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Research Paper Review

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Effect of neck muscle strength and anticipatory cervical muscle activation on the kinematic response of the head to impulsive loads

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ABSTRACT

Background: *Greater neck strength and activating the neck muscles to brace for impact are both thought to reduce an athlete's risk of concussion during a collision by attenuating the head's kinematic response after impact. However, the literature reporting the neck's role in controlling postimpact head kinematics is mixed. Furthermore, these relationships have not been examined in the coronal or transverse planes or in pediatric athletes.*

Hypotheses: *In each anatomic plane, peak linear velocity (ΔV) and peak angular velocity ($\Delta\omega$) of the head are inversely related to maximal isometric cervical muscle strength in the opposing direction (H1). Under impulsive loading, ΔV and $\Delta\omega$ will be decreased during anticipatory cervical muscle activation compared with the baseline state (H2).*

Study Design: *Descriptive laboratory study.*

Methods: *Maximum isometric neck strength was measured in each anatomic plane in 46 male and female contact sport athletes aged 8 to 30 years. A loading apparatus applied impulsive test forces to athletes' heads in flexion, extension, lateral flexion, and axial rotation during baseline and anticipatory cervical muscle activation conditions. Multivariate linear mixed models were used to determine the effects of neck strength and cervical muscle activation on head ΔV and $\Delta\omega$.*

Results: *Greater isometric neck strength and anticipatory activation were independently associated with decreased head ΔV and $\Delta\omega$ after impulsive loading across all planes of motion (all $P < .001$). Inverse relationships between neck strength and head ΔV and $\Delta\omega$ presented moderately strong effect sizes ($r = 0.417$ to $r = 0.657$), varying by direction of motion and cervical muscle activation.*

Conclusion: *In male and female athletes across the age spectrum, greater neck strength and anticipatory cervical muscle activation ("bracing for impact") can reduce the magnitude of the head's kinematic response. Future studies should determine whether neck strength contributes to the observed sex and age group differences in concussion incidence.*

Clinical Relevance: *Neck strength and impact anticipation are 2 potentially modifiable risk factors for concussion. Interventions aimed at increasing athletes' neck strength and reducing unanticipated impacts may decrease the risk of concussion associated with sport participation.*

Keywords: *head injuries/concussion; head kinematics; injury biomechanics; neck muscle activation; neck strength*

ANALYSIS

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Background Information

Sport- and recreation-related concussion is a common injury that is now globally recognized as a major public health concern (1, 2). One reason is that between 10-25% of concussed athletes go on to develop prolonged symptoms (3, 4). Risk factor identification and the development of injury prevention strategies are therefore critical. While all athletes are at risk for sustaining concussion, the risk appears to be greater in pediatric and female athletes (5-8). *Low neck strength is a potentially modifiable risk factor that may contribute to an elevated concussion risk in these populations.* Since studies have shown that women have less neck strength than men and children have less strength than adults (9-13), these populations may be at a disadvantage with regard to controlling the head's response during an impact because of less tensile stiffness to resist cervical movement. The overall body of literature addressing this relationship suggests that interventions aimed at increasing athlete's neck girth, strength, and stiffness still hold promise as a means of reducing their risk of sport-related concussion. Therefore, the purpose of this study was to determine the influence of neck strength and muscle activation status on resultant head kinematics after impulsive loading, in athletes of both sexes, ranging in age from pediatric to adult. Three principal anatomic planes (sagittal, coronal and transverse) were studied. Primary outcome variables include change in peak linear velocity (ΔV) and angular velocity ($\Delta\omega$) of the head. Two hypotheses (H1 and H2) were tested:

1. H1: In each anatomic plane, ΔV and $\Delta\omega$ will be inversely related to maximum cervical muscle force generated in the opposing direction.
2. H2: ΔV and $\Delta\omega$ will be decreased during anticipatory cervical muscle activation compared with the baseline cervical muscle activation state.

PERTINENT RESULTS

A total of 46 contact sport athletes (24 male; 22 female) aged 8 to 30 years participated in this study. Participant ages were similar between sexes (16.3 ± 5.0 years for males vs. 15.0 ± 4.4 years for females; P = 0.325), with 14 males and 12 females of high school age or younger and 10 males and 10 females of college age or older. Male participants were taller (167.2 ± 12.4 cm vs. 155.9 ± 12.8 cm; P = 0.004) and heavier (70.3 ± 28.8 kg vs. 53.3 14.4 kg; P = 0.015) than females.

The results of this study support the theory that greater neck strength and anticipatory muscle activation are associated with an attenuated kinematic response to impulsive force(s) acting on an athlete's head across all planes of motion ($p < 0.001$).

