Evaluating the effect of muscle activation on head kinematics during non-injurious impact in human volunteers

K. A. Reynier[1], A. Alshareef[1], D. Shedd[1], E. Sanchez[2], J. Funk[2], and M. B. Panzer[1]
[1] University of Virginia; [2] Biocore LLC

ABSTRACT

Concussion is a major problem in contact sports, automotive impacts, and recreational activities. Literature suggests that bracing neck muscles increases the effective mass of the head which can lower head kinematics and the risk of injury. Few studies have tried to test this hypothesis with mixed results, and most were performed with loading conditions not consistent in duration with head impact. The goal of this study is to determine the effect of active muscle tension on the head kinematics of a human volunteer in response to a direct impact to the head.

The volunteer study was completed using twenty male volunteers. Each subject completed a series of baseline tests, including magnetic resonance imaging (MRI) and neuro-cognitive assessments. The subjects experienced three non-injurious impacts delivered by a 3.7 kg padded spherical impactor at 2 m/s. The subjects were instructed to provide different levels of neck muscle activation for each test (passive, co-contraction, and unilateral isometric contraction). Follow-up MRI imaging and neuro-cognitive assessments were completed to ensure no injury was induced. There were no deviations from baseline for all subjects, and all subjects were asymptomatic following impacts at both one-day and one-week post.

The largest resultant linear acceleration (12.1 ± 1.5 g) and angular velocity (-6.9 ± 0.6 rad/s) were associated with passive musculature. Maximum muscle contraction during the unilateral tensing resulted in a decrease in linear acceleration (10.7 ± 1.7 g) and angular velocity (-6.2 ± 0.6 rad/s). This data could be used to make important conclusions about techniques to reduce injury in higher impact scenarios.

INTRODUCTION

Concussion is a major problem in contact sports with between 1.6 and 3.8 million reported concussions per year (Langlois, 2006). One hypothesis in the medical and biomechanical literature is that actively tensing the neck muscles prior to an impact can decrease the resulting head kinematics and protect the subject from a concussion; however, few studies have tested this hypothesis with mixed results (Eckersley, 2017; Mansell, 2005; Mihalik, 2010; Tierney, 2005). The role of neck muscle tension and muscle strength in head injury mitigation is unknown, but is believed to decrease the risk of concussion by increasing the effective mass of the head (Collins, 2014; Viano, 2007). Previous studies have determined that pre-impact neck muscle activation will reduce head kinematics; however, the loading conditions applied in these studies have longer impact durations than a head impact (Reid, 1981; Eckner, 2014; Hendler, 1974; Tierney, 2005). No study has investigated the effect of active muscle tension on head kinematics following a direct impact to a volunteer.

The goal of this study was to determine the effect of active neck tensing on the head kinematics of a human volunteer in response to low-severity, non-injurious impacts to the head.

METHODS

Study Design

The current study was approved by the University of Virginia Institutional Review Board, and all subjects signed informed consent forms prior to participation in the study. Twenty healthy males (age = 22.8 ± 3.0 years, height = 177.4 ± 3.5 cm, mass = 78.2 ± 9.5 kg) volunteered to complete the study. Exclusion criteria included history of concussion, seizures, migraines, neurologic conditions, skull or brain surgery, or cognitive impairment.

The subjects each completed four appointments over approximately two weeks. During the first appointment, subjects completed a baseline assessment that involved neuropsychological tests, balance assessment, and magnetic resonance imaging (MRI) scans. The second appointment consisted of three non-injurious impacts at increasing levels of muscle activation. One day after the impacts, subjects completed additional neuropsychological exams, balance assessments, and MRI scans. One week after the impacts, an additional MRI scan was completed for each subject. The one day and one week assessments were compared to baseline to determine if any deviation from baseline was present after the non-injurious impacts.

