Published in final edited form as:

Am J Phys Med Rehabil. 2018 April ; 97(4): 292–297. doi:10.1097/PHM.0000000000000843.

Feasibility and Effect of Cervical Resistance Training on Head Kinematics in Youth Athletes: A Pilot Study

James T. Eckner, M.D, M.S.¹, Alireza Goshtasbi², Kayla Curtis, M.S.^{2,3}, Aliaksandra Kapshai, M.S.², Erik Myyra, C.S.C.S.^{1,4}, Lea M. Franco, M.S.¹, Michael Favre, M.Ed., R.S.C.C.*D., C.S.C.S.⁵, Jon A. Jacobson, M.D.⁶, James A. Ashton-Miller, Ph.D.²

¹University of Michigan – Physical Medicine and Rehabilitation

²University of Michigan - Mechanical Engineering

³Current affiliation is DISHER - Ann Arbor, MI

⁴Current affiliation is Towson University – Towson, MD

⁵University of Michigan - Athletics

⁶University of Michigan - Radiology

Abstract

Greater neck girth and strength may be associated with a lower risk of sport related concussion (SRC) due to mitigation of head accelerations by the neck. However, neck strengthening exercise remains unstudied in youth athletes. Therefore, this pilot study assessed the feasibility and effect of targeted neck strengthening exercises in youth athletes. Seventeen participants were allocated to perform 8-week manual resistance-based neck strengthening (n=13) or control resistance exercise (n=4) programs. Before and after the intervention, participants completed laboratory-based assessments of neck size, strength, and head kinematics during standardized test loading in each plane of motion. Descriptive statistics were calculated to compare pre-/post changes between the two groups. All participants safely and successfully completed the intervention. Neck girth and strength increased in both groups, with greater increases in the neck strengthening group. Across all planes of motion, overall changes in head linear and angular velocity (V and ω) decreased in both groups, with greater decreases in ω in the neck strengthening group and greater decreases in V in controls. These results suggest the potential for resistance exercise training to reduce youth athletes' risk for SRC by increasing neck girth and strength. Additional research is needed to determine optimal neck strengthening programs.

Keywords

Concussion; Neck Strength; Sports Medicine; Resistance Training

Correspondence: James T. Eckner, M.D., M.S., Department of PM&R, University of Michigan, 325 E. Eisenhower Pkwy, Ann Arbor MI 48108, Ph: (734) 936-7200, Fax: (734) 615-6713, jeckner@med.umich.edu.

Author Disclosures:

We have no competing interests to declare.

INTRODUCTION

Sport and recreation-related concussion (SRC) is a common injury estimated to affect as many as 3.8 million Americans each year.¹ Concussions are associated with significant short- and long-term morbidity and are now widely recognized as a major public health concern in the U.S.² While all athletes are at risk for SRC, children and females are at elevated risk.^{3–6} This may be due, in part, to the fact that they have smaller, weaker necks as compared to adults and males.^{7–11} A larger, stronger neck has been theorized to more effectively counter external forces acting on the head, thus decreasing the magnitude of the head's kinematic response to impact and in turn reducing the risk of SRC.^{12,13}

The strongest evidence that greater neck girth and strength reduce the risk of SRC comes from a large epidemiological study involving 6,704 high school male and female soccer, basketball, and lacrosse athletes.¹⁴ In this study, the risk of sustaining SRC was significantly associated with smaller mean neck circumference, lower mean neck to head circumference ratio, and lower overall neck strength, with a 5% decrease in odds of concussion reported for every one-pound increase in neck strength. In addition to this field-based study, multiple laboratory-based research studies have also demonstrated inverse associations between neck size, strength, and stiffness and head acceleration magnitudes following application of small test loads to the head.^{15–18}

If greater neck girth and strength are associated with lower magnitudes of head acceleration in response to an applied load and a decreased risk of concussion in populations of athletes, then it follows that strengthening an individual athlete's neck should lead to decreased head accelerations during test load application in the lab as well as a reduced risk for SRC in the field. To date, only a single interventional study has addressed this question in a laboratory setting,¹⁹ and no studies have investigated the effect of neck strengthening exercise on athletes' risk of SRC in the field. In the aforementioned lab-based study, Mansell et al. randomly assigned 36 male and female collegiate soccer athletes to either an 8-week cervical resistance training program consisting of isotonic neck flexion and extension exercises or a control program including the same upper and lower extremity exercises without targeted cervical resistance training. While the neck exercise group demonstrated overall increases in neck girth and isometric strength, no corresponding decrease in peak angular head acceleration magnitudes was observed during test loading.

