Neck Kinematics and Electromyography While Wearing Head Supported Mass During Running

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BACKGROUND: Advanced combat helmets (ACH) coupled with night-vision goggles (NVG) are required for tactical athletes during training and service. Head and neck injuries due to head supported mass (HSM) are a common occurrence in military personnel. The current study aimed to investigate the effects of HSM on neck muscle fatigue that may lead to chronic stress and injury of the head and neck.

METHODS: Subjects wore an ACH and were affixed with electromagnetic sensors to obtain kinematic data, as well as EMG electrodes to obtain muscle activations of bilateral sternocleidomastoid, upper trapezius, and paraspinal muscles while running on a treadmill. Subjects performed a 2-min warmup at a walking pace, a 5-min warmup jog, running at a pace equal to 90% maximum heart rate until absolute fatigue, and lastly a 2-min cooldown at a walking pace. Kinematic and EMG data were collected over each 2-min interval. Days later, the same subjects wore the same ACH in addition to the NVG and performed the same protocol as the first session.

RESULTS: This study showed significant differences in muscle activation of the right upper trapezius [$F(1,31) = 10.100$] and both sternocleidomastoid [$F(1,31) = 12.280$] muscles from pre-fatigue to absolute fatigue. There were no significant differences noted in the kinematic variables.

DISCUSSION: This study suggests that HSM can fatigue bilateral neck flexors and rotators, as well as fatigue the neck extensors and rotators on the contralateral side of the mounted NVG.

KEYWORDS: EMG, fatigue, helmet, night vision goggles.

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Tactical athletes are individuals in service professions (e.g., military, firefighters, law enforcement, and emergency responders) who typically have significant physical fitness and performance requirements associated with their work. To achieve mission success, these individuals face stressful, rigorous, and demanding challenges, often under life-threatening conditions, while carrying heavy gear and equipment.[23] Tactical athletes are often required to wear helmets and other protective and mission essential equipment on the head while performing their duties. The weight borne by the head and neck (head supported mass, or HSM) is known to change muscle activity about the neck and shoulders,[7,10,16] and may potentially impact structures of the spine.[5,28] Neck pain is commonly reported in service members and multiple studies have been conducted to determine causes and solutions for this issue.[9,10,12,14,26] Much of this work has focused on assessing the impact of HSM on the neck and shoulders of rotary and fixed wing pilots. Research suggests that flight helmet weight and gravitational forces down the vertical axis of the body from head to foot (+G_z forces),[1] night vision goggles,[2] vehicle vibration,[1] and sitting for long missions all contribute to neck pain reports in pilots.[24,25]

Dismounted service members (those that do not spend most of their time in a vehicle or aircraft) and other tactical athletes must also wear HSM for extended periods of time. Service members wear the advanced combat helmet (ACH, 4.0 lb/1.8 kg) during training and deployments, with monocular night vision goggles (NVGs, 2.0 lb/0.9 kg) during night missions.

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While vital to mission success, the monocular design of the NVGs creates a lever arm that moves the center of gravity of the weight forward and to one side, creating an unequal distribution of stress on the structures of head, neck, and shoulders.[8] Counterweights are often added to the back of the helmet of both pilots and dismounted service members, adding to the overall weight, but counteracting the unequal force distribution, which may reduce discomfort.[11]

HSM is worn by dismounted service members and other tactical athletes during all types of mission associated activities, such as walking, running, jumping, riding in vehicles, ruck marching with heavy loads, climbing over walls, crawling, and during airborne operations. The impact of HSM on the activity of the muscles of the neck and shoulders during these non-seated activities has yet to be investigated. It is important to understand how this equipment is impacting the structures of the neck and shoulders if we are to understand and eventually mitigate the neck pain experienced by tactical athletes. The objective of this study was to assess neck muscle activation [bilateral paraspinals, upper trapezius, and sternocleidomastoid (SCM)], as well as head and trunk kinematics during running prefatigued and fatigued, during two helmet conditions (wearing an ACH vs. wearing an ACH with NVGs). It was hypothesized that there would be a difference in muscle activation as well as head and trunk kinematics pre- vs. postfatigue running during the two helmet conditions.