Testing Protocol

A 3.7 kg spherical impactor (radius = 2 in) delivered a 2 m/s impact 7.5 cm above the right tragus. The spherical impactor included an angular rate sensor (ARS3 Pro; DTS, Seal Beach, CA) and an accelerometer (AC-65; Meggitt, Irvine, CA) located at the centroid to record the ball kinematics during each impact. A bifilament pendulum system was used to ensure consistent impacts and limit the energy transferred to the subjects' heads (Figure 1). Subjects wore a custom-fit, rigid mouth piece that was molded to their upper dentition, and a six degree-of-freedom sensor to record head kinematics (6DX Pro; DTS, Seal Beach, CA) was housed on the mouth piece near the volunteer's hard palate. Muscle activity of the sternocleidomastoid (SCM) and upper trapezius were recorded using surface electromyography sensors (band-pass filter, 20-450 Hz; common mode rejection ratio, > 80 dB) (Trigno Wireless; Delsys Incorporated, Natick, MA) to quantify muscle activation (Falla, 2002; Burnett, 2007).

Prior to the impacts, maximum voluntary contractions were recorded for the SCM and trapezius muscles. Each subject received one non-injurious impact at each of the following levels of muscle activation: passive, maximum co-contraction, and maximum unilateral contraction. For the passive condition, subjects were instructed to remain as relaxed as possible with their head and neck in a neutral position while looking forward. To reduce any pre-impact activation, the subjects were told the impactor would be released within a certain time limit, but they were not told when the release would occur. For the co-contracted condition, the subjects were instructed to brace for impact by tensing muscles on both sides of their necks. The subjects were told when the impactor would be released so they could prepare for the impact. For the unilateral condition, each subject wore a head strap that was attached to the testing rig and were instructed to pull against the post with maximum force towards the impactor. This activated the muscles, primarily, on the right side of the neck; the subjects were again told when the impactor would be released so they could be pulling with maximum force during the impact.

RESULTS

All subjects were asymptomatic immediately after impacts and at both one-day and one-week post impacts; there were no deviations from baseline assessments.

During passive activation, the maximum resultant linear head acceleration was 12.1 ± 1.8 g, and the maximum x-angular velocity was -6.9 ± 0.6 rad/s (Figure 2). The maximum resultant linear acceleration during co-contraction was 12.1 ± 1.5 g, and the maximum x-angular velocity was -6.56 ± 0.7 rad/s. The maximum resultant linear acceleration and x-angular velocity of the head decreased during the unilateral contraction to 10.7 ± 1.7 g and -6.2 ± 0.6 rad/s. Statistical significance was determined using a paired t-test for equal means ($p < 0.05$). The change in both peak linear acceleration and angular velocity between passive activation and maximum unilateral contraction were statistically significant. There was no statistically significant difference between the x-angular accelerations for any of the activation conditions.

