer or more trials to reach fatigue and determine maximal strength. Likewise, trials were stopped once the tester observed substantial pitch changes as a somewhat objective measure. Therefore, future studies should aim to use live accelerometer feedback to determine test trial cutoffs. Finally, it is possible that the participants isometrically braced before the load drop during the chest perturbation testing as the drop lever was within eyesight. However, neck muscle activity (via electromyography) was not assessed, so it is unclear whether the 16-week intervention impacted the amount or onset of muscle activity in head stabilizing musculature.[32,35]

Conclusions

The 16-week neck strengthening program improved neck strength and reduced head kinematics of youth soccer players. Women were weaker and displayed greater head kinematics but improved strength and reduced head kinematics more than the men. However, these results are favorable only in the context of the study's limitations. Further research using a control group, a more extended intervention, electromyographic measurement, examining head kinematics in response to heading a ball, and longitudinal concussion rates are needed to understand the impact of improved neck strength and kinematics on concussion injuries in youth athletes.

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