METHODS

The goal of the experiment was to determine the muscle activations of selected neck muscles in healthy college students wearing two types of HSM, a helmet and a helmet with NVGs, while running to fatigue. Subjects reported for testing on 2 separate days, at least 1 week apart, and at approximately the same time of day where HSM treatment was randomized. The selected muscles for analysis were the bilateral paraspinals, SCM, and upper trapezius. Surface electromyographic (EMG) data were normalized by percent of the subject's maximum voluntary isometric contraction (%MVIC).[17,19] Head and trunk kinematics were also assessed. Descriptive statistics were used to investigate muscle activations as well as trunk and head kinematics while running with moderate effort and while running at a rate of perceived exertion (RPE) of 20 on the Borg scale.[4]

Subjects

There were 39 healthy male and female college students (21.90 ± 2.48 yr; 176.47 ± 10.29 cm; 75.85 ± 14.60 kg) who, regardless of sex, consented to participate. Healthy was defined as having no history of upper or lower extremity injury in the past 6 mo and currently participating in physical activity at least 30 min/d most days of the week. All data were collected in the University Sports Medicine and Movement Laboratory. The University Institutional Review Board approved all testing protocols. Prior to data collection all testing procedures were explained to each subject and informed consent was obtained.

Equipment

EMG data were collected via a Delsys Bagnoli 8-channel EMG system (Delsys Inc., Natick, MA). Data were sampled at a rate of 1000 Hz and the signal was full wave rectified and root mean squared at 100 ms.[17,19] Electromyographic data were collected through The MotionMonitor™ (Innovative Sports Training, Chicago, IL) and post-processing analyses were performed through MATLAB (The Math Works, Inc. 8.2.0, Natick, MA).

Kinematic data were collected with The MotionMonitor™ (Innovative Sports Training) synchronized with an electromagnetic tracking system (Track Star, Ascension Technologies Inc., Burlington, VT). There were 11 electromagnetic sensors attached to the following locations: 1) the posterior aspect of the ACH, 2) the posterior/medial aspect of the torso at T1, 3) the posterior/medial aspect of the pelvis at S1, 4–5) the bilateral middle/lateral aspect of the upper arm, 6–7) the bilateral middle/lateral aspect of the forearm, 8–9) the bilateral middle/lateral aspect of the upper leg, and 10–11) the bilateral middle/lateral aspect of the lower leg. Medial and lateral aspects of each joint were identified and digitized. Joint centers were calculated by the midpoint of the two points digitized. A link segment model was then developed through digitization of bony landmarks used to estimate the joint centers for the hip, shoulder, thoracic vertebrae 12 (T12) to lumbar vertebrae 1 (L1), and cervical vertebrae 7 (C7) to thoracic vertebrae 1 (T1) (**Fig. 1**). The spinal column was defined as the digitized space between the associated spinous processes, whereas the ankle and knee were defined as the midpoints of the digitized medial and lateral malleoli, and the medial and lateral femoral condyles, respectively.[27]

Procedure

The location of the bilateral paraspinals, SCM, and upper trapezius were identified through palpation of the muscle belly. Identified locations were shaved, abraded, and cleaned using standard medical alcohol swabs for electrode placement. Bipolar electrodes (inter electrode distance: 10 mm) were attached over the muscle bellies and positioned parallel to the muscle fibers using previously published standardized methods.[3,6] Electrode placement for the paraspinal muscle group were approximately 2 cm from the midline over the muscle belly at cervical spine four (C4).[3,6] SCM electrode placement was half the distance between the mastoid process and the sternal notch, posterior to the center of the muscle belly, parallel to the muscle fibers.[3,6] Upper trapezius placement was at the angle of the neck and shoulder, over the muscle belly, parallel with the muscle fibers[3,6] (**Fig. 2**). Surface electrodes were chosen because they have been deemed to be a noninvasive technique that is able to reliably detect surface muscle activity.[3]

Manual muscle testing (MMT) techniques by Kendall et al.[13] were used to determine the MVIC to which all EMG data were normalized during a steady state contraction. Three MMTs lasting 5 s were performed for each muscle, with the first and last second of each test removed to obtain steady state results. The same trained examiner performed all MMTs.