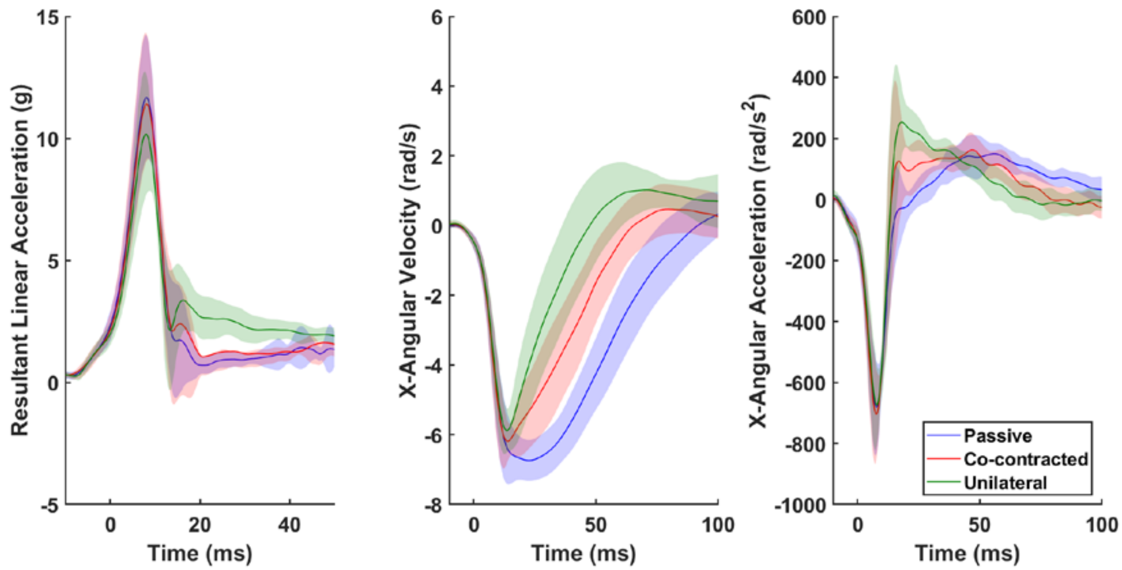

Figure 2: The mean (± 1 SD) resultant linear acceleration, x-angular velocity, and x-angular acceleration for each muscle activation condition.

The level of muscle activation prior to each impact was recorded and quantified using the area under the EMG signal for 250 ms before the impact (Table 1). The largest muscle activation occurred within the right muscles during the maximal unilateral contraction.

Table 1: The mean (± 1 SD) muscle activation prior to impact for each muscle and activation condition

Activation Condition	Muscle	Area Before Impact (% MVC • s)
Passive	R-SCM	0.88 ± 0.87 † §
	L-SCM	0.62 ± 0.38 † §
	R-Trap	2.42 ± 1.65 † §
	L-Trap	4.04 ± 2.69 §
Co-contracted	R-SCM	5.21 ± 4.77 * §
	L-SCM	5.35 ± 5.29 *
	R-Trap	6.83 ± 6.45 * §
	L-Trap	7.03 ± 5.87
Unilateral	R-SCM	9.68 ± 5.72 * † ¥
	L-SCM	3.54 ± 3.27 * ¥
	R-Trap	12.18 ± 5.02 * † ¥
	L-Trap	6.30 ± 3.70 * ¥

* - significantly different compared to passive ($p < 0.05$)
† - significantly different compared to co-contracted ($p < 0.05$)
§ - significantly different compared to unilateral ($p < 0.05$)
¥ - significantly different between left and right muscles during the same activation condition ($p < 0.05$)

DISCUSSION

The goal of this study was to determine the effect neck muscle activation has on head kinematics during non-injurious impacts to the head of volunteers. Overall, as the level of neck activation increased from passive to maximum unilateral contraction, the corresponding head kinematics decreased. While co-contraction did not create a significant decrease in resultant linear acceleration, the co-contraction did significantly decrease x-angular velocity. For both resultant linear acceleration and x-angular velocity, there was a significant change between the passive and unilateral linear acceleration and angular velocities. It is hypothesized that angular velocity is related to concussion risk; therefore, the reduction in peak angular velocity by increasing muscle activation prior to impact, pre-impact muscle tension may reduce the risk of concussion for low severity impacts (Sanchez, 2018).

The area under the curve for the 250 ms prior to the impact was calculated to quantify the varying levels of muscle activation between the three conditions. The area for each muscle before impact during the passive condition was significantly different than both the co-contracted and unilateral pre-impact muscle activations for the respective muscle. The difference in muscle activity before impact for both the right and left SCMs and trapezii were statistically significant during the unilateral condition, but not different during the co-contracted condition. These measures confirm the design of a minimal contraction (passive), an equal contraction (co-contracted), and a single-side contraction (unilateral).

Based on the design of the study, there are a few inherent limitations to the current study. Because the study involves human volunteers, the impacts must be non-injurious. The current conclusions cannot be extended to higher severity impacts, and additional analysis is needed to determine the role of pre-impact muscle tension on mitigating concussion risk for larger impacts. This study also only looked into a lateral impact of the head and rotation about the x-axis. Additional testing would be needed to determine the effect of neck muscle tension when an impact causes rotation about other axes.

CONCLUSIONS

The following outcomes were concluded from this study:

- As subjects increased neck muscle activation from passive contraction to maximal unilateral contraction, the head linear acceleration and angular velocity decreased.
- Resultant linear acceleration from the unilateral neck tensing condition were significantly lower than both the passive and co-contracted conditions and decreased with increased muscle activation.
- Maximum head angular velocity was significantly different for each muscle condition and decreased with increased muscle activation.
- Since angular velocity magnitude is related to concussion risk, these results support prior hypotheses that activating neck muscles prior to impact will decrease the risk of concussion (Sanchez, 2018).