We therefore conducted this pilot investigation to study the feasibility and effect of targeted neck strengthening exercises applied in each anatomical plane of motion in youth athletes. Our rationale was that a less highly-trained youth population training in all 3 planes of motion might have greater potential for improvement than the elite collegiate athletes previously studied,¹⁹ who may have been limited by a ceiling effect and trained only in sagittal plane flexion/extension. We hypothesized that athletes performing the neck strengthening exercises would experience decreased head accelerations during test loading in each anatomical plane (primary outcomes), with associated increases in measures of neck size and strength (secondary outcomes). We also conducted an exploratory analysis to assess for changes in voluntary muscle activation patterns during anticipatory cervical muscle co-

contraction, given our prior work demonstrating that bracing for impact reduced athletes' head accelerations during test load application.¹⁵

METHODS

This pilot study was conducted during a single summer using a prospective, two-cohort repeated measures design. Participants completed two identical laboratory sessions 1 week before and 1 week after an 8-week supervised resistance exercise program administered by a Certified Strength and Conditioning Specialist (CSCS). The exercise program included general resistance training exercises for all participants, plus additional exercises designed to target the cervical musculature for those participants allocated to the neck strengthening exercise group. During each laboratory session, overall neck girth, the sonographic cross sectional area (CSA) of the sternocleidomastoid (SCM) muscle, the peak moment generated by the neck during maximum voluntary isometric contraction (MVIC) in each plane of motion, and the head's linear and angular accelerations in response to application of standardized test loads in each plane of motion were measured. Surface electromyography (sEMG) of four key cervical muscles was also recorded during MVIC testing and voluntary cervical muscle co-contraction.

Study participants:

A total of 17 (n=15 male; n=2 female) participants aged 14.8 ± 1.8 years participated in this pilot study. Male and female athletes competing in an organized contact or collision sport at either the middle-school or high-school level were eligible. Recruitment was through postings in local schools and athletic facilities, as well as through the University of Michigan's online clinical research recruitment website. Potential participants were excluded if they had sustained a concussion or experienced any neck pain in the preceding 6 months; had any history of significant neck injury, including whiplash, stinger/burner, or cervical radiculopathy; migraine headaches; any other neuro-musculoskeletal disease/injury involving the spine or upper extremities; any condition known to be associated with atlanto-axial instability; a personal or parental history of anxiety disorder; if they reported any unexplained episodes of upper extremity numbness or weakness; or if they were pregnant. Other exclusion criteria were participation within the previous 6 months in a resistance training program including exercises intended to target the neck musculature, or any inability to participate in resistance exercise training. All potential participants also underwent a brief screening examination to rule out any physical findings potentially associated with cervical spine injury, cervical radiculopathy, or myelopathy. All participants provided informed written consent, or assent with parental consent for minors. This study was approved by the University of Michigan's IRB-MED and registered with [ClinicalTrials.gov](https://clinicaltrials.gov/ct2/show/study/NCT02455037) (ID# NCT02455037).

Exercise program details:

Participants completed a total of 16 twice-weekly exercise sessions with the CSCS over a period of 8 weeks, with a minimum of one day of rest between consecutive sessions. Participants were allocated into the neck strengthening (n=13) and control (n=4) groups using weighted block randomization, stratified by sex and age group (middle-school vs. high