The paraspinals were tested with the subject prone. Subjects were instructed to perform cervical extension while the

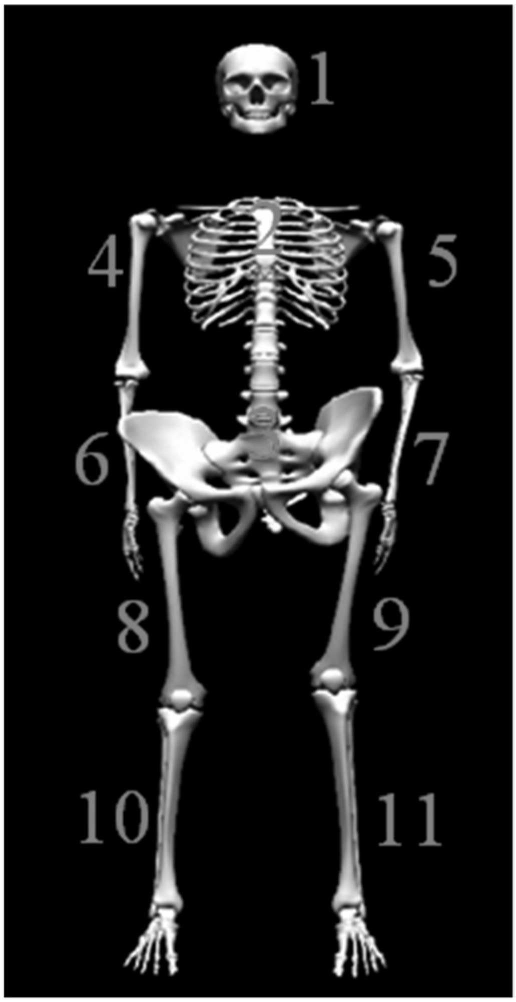

Fig. 1. Electromagnetic sensor placement.

investigator provided resistance.[13] The SCM was tested with the subjects supine. Subjects were instructed to perform cervical rotation while the investigator provided resistance.[13] To test the upper trapezius, each subject sat while the investigator applied pressure against the shoulder in the direction of depression and against the head in the direction of flexion anterolaterally.[13]

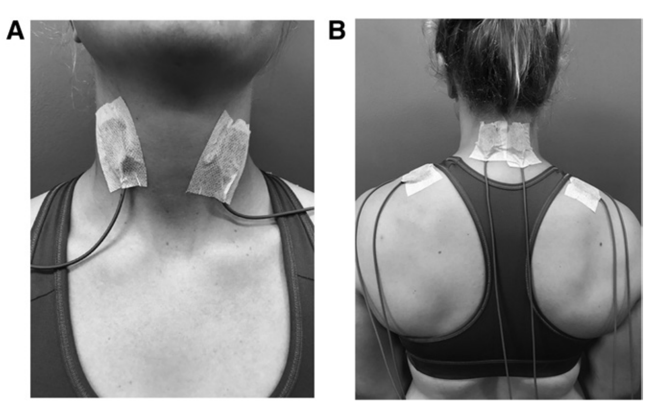

Fig. 2. A) EMG sensor placement for the sternocleidomastoid (SCM) muscle. B) EMG sensor placement for the paraspinal (PS) and upper trapezius (UT) muscles.

Once all electromagnetic sensors were placed and MMTs were completed, subjects were instructed on the treadmill (Nordic Track C990, Logan, UT) running protocol. Prior to testing, all subjects were assessed for proper helmet fitting and comfort of sensor placement. They were also debriefed on the Borg scale and how to properly report their level of exertion to maintain consistency between subjects. Lastly, they were informed when data was being collected as to prevent extraneous movement that might alter the data (i.e., looking down, scratching, or adjusting clothing). Subjects were instructed to walk for 2 min at 3.2 mph. Following 2 min, subjects increased the speed to a self-selected speed of what they would typically choose if they were jogging for 30 min. Once jogging speed was determined, subjects were instructed to jog at that self-selected speed for 5 min. Following the 5-min jog, the treadmill speed was increased, by the investigator, until the subject's heart rate was 90% of the maximum. Heart rate data were collected via a Bluetooth heart rate sensor (Polar H7 Bluetooth Heart Rate Sensor, Lake Success, NY). Maximum heart rate was determined by subtracting the subject's age from 220.[15] Subjects ran at the selected speed that elicited 90% maximum heart rate until they reported an RPE of 20 on the Borg scale.[4] Once subjects reached an RPE of 20, they were instructed to run for 2 additional minutes. Following the final 2 min of running at an RPE of 20, the treadmill speed was reduced to 3.2 mph for a 2-min cooldown. The aforementioned treadmill protocol was used for both helmet conditions. EMG and kinematic data were collected for three strides during the last 30 s of the 5-min jog and three strides during the last 30 s of the 2-min run at an RPE of 20.