- Regarding the influence of neck strength (H1), the magnitude of the inverse relationship between neck muscle strength and ΔV and $\Delta\omega$ fell between $r = 0.417$ and $r = 0.657$ (moderately strong effect sizes).
- The strength of these associations varied between the directions of motion and cervical muscle activation states.
- The applied forces and associated head kinematics were well below those necessary to induce concussion. The lowest magnitude of linear acceleration associated with a concussive head impact measured in an athlete instrumented with the Head Impact Telemetry System is 31.8 g and most concussions result from head impacts in the 90-150 g range. The greatest linear acceleration recorded for any single trial during this study was 4 g.
- Regarding the influence of cervical muscle activation (H2), this study found that anticipatory activation to brace for impact significantly decreased ΔV (by 12.3%) and $\Delta\omega$ (by 9.7%), $p < 0.001$.
- This independent effect was consistent across the spectrum of participants' neck strength. It would be expected that cervical muscle co-contraction should increase the neck's resistance to head motion because of external forces.

CLINICAL APPLICATION & CONCLUSIONS

The present study assessed head-neck stabilization in the sagittal, coronal and axial planes. This is significant because sport-associated head impacts in the real world occur in all planes of motion, and there is evidence to suggest that coronal plane lateral flexion may be more injurious than head motion primarily involving sagittal plane flexion and extension (14, 15). This study's findings suggest that "bracing for impact" may be an effective strategy for decreasing the risk of concussion associated with sport collision by reducing the magnitude of post-impact head kinematics. Neck strength and impact anticipation are two potentially modifiable risk factors for concussion. Interventions aimed at increasing athletes' neck strength and reducing unanticipated impacts may decrease the risk of concussion associated with sport participation. Furthermore, these results also suggest that "heads up" coaching and training strategies aimed at improving athlete's sense of awareness of their surroundings and their anticipation of body collisions may be an effective means of improving player safety by facilitating cervical muscle activation to brace for impact.

STUDY METHODS

Participants

Participants represented a broad range of competitive levels and included 15 soccer players, 14 ice hockey players, 9 football players, 5 martial artists, 2 wrestlers, and 1 lacrosse player.

Potential participants were *excluded* if they had a self- or parent-reported history of concussion, neck injury, migraine headache, or stinger/cervical radiculopathy, cervical musculoskeletal injury, cervical myelopathy, corrected vision less than 20/40, recent exposure to head lice and known or suspected pregnancy.

Each participant completed a brief set of warm up exercises consisting of 1 set of static neck stretches in each plane (flexion, extension, left and right lateral flexion and left and right rotation), one repetition each for 12 seconds, followed by one set of dynamic neck and shoulder circles lasting 12 seconds in each direction before data collection.

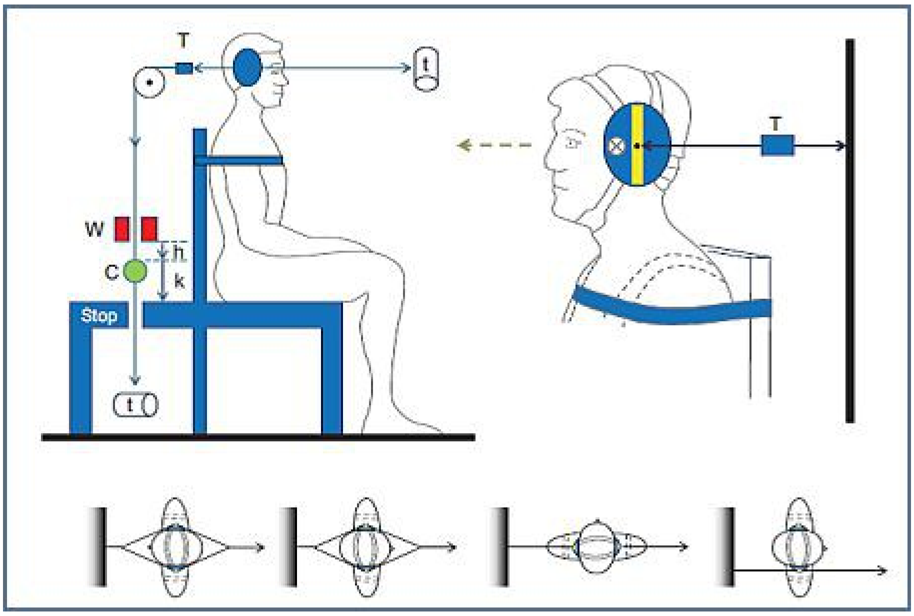
Instrumentation

Neck circumference (girth) was measured at the level of the thyroid cartilage using a flexible metric tape. Head mass, which was used in estimating the location of the head's center of mass, was measured with participants lying supine with their cervical musculature relaxed by suspending the head in a custom head support affixed to a cable with an in-line force transducer. Sonographic cross-sectional area of the right sternocleidomastoid (SCM) muscle at its midpoint was measured with participants sitting upright using an Ultrasonix RP Touch Research ultrasound machine.