school). This strategy was adopted to guarantee that at least some participants in each sex/age-group stratum would be allocated to the neck strengthening group in the event of low or imbalanced enrollment. All participants performed a standardized set of general resistance exercises targeting the chest, shoulders, back, upper and lower extremities, and core. In addition, those participants allocated to the neck strengthening group also performed manual resistance exercises in sagittal plane flexion and extension, coronal plane lateral flexion in both directions, and axial plane rotation in both directions, as well as dumbbell shoulder shrugs under a similar protocol to that recently advocated by Caswell et al.²⁰ The manual resistance exercises were performed lying horizontally on a standard weight lifting bench in the supine (flexion and axial rotation), prone (extension), or right/left-side-lying position (lateral flexion) as illustrated in Figure 1. For each repetition, the CSCS applied steady manual resistance through the full cervical range of motion during both the concentric and eccentric phases of motion so each repetition lasted for a total duration of 3 seconds. During the more technically-challenging axial rotation exercises the CSCS applied resistance at the chin, rather than the posterior jaw, to ensure training in rotation as opposed to lateral flexion and/or extension. The dumbbell shoulder shrugs were performed at a tempo allowing for steady controlled movement to be maintained throughout the concentric and eccentric phases with a brief pause at the top of the shrug motion using the maximum load comfortably completed by each participant for the target number of repetitions while maintaining correct form. The neck strengthening exercise program progressed in volume and intensity over the 8 weeks to accommodate muscular fitness adaptation as follows: Week 1: 1 set x 10 repetitions for shrugs and 1 set x 6 repetitions for the manual resistance exercises; Week 2: 1 set x 10 repetitions for both shrugs and manual resistance exercises; Week 3: 2 sets x 10 repetitions for both; Weeks 4–8: 3 sets x 10 repetitions for both. Exercise sessions took approximately 40 and 60 minutes for participants in the control and neck strengthening exercises groups, respectively. All exercises were performed in accordance with National Strength and Conditioning Association standards.²¹

Laboratory testing protocol:

During each laboratory session, the *areas under the linear and angular head acceleration curves* (primary outcome measures) were recorded during standardized test loading in flexion, extension, right lateral flexion, and left axial rotation using a customized laboratory testing apparatus as previously described by our group.¹⁵ Briefly, participants sat upright with their torsos belted to a vertical stabilizing pad and actively co-contracted their cervical musculature to brace their heads against standardized test loads delivered in each plane of motion by a weight drop apparatus affixed to their head by a tight fitting headgear as illustrated in Figure 2. Participants wore triads of optoelectronic markers (infrared emitting diodes) affixed to their heads to allow tracking of their head position in space by a Certus optoelectronic camera system (Northern Digital, Inc., Waterloo, ON, Canada). The primary outcomes are presented as the changes in linear and angular velocity of the head, $\dot{V}$ in m/s and $\dot{\omega}$ in $^{\circ}/s$, given the mathematical equivalence of these values to the areas under the acceleration vs. time curves.

Secondary outcome measures assessed neck size and strength. *Neck girth* was measured (in cm) using a flexible metric tape at the level of the thyroid cartilage.¹⁵ The *anatomic CSA* of

the left SCM muscle was measured (in cm^2) in the muscle's short axis, i.e., normal to the muscle fiber orientation, at the mid-point between the sternal notch and the mastoid process using a Sonix Touch Research ultrasound machine with a 38 mm, 14 MHz linear array transducer (Analogic Corp., Peabody MA).¹⁵ The *peak cervical moments generated during MVIC in flexion, extension, left lateral flexion, and axial rotation to the right* were determined using a two-step process. First, the peak force generated by the neck while pulling a cable, affixed to the head by tight-fitting headgear and fixed at the opposite end to the wall, was measured (in N) using an in-line force transducer (TLL-500; Transducer Techniques, Temecula, California, USA) as illustrated in Figure 2.¹⁵ Measured force values were then converted to moments (in $\text{N}\cdot\text{m}$) by multiplying each force value by the neck's estimated moment arm, assuming a fixed axis of rotation about C7 for flexion, extension, and lateral flexion,^{22,23} and a fixed axis of rotation about the midpoint of the ears for axial rotation.²⁴

Descriptive statistics were calculated to present pre, post, and change values for each primary and secondary outcome measure. Single sample t-tests were used to assess whether pre-post changes differed from zero within each group, while independent samples t-tests were used to compare pre-post changes between the two groups.