Statistical Analysis

All data were analyzed using Statistical Package for Social Science (SPSS) software (version 23; SPSS Inc., Chicago, IL) with statistical significance set a priori at $P \leq 0.05$ for all analyses. Kinematic data for the following variables were analyzed: head flexion, head lateral flexion, head rotation, trunk flexion, trunk lateral flexion, and trunk rotation. Shapiro-Wilk's Test for Normality revealed normality of the data. Levene's test for the homogeneity of variances was tested and found to uphold the assumption of equal variances in the data. A 2 (NVG, ACH) $\times$ 2 (pre, post) $\times$ 6 (Variable) mixed factorial ANOVA was conducted analyzing mean differences. Surface EMG data from each muscle were normalized and expressed as a percent contribution of the MVIC (%MVIC). A 3 (muscles) $\times$ 2 (pre, post) $\times$ 2 (ACH, NVG) $\times$ 2 (left, right) mixed factorial ANOVA was conducted to investigate differences between different running conditions and activity of the bilateral SCM, upper trapezius, and paraspinal muscles when running to absolute fatigue.

RESULTS

Means and standard deviations for the kinematic outcome variables are presented in **Table I**. There were no significant main

Table I. Muscle Activation as a %MVIC While Wearing the Advanced Combat Helmet (ACH) and ACH + Night Vision Goggles (NVG).

	ACH† MEAN ± SD	ACH + NVG† MEAN ± SD
R. SCM†,*		
Prefatigue	23.01 ± 20.07	17.32 ± 17.31
Fatigue	14.41 ± 18.46	12.23 ± 17.76
L. SCM†,*		
Prefatigue	14.40 ± 17.95	13.74 ± 14.52
Fatigue	17.33 ± 18.58	16.43 ± 22.28
R. UT†,*		
Prefatigue	36.77 ± 28.87	35.17 ± 34.15
Fatigue	17.94 ± 23.24	18.06 ± 20.82
L. UT†		
Prefatigue	17.84 ± 18.04	20.62 ± 16.29
Fatigue	10.09 ± 11.57	11.65 ± 11.70
R. PS†		
Prefatigue	29.59 ± 17.39	28.51 ± 22.33
Fatigue	28.31 ± 17.98	30.26 ± 23.18
L. PS†		
Prefatigue	34.33 ± 23.78	26.19 ± 19.30
Fatigue	27.61 ± 22.47	25.25 ± 23.53

Values are displayed as % maximum voluntary isometric contraction (%MVIC).
† ACH: advanced combat helmet; NVG: night vision goggles; R. SCM: right sternocleidomastoid; L. SCM: left sternocleidomastoid; R. UT: right upper trapezius; L. UT: left upper trapezius; R. PS: right paraspinal muscle; L. PS: left paraspinal muscle.
* Indicates significance.

effects of Group or Time on the kinematic variables, nor was there a Group × Time interaction.

Descriptive statistics for the EMG outcome variables for the bilateral SCM, upper trapezius, and paraspinal muscles are presented in **Table II**. MANOVA results revealed a significant Time × Side interaction for the upper trapezius [$F(1,31) = 10.100$, $P = 0.003$, Wilks' $\Lambda = 0.754$, partial eta squared = 0.246]. Post hoc dependent samples *t*-test revealed a significant mean difference for the right upper trapezius in both conditions (ACH and NVG) from pre- to post-trial. Mixed factorial ANOVA results also indicate a significant Time × Side interaction for the SCM muscle [$F(1,31) = 12.280$, $P = 0.001$, Wilks' $\Lambda = 0.716$, partial eta squared = 2.84]. Dependent samples *t*-test revealed a significant mean difference for bilateral muscle activity of the SCM in both conditions (ACH and NVG) from pre- to postfatigued running trials.