Assessment of Maximum Isometric Neck Strength and Rate of Force Development:

Participants sat upright in a rigid-backed seat, with their shoulders and torso stabilized against the seatback by a strap, while wearing customized snugly fitting wrestling headgear attached to an adjustable cable with an in-line force transducer capable of being positioned for pulling against a fixed beam in flexion, extension, left lateral flexion or right axial rotation (see picture below). The participants were instructed to perform maximal isometric neck muscle contractions by gradually increasing the amount of force generated by their neck over 3 seconds until they were pulling with maximal effort in the specified direction. If activation of core or back musculature resulting in obvious torso movement was observed by the study team, the trial was discarded and repeated. The greatest of 3 peak force values in each plane was recorded as the maximum isometric neck strength value. Rate of force development was then assessed by instructing participants to perform similar neck muscle contractions "as rapidly as possible" in each of the specified directions without performance feedback.

Study Apparatus Diagram:



Method of External Force Application to the Head:
Participants were set-up using the adjustable cable with an in-line force transducer positioned for pulling against a fixed beam in flexion, extension, right lateral flexion and left axial rotation. A 1-kg weight located above the cable clamp was free to slide up and down the vertical portion of the cable, such that upon release, the weight free-fell until it contacted the landing pad (to limit maximum displacement of the participants head-neck segment to prevent injury), applying a force to the headgear proportional to the height from which the weight was dropped and proportional to the participant's body mass. A second cable attached to the headgear ran horizontally in the opposite direction to a constant force spring to counterbalance the weight of the first cable. The procedure was repeated over three trials in each orientation under both muscle activation conditions, with at least a 30-second rest between trials.

Measurement of Head Kinematics:
Kinematics were measured using the Optotrak motion capture system that tracked markers attached to participants' forehead, directly above the left or right eye, depending on the direction of impulsive loading and the associated orientation of the kinematic camera. To account for differential impulsive load magnitudes between participants, all kinematic outcome variables were normalized by dividing by the energy associated with the impulse. Average, normalized kinematic head response values were then calculated for each parameter in each orientation under both muscle activation conditions for every participant. The normalized peak linear and angular velocities of the head are referred to as ΔV and $\Delta\omega$, respectively.

Statistical Analysis:
To test H1 and H2, multivariate mixed models were used across all directions of head motion, with adjustment for age and sex. For the primary analysis, maximum isometric neck strength in the opposing direction and cervical muscle activation status were considered primary predictor variables, while ΔV and $\Delta\omega$ were considered the primary kinematic outcome variables. Participants were dichotomized into two age groups (high school or younger athletes and collegiate or older athletes). Pearson product-moment correlation coefficients were calculated to describe the relationships between neck strength and ΔV and $\Delta\omega$ in each direction, under each cervical muscle activation state (baseline versus anticipatory). Secondary analyses assessed the relationships between neck circumference and ΔV and $\Delta\omega$ in each direction as well as between SCM cross-sectional area ΔV and $\Delta\omega$ in sagittal extension.

STUDY STRENGTHS / WEAKNESSES

Strengths

- This study was the first to address head-neck stabilization in the coronal and axial planes in addition to the sagittal plane.
- The magnitude of the load applied to participants' heads by the weight drop apparatus in direct proportion to their body mass was driven by participant safety in the pediatric athletes (that is, the data was normalized to account for unequal impulsive load magnitudes between participants) to avoid injury.
- Future studies can use the study findings to test whether neck strength contributes to observed sex and age group differences in concussion incidence.

Weaknesses

- In this study the magnitude of the drop weight of the apparatus was directly proportionate to body mass (because of the heterogeneity of the subjects), which is a novel technique and differs from other studies in this area. Hence, this limits direct comparison between this study data and previous studies.
- Measuring neck strength accurately is challenging and potential error associated with this measurement is a limitation inherent in any research involving neck strength assessment (16).
- Some inaccuracy may have resulted from incomplete stabilization of the torso during maximum isometric strength assessment (i.e. athletes could potentially accelerate their torso within the constraints of the stabilizing belt in the same direction as the force measurement while maintaining their original head position, allowing them to significantly increase the force generated in those muscles).
- SCM generates neck moments predominately in forward flexion and to a much lesser degree in the other planes of motion, hence measuring the cross-sectional area of SCM as a proxy measure of neck strength may not have been sufficient. Additional imaging methods to individually assess the morphology of cervical muscles for force generation in each direction should be employed in future studies.
- Electromyography was not used in this study to quantify the degree of muscle activation during baseline and anticipatory muscle activation conditions, which should be considered in future studies.
- The headgear was one-size-fits-all with adjustable straps, however, subjectively the authors found that in some participants the fit was too tight or loose. This may have resulted in some relative headgear motion that was not directly coupled to the motion of the head, possibly contributing to greater headgear-to-head motion in females and younger athletes. This may represent an underestimation of the true magnitude of the relationships studied, as greater headgear-to-head motion in those participants with smaller, weaker necks may have obscured the true effect sizes.

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