For the exploratory muscle activation analysis, Delsys Trigno sEMG electrodes (Delsys Inc., Natick MA) were placed over the left SCM, upper trapezius (TRAP), splenius capitis (SPL), and semispinalis capitis (SEMI) muscles using previously described surface landmarks.^{24,25} These muscles were selected because they have been shown to be primarily responsible for force generation in the four planes of cervical spine motion.²⁶ The activation of each target muscle was measured during MVIC testing, as well as during voluntary cervical muscle co-contraction where participants were instructed to maximally activate their neck muscles as if bracing for a collision. Raw sEMG data were processed and normalized with respect to each muscle's maximum amplitude.^{24,27,28} The number of participants with at least 1 standard deviation increase in voluntary cervical muscle activation (i.e., an increase in the *percentage of maximal sEMG amplitude achieved during active bracing* following the intervention, as compared to baseline) was compared between the two groups for each muscle.

RESULTS

The stratified group allocation strategy resulted in 10 high school-aged males, 1 high school-aged female, 1 middle school-aged male, and 1 middle school-aged female in the intervention group, and 4 high-school-aged males in the control group. As a result of the imbalanced sex-age group mix, the neck strengthening group was slightly younger (14.6 ± 1.9 yrs. vs. 15.5 ± 1.7 yrs.), shorter (166.7 ± 9.2 cm vs. 174.1 ± 5.3 cm) and lighter (65.5 ± 13.2 kg vs. 67.8 ± 17.9 kg) as compared to the control group (all $p > 0.05$).

Absolute pre/-post decreases in $\dot{V}$ and ω were observed in both groups in all planes of motion, except for ω in axial rotation. The magnitude of within-group change reached statistical significance in the intervention group for $\dot{V}$ and ω in extension ($p = 0.004$, and $p = 0.001$, respectively), and for ω in lateral flexion ($p = 0.011$). Within group pre/-post change magnitudes were significant for $\dot{V}$ in lateral flexion in both groups ($p = 0.005$ and p

= 0.033 for the intervention and control groups, respectively). Absolute pre/-post increases were observed in the intervention group for every secondary outcome measure, with the exception of SCM CSA, although the magnitude of within-group change reached statistical significance only for neck girth ($p = 0.009$). In the control group, absolute pre/-post increases were observed for neck girth, flexion moment, and rotation moment, with the magnitude of within-group change reaching statistical significance for rotation moment ($p = 0.023$).

Pre/-post changes did not significantly differ between the intervention and control groups for any primary or secondary outcome variable (all $p > 0.05$). The mean (SD) initial, final, and pre/-post change values for each primary and secondary outcome measure in both groups are presented in Table 1. Across all planes of motion, a trend toward a greater overall decrease in $\dot{V}$ was observed in the control group [-8.8 (5.3) cm/s vs. -5.3 (7.0) cm/s; $p = 0.136$], while trends toward greater overall decreases in ω [-10.9 (34.7) °/s vs. -10.0 (40.3) °/s; $p = 0.931$] and greater overall increases in moment [$+1.8$ (4.6) N•m vs. $+0.7$ (3.8) N•m; $p = 0.385$] were observed in the intervention group. None of the overall comparisons combined across directions reached statistical significance.

The exploratory muscle activation analyses demonstrated increases of at least 1 SD in cervical muscle activation during voluntary co-contraction following the exercise intervention in 4/13 (30.8%) vs. 0/4 (0%) participants in the neck strengthening and control groups, respectively, for SCM; 5/13 (38.5%) vs. 1/4 (25%) for TRAP; 0/13 (0%) vs. 0/4 (0%) for SPL; and 2/13 (15.4%) vs. 0/4 (0%) for SEMI.

DISCUSSION

In this pilot study, we investigated the feasibility and effect of a manual resistance-based neck strengthening exercise intervention that can be easily implemented in youth athletes without expensive equipment. While all exercises were administered by a CSCS in this study, appropriately trained coaches or even athletes themselves could potentially administer these manual resistance exercises in practice. Importantly, all participants were able to safely and successfully complete the 8-week program. This stated, the subjective impression of the CSCS who administered the exercises was that the level of participant engagement was noticeably greater in the high school-aged participants than the younger middle school-aged athletes. This is not surprising given that resistance training programs on the whole are typically emphasized more at the high school level and beyond. In addition, older, more physically mature adolescents are likely to achieve greater muscle adaptation in response to resistance training than younger adolescents, particularly younger pre-pubertal adolescents. We suspect all athletes may potentially stand to benefit from neck strengthening exercises but that greater results may be obtained in high school-aged athletes as compared to younger individuals.