Table II. Kinematic Differences Between Prefatigue and Fatigue Conditions at First and Last Time Intervals.

	ACH† MEAN ± SD	ACH + NVG† MEAN ± SD
Head Flexion		
Prefatigued	10.23 ± 13.60	10.59 ± 12.46
Fatigued	11.62 ± 10.74	7.52 ± 9.89
Head Lateral Flexion		
Prefatigued	−1.17 ± 8.76	1.01 ± 9.86
Fatigued	0.05 ± 9.20	0.11 ± 9.33
Head Rotation		
Prefatigued	1.00 ± 10.92	−1.00 ± 8.52
Fatigued	−0.08 ± 10.36	−0.02 ± 7.73
Trunk Flexion		
Prefatigued	−11.62 ± 6.21	−11.53 ± 5.18
Fatigued	−13.23 ± 6.56	−11.53 ± 5.14
Trunk Lateral Flexion		
Prefatigued	−1.92 ± 4.65	−2.39 ± 4.01
Fatigued	−1.73 ± 4.78	−1.65 ± 4.28
Trunk Rotation		
Prefatigued	−1.15 ± 5.72	−0.18 ± 6.31
Fatigued	−0.11 ± 5.73	−0.48 ± 5.60

Values displayed as degrees away from neutral stance midline (0°).
† ACH: advanced combat helmet; NVG: night vision goggles.

DISCUSSION

The objective of this study was to assess muscle activation of the neck musculature, as well as head and trunk kinematics during running prefatigued and postfatigued, during two helmet conditions (wearing an ACH vs. wearing an ACH with NVGs). It was hypothesized that there would be a difference in muscle activation as well as head and trunk kinematics pre- vs. postfatigue running during the two helmet conditions. However, the current study only revealed alterations in muscle activation and no alterations in head or trunk kinematics. The fact that only muscle activations were altered could suggest that the fatigue protocol was either not taxing enough on the subjects and/or was not implemented long enough to allow for the kinematic changes to appear that would have been associated with the muscle activation changes.

Muscle activation changes were found in the bilateral SCM and right upper trapezius. The role of the SCM muscle is to perform head rotation to the opposite side as well as head flexion. Results revealed significant bilateral SCM muscle activation changes between the different helmet conditions, as well as pre- vs. postfatigue. The right SCM decreased activation from pre- to postfatigue in both helmet conditions, while the left SCM increased activation from pre- to postfatigue in both helmet conditions. The lack of change in head kinematics helps explain EMG changes in the SCM. The SCM responded on the right side by decreasing muscle activity and on the left side increasing activation. This was likely an attempt to maintain the head in a neutral position while counteracting the unilateral weight of the NVGs. Additionally, the right upper trapezius significantly decreased activation during postfatigued running in both helmet conditions. Lack of kinematic changes in head and trunk posture suggests that under the fatiguing conditions used in this protocol, the SCM and right trapezius muscles were able to adequately compensate for the unequal forces from the NVGs without a resulting change in kinematics.

Contrary to our hypothesis, there were no kinematic changes in head and trunk postures. It should be noted that other studies examining acute bouts of fatigue have also reported similar results.[18,20–22] Thus, future investigation into either residual fatigue or cumulative fatigue should use a longer (chronic) fatiguing protocol more representative of the long duration of these forces service members are exposed to in the field. Other limitation of this work includes the lab-based assessment as compared to a real-world field assessment. Also, subjects were unaccustomed to wearing HSM. It may be that service members experienced with wearing this equipment may have a different physiological response.

These results indicate that the muscles of the cervical spine fatigue unequally when exposed to an acute running fatigue protocol and HSM commonly used in military training. Future work should assess the impact of fatigue caused by chronic exposure to HSM and how muscle and kinematic response differs in those naive to this equipment (military trainees) and experienced services members accustomed to wearing this equipment.

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