ACKNOWLEDGEMENTS

The research presented in this paper was made possible by a grant from Football Research, Inc. (FRI), the National Football League, and Biomechanical Consulting and Research, LLC (Biocore). The views expressed are solely those of the authors and do not represent those of FRI, or any of their affiliates or funding sources.

REFERENCES

BURNETT, A., GREEN, J., NETTO, K., RODRIGUES, J. (2007). Examination of EMG Normalisation Methods for the Study of the Posterior Neck Muscles in Healthy Controls. Journal of Electromyography Kinesiology, 71: 635-641.

COLLINS, C.L., FLETCHER, E.N., FIELDS, S.K., KLUCHUROSKY, L., ROHRKEMPER, M.K., COMSTOCK, R.D. CANTU, R.C. (2014). Neck Strength: a Protective Factor Reducing Risk for Concussion in High School Sports. Journal of Primary Prevention, 35: 309-319.

ECKERSLEY, C.P., NIGHTINGALE, R.W., LUCK, J.F., BASS, C.R. (2017). Effect of Neck Musculature on Head Kinematic Response Following Blunt Impact. International Research Council on Biomechanics of Injury 2017, Antwerp, Belgium.

ECKNER, J.T., OH, Y.K., JOSHI, M.S, RICHARDSON, J.K., ASHTON-MILLER, J.A. (2014). Effect of Neck Muscle Strength and Anticipatory Cervical Muscle Activation on the Kinematic Response of the Head to Impulsive Loads, 42: 566-576.

FALLA, D., DALL'ALBA, P., RAINOLDI, A., MERLETTI, R., JULL, G. (2002). Location of Innervation Zones of Sternocleidomastoid and Scalene Muscles – a Basis for Clinical and Research Electromyography Application. Clinical Neurophysiology, 113: 57-63.

HENDLER, E., O'ROURKE, J., SCHULMAN, M., KATZEFF, M., DOMALSKI, L., RODGERS, S. (1974). Effect of Head and Body Position and Muscular Tensing on Response to Impact. SAE Paper No. 741184, 303-337.

LANGLOIS, J.A., RUTLAND-BROWN, W., WALD, M.M. (2006). The Epidemiology and Impact of Traumatic Brain Injury: A Brief Review. Journal of Head Trauma Rehabilitation, 21: 375-378.

MANSELL, J. TIERNEY, R.T., SITLER, M.R., SWANIK, K.A., STEARNE, D. (2005). Resistance Training and Head-Neck Segment Dynamic Stabilization in Male and Female Collegiate Soccer Players. Journal of Athletic Training, 40: 310-319.

MIHALIK, J.P., BLACKBURN. J.T., GREENWALK, R.M., CANTU, R.C., MARSHALL, S.W., GUSKIEWICZ, K.M. (2010). Collision Type and Player Anticipation Affect Head Impact Severity Among Youth Hockey Players. Pediatrics, 125: 1394-1401.

REID, S.E., RAVIV, G., REID, S.E. JR. (1981). Neck Muscle Resistance to Head Impact. Aviation, Space, and Environmental Medicine. 52: 78-84.

SANCHEZ, E.J., GABLER, L.F., MCGHEE, J.S., OLSZKO, A.V., CHANCEY, V.C, CRANDELL, J.R., PANZER, M.B. (2018). Evaluation of Head and Brain Injury Risk Functions Using Sub-Injurious Human Volunteer Data. Journal of Neurotrauma, 34: 2410: 2424.

TIERNEY, R.T., SITLER, M.R., SWANIK, C.B., HIGGINS, M., TORG, J. (2005). Gender Differences in Head-Neck Segment Dynamic Stabilization during Head Acceleration. Medicine and Science in Sports and Exercise, 37: 272-279.

VIANO, D.C., CASSON, I.R., PELLMAN, E.J. (2007). Concussion in Professional Football: Biomechanics of the Struck Player – Part 14. Neurosurgery, 61: 313-328