With regard to this study's primary outcomes, $\dot{V}$ and ω , our results differ from those of Mansell et al., who found no overall decreases in sagittal-plane angular accelerations in response to application of similar laboratory-based test loads in collegiate soccer athletes. In fact, upon completion of the neck strengthening intervention, the collegiate athletes in the

previous investigation exhibited a 40% overall increase in angular head acceleration as compared to baseline in flexion. Pre/post- angular acceleration changes in extension failed to reach statistical significance in the previous study, but increased from baseline for three out of four sex-by-condition comparisons. The reason for the observed differences between our present results and those of Mansell et al. is unclear. We suspect that the differential results may be at least partially attributable to the less highly-trained youth population we studied and our inclusion of resistance exercises in all planes of motion.

Small increases in overall neck girth were observed in both groups, with a 1.6 times greater increase in those who were allocated to the neck strengthening group. However, the small increases in overall neck girth were not associated with measurable increases in the anatomical CSA of the SCM muscle. It is possible the increased neck girth was attributable to muscle hypertrophy, but that the magnitude of hypertrophy occurring over the 8-week study period was too small to be identified in a single cervical muscle. Our observed decreases in $\dot{V}$ and ω with only small associated increases in neck girth suggest potential beneficial effects from neck strengthening exercise without obvious cervical muscle hypertrophy. This has the potential to increase compliance with neck strengthening programs in those female athletes who may be concerned about the appearance of a big neck.

Neck strength, measured as the peak cervical moments generated during MVIC in each plane of motion, generally increased in both groups, with greater increases observed in the neck strengthening group than controls in flexion, extension, and lateral flexion. Across all planes of motion, neck strength increased 2.6 times more in the neck strengthening group than in controls. It is unclear whether the relatively smaller increases in neck strength observed in the control group were due to indirect effects of the general resistance training exercises performed by this group or simply age-associated effects of normal growth and maturation. However, we believe the targeted manual-resistance exercises and dumbbell shrugs performed by the neck strengthening group are likely responsible for the greater strength gains observed in this group.

The exploratory muscle activation analyses demonstrated that 53.8% of participants in the neck strengthening group experienced increased sEMG activation during voluntary cervical muscle co-contraction in at least one of the 4 target muscles following the intervention (21.2% of the 52 individual muscle-specific assessments), as compared to only 25% of those in the control group (6.3% of the 16 muscle-specific assessments). This suggests targeted neck strengthening exercises may influence voluntary cervical muscle activation patterns, which is a relevant finding given our previous work demonstrating that bracing for impact is associated with a reduction in $\dot{V}$ and ω during load application.¹⁵

This is the first study to investigate a targeted neck strengthening exercise intervention applied in each plane of motion in a youth athlete population. These pilot results are encouraging with respect to the potential for neck strengthening to reduce the risk of concussion in youth athletes, but enthusiasm must be tempered by this pilot study's limitations. The biggest limitations of this investigation were the small, imbalanced study population and the imbalanced allocation of participants to the two study groups. These factors limit the study's power to detect statistically significant differences in pre/-post

changes between the groups. In fact, post-hoc power calculations suggest that between-group differences between 1.4 and 26.5 times greater than those observed in the primary outcome measures, V and ω , and between 2.9 and 24 times greater than those observed in the secondary outcomes would have been necessary to achieve 80% power to detect statistically significant differences at $\alpha = 0.05$. Furthermore, caution must be exercised when interpreting the differences in the statistical significance of observed within-group changes given that there were fewer subjects, and therefore there was less power to detect change in the control group. In addition, this pilot study assessed only a single targeted neck strengthening exercise program and the force applied by the CSCS during the manual resistance exercises was not objectively quantified, so we cannot comment on the potential effects of different exercise programs or any potential dose-response effects. Also, while the SCM has been shown to be the single muscle making the greatest contribution to force generation across all planes of cervical spine motion,²⁶ its inclusion as the only cervical muscle assessed with ultrasound excludes other relevant muscles such as TRAP, SPL, and SEMI. Lastly, we performed each lateralized assessment either to the left or the right, so our study design did not have the ability to detect any potential left-right asymmetry that may have been present.

The observed increases in neck girth and strength and the associated decreases in V and ω in this pilot study are encouraging with respect to the potential for resistance training exercises to reduce youth athletes' risk for SRC. This is significant because SRC accounts for approximately 13.2% of all high school athletic injuries,⁶ in the 7.8 million athletes who compete at the high school level in the US each year.²⁹ These pilot results support the need for additional research to determine the incremental benefit of targeted neck strengthening exercises over general resistance training, as well as to define optimal exercise protocols for concussion risk reduction across the youth athlete population.

ACKNOWLEDGEMENTS

This study was funded by a Pilot Grant from the University of Michigan Injury Center and a Mid-Career Investigator Research Grant from the Foundation for Physical Medicine and Rehabilitation. Dr. Eckner received partial effort support from a Career Development Award from the National Institutes of Health (1 K23 HD078502-01A1). The authors would like to thank Ms. Diane Carr for her assistance on this project, and the Ann Arbor YMCA for the use of its facilities. We would also like to thank Dr. Corrie Yablon and Mr. Jesse Richards for their contributions to the project.

As is stated in the Acknowledgements, this work was funded by a Pilot Grant from the University of Michigan Injury Center and a Mid-Career Investigator Research Grant from the Foundation for Physical Medicine and Rehabilitation. In addition, Dr. Eckner received partial effort support from a Career Development Award from the National Institutes of Health (1 K23 HD078502-01A1). The authors do not stand to benefit financially from this work. Preliminary results of this work have been presented in poster format as conference abstracts at the 2016 Big Sky Athletic Training Sports Medicine Conference, the American College of Sports Medicine 63rd Annual Meeting and 7th World Congress on Exercise is Medicine, the 2016 American Academy of Neurology Sports Concussion Conference, and the American Academy of Physical Medicine and Rehabilitation 2016 Annual Assembly.

REFERENCES

1. Langlois JA, Rutland-Brown W, Wald MM. The epidemiology and impact of traumatic brain injury. *J Head Trauma Rehabil.* 2006;21(5):375–378. [PubMed: 16983222]
2. Mccrea M, Guskiewicz KM, Marshall SW, et al. Acute effects and recovery time following concussion in collegiate football players. *JAMA.* 2003;290(19):2556–2563. [PubMed: 14625332]

3. CDC. Nonfatal traumatic brain injuries from sports and recreation activities--United States, 2001–2005. *MMWR Morb Mortal Wkly Rep.* 2007;56(29):733–737. [PubMed: 17657206]
4. Dick RW. Is there a gender difference in concussion incidence and outcomes? *Br J Sports Med.* 2009;43(Suppl_1):i46–i50. [PubMed: 19433425]
5. Hootman JM, Dick R, Agel J. Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. *J Athl Train.* 2007;42(2):311–319. [PubMed: 17710181]
6. Marar M, McIlvain NM, Fields SK, Comstock RD. Epidemiology of concussions among United States high school athletes in 20 sports. *Am J Sports Med.* 2012;40(4):747–755. [PubMed: 22287642]
7. Garces GL, Medina D, Milutinovic L, Garavote P, Guerado E. Normative database of isometric cervical strength in a healthy population. *Med Sci Sports Exerc.* 2002;34(3):464–470. [PubMed: 11880811]
8. Hamilton DF, Gatherer D, Jenkins PJ, et al. Age-related differences in the neck strength of adolescent rugby players: A cross-sectional cohort study of Scottish schoolchildren. *Bone Joint Res.* 2012;1(7):152–157. [PubMed: 23610685]
9. Jordan A, Mehlsen J, Bulow PM, Ostergaard K, Danneskiold-Samsøe B. Maximal isometric strength of the cervical musculature in 100 healthy volunteers. *Spine.* 1999;24(13):1343–1348. [PubMed: 10404577]
10. Lavallee AV, Ching RP, Nuckley DJ. Developmental biomechanics of neck musculature. *J Biomech.* 2013;46(3):527–534. [PubMed: 23127787]
11. Staudte HW, Duhr N. Age- and sex-dependent force-related function of the cervical spine. *Eur Spine J.* 1994;3(3):155–161. [PubMed: 7866827]
12. Broglio SP, Sosnoff JJ, Shin S, He X, Alcaraz C, Zimmerman J. Head impacts during high school football: a biomechanical assessment. *J Athl Train.* 2009;44(4):342–349. [PubMed: 19593415]
13. Viano DC, Casson IR, Pellman EJ. Concussion in professional football: biomechanics of the struck player--part 14. *Neurosurgery.* 2007;61(2):313–327; discussion 327–328. [PubMed: 17762744]
14. Collins CL, Fletcher EN, Fields SK, et al. Neck strength: a protective factor reducing risk for concussion in high school sports. *J Prim Prev.* 2014;35(5):309–319. [PubMed: 24930131]
15. Eckner JT, Oh YK, Joshi MS, Richardson JK, Ashton-Miller JA. Effect of neck muscle strength and anticipatory cervical muscle activation on the kinematic response of the head to impulsive loads. *Am J Sports Med.* 2014;42(3):566–576. [PubMed: 24488820]
16. Reid SE, Raviv G, Reid SE Jr. Neck muscle resistance to head impact. *Aviat Space Environ Med.* 1981;52(2):78–84. [PubMed: 7213298]
17. Simoneau M, Denninger M, Hain TC. Role of loading on head stability and effective neck stiffness and viscosity. *J Biomech.* 2008;41(10):2097–2103. [PubMed: 18571655]
18. Tierney RT, Sitler MR, Swanik CB, Swanik KA, Higgins M, Torg J. Gender differences in head-neck segment dynamic stabilization during head acceleration. *Med Sci Sports Exerc.* 2005;37(2):272–279. [PubMed: 15692324]
19. Mansell J, Tierney RT, Sitler MR, Swanik KA, Stearne D. Resistance training and head-neck segment dynamic stabilization in male and female collegiate soccer players. *J Athl Train.* 2005;40(4):310–319.
20. Caswell SV, Turner T, York M, Ambegaonkar JP, Caswell AM, Cortes N. Neck Strengthening Recommendations for Concussion Risk Reduction in Youth Sport. *Int J Athl Ther Train.* 2014;19(6):22–27.
21. Triplett N, Williams C, McHenry P, Doscher M. Strength and conditioning professional standards and guidelines. Colorado Springs, CO: National Strength and Conditioning Association; 2009.
22. Portero R, Lecompte J, Thoumie P, Portero P. Musculo-tendinous stiffness of the in vivo head-neck segment in response to quick-releases: A reproducibility study. *Isokinet Exerc Sci.* 2011;19(1):7–12.
23. Schmidt JD, Guskiewicz KM, Blackburn JT, Mihalik JP, Siegmund GP, Marshall SW. The influence of cervical muscle characteristics on head impact biomechanics in football. *Am J Sports Med.* 2014;42(9):2056–2066. [PubMed: 24928761]

24. Vasavada AN, Peterson BW, Delp SL. Three-dimensional spatial tuning of neck muscle activation in humans. *Exp Brain Res*. 2002;147(4):437–448. [PubMed: 12444475]
25. Keshner EA, Campbell D, Katz RT, Peterson BW. Neck muscle activation patterns in humans during isometric head stabilization. *Ext Brain Res*. 1989;75(2):335–344.
26. Vasavada AN, Li S, Delp SL. Influence of muscle morphometry and moment arms on the moment-generating capacity of human neck muscles. *Spine*. 1998;23(4):412–422. [PubMed: 9516695]
27. Dewald JP, Pope PS, Given JD, Buchanan TS, Rymer WZ. Abnormal muscle coactivation patterns during isometric torque generation at the elbow and shoulder in hemiparetic subjects. *Brain*. 1995;118 (Pt 2):495–510. [PubMed: 7735890]
28. Thelen DG, Ashton-Miller JA, Schultz AB, Alexander NB. Do neural factors underlie age differences in rapid ankle torque development? *J Am Geriatr Soc*. 1996;44(7):804–808. [PubMed: 8675928]
29. The National Federation of State High School Associations. 2014–15 High School Athletics Participation Survey. 2016 http://www.nfhs.org/ParticipationStatics/PDF/2014-15_Participation_Survey_Results.pdf Accessed March 9, 2016.

Figure 1.
Demonstration of the manual resistance neck strengthening exercise preformed in extension.

Figure 2.

Schematic illustration of the laboratory test loading apparatus configured for extension loading (top left) and the strength testing apparatus configured for flexion MVIC testing (top right). Differential cable configurations for test loading in extension, flexion, lateral flexion, and axial rotation (bottom). t = constant force springs; W = 1 kg drop weight; h = weight drop height; C = cable clamp; T = in-line force transducer; X = estimated head center of mass. Reprinted with permission.

Mean (SD) initial, final, and pre-post change values for each primary and secondary outcome measure in the neck strengthening and control groups.

TABLE 1

Outcome Measure	Neck Strengthening Group				Control Group		
	Initial Measurement	Final Measurement	Pre-Post Change	Initial Measurement	Final Measurement	Pre-Post Change	
Flexion V (cm/s)	11.5 (6.2)	9.0 (4.0)	↓ 2.5 (6.5)	17.1 (1.3)	6.6 (5.4)	↓ 10.5 (6.7)	
Flexion ω (°/s)	74.1 (43.4)	62.4 (39.0)	↓ 11.8 (42.9)	85.7 (8.1)	43.0 (16.5)	↓ 42.8 (23.6)	
Extension V (cm/s)	15.4 (7.4)	9.1 (4.4) *	↓ 6.3 (6.4)	14.0 (0.5)	7.3 (2.7)	↓ 6.7 (5.4)	
Extension ω (°/s)	70.5 (29.6)	39.9 (30.5) *	↓ 30.7 (26.1)	59.9 (12.7)	38.1 (16.7)	↓ 21.8 (28.4)	
Lat. Flexion V (cm/s)	15.8 (0.7)	8.7 (5.2) *	↓ 7.3 (7.5)	17.2 (2.5)	7.7 (4.0) *	↓ 9.5 (5.0)	
Lat. Flexion ω (°/s)	51.6 (28.2)	35.6 (20.4) *	↓ 16.0 (19.4)	46.6 (10.2)	33.8 (22.3)	↓ 12.8 (15.0)	
Rotation ω (°/s)	109.9 (32.7)	126.8 (22.2)	↑ 16.9 (31.0)	89.2 (66.6)	118.3 (25.8)	↑ 29.1 (53.4)	
Neck girth (cm)	34.3 (3.6)	34.9 (3.5) *	↑ 0.5 (0.6)	34.3 (3.5)	34.5 (3.0)	↑ 0.3 (0.9)	
SCM CSA (cm²)	3.1 (1.0)	3.1 (1.0)	0.0 (0.3)	3.3 (0.6)	3.2 (0.6)	0.0 (0.2)	
Flexion Moment (N•m)	16.0 (8.6)	17.7 (7.7)	↑ 1.6 (4.5)	21.7 (6.3)	22.6 (6.5)	↑ 1.0 (2.7)	
Extension Moment (N•m)	17.1 (9.5)	20.7 (8.0)	↑ 3.6 (6.9)	24.4 (10.0)	24.1 (3.2)	↓ 0.4 (7.5)	
Lat. Flexion Moment (N•m)	15.5 (8.4)	17.1 (5.6)	↑ 1.6 (3.9)	16.1 (6.0)	16.6 (4.1)	↓ 0.5 (2.6)	
Rotation Moment (N•m)	7.1 (4.7)	7.7 (3.5)	↑ 0.6 (2.2)	7.5 (4.0)	9.1 (3.2) *	↑ 1.6 (0.8)	

V = Change in head linear velocity; ω = change in head angular velocity; SCM = sternocleidomastoid; CSA = anatomical muscle cross sectional area.

* designates significant within-group pre/-post change at $p < 0.05$.