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TITLE: Examining the Effects of Head Supported Mass on Cervical Spine Biomechanics and Injury Risk in Special Forces Operators

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<b>14. ABSTRACT</b> Military personnel face unique challenges and occupational loads under difficult conditions that put them at significant risk for musculoskeletal injury. Improved technology and assistive exoskeletons have increased soldier head supported mass (HSM), and it is believed current HSM requirements exceeds functional occupational limits of what can be borne safely, contributing to cervical spine (C-spine) musculoskeletal injury risk. A subset of these functional limits has been investigated through the lens of helicopter and fixed wing aviation pilot HSM with respect to two specific scenarios, vibrational loading and high G events. These studies used both experimental and modeling approaches to develop HSM design criterion. Our overall objective for this project is to determine the chronic effects of repeated loading with HSM and to assess intervertebral stresses through biomechanics modeling to provide mitigation strategies for the effects of HSM on the modifiable musculoskeletal cervical spine characteristics military personnel. Determining the effects of HSM on musculoskeletal and neuromuscular functional joint stability characteristics will drive the design of chronic injury prevention programs, equipment design guidelines, and other potential injury countermeasures. These targeted injury prevention programs and design guidance can lead to a reduction of musculoskeletal injuries to soldiers from repetitive loading and increase operational effectiveness, lengthening military careers, and improving post-military health.					
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## 1. Introduction:

Military personnel face unique challenges and occupational loads under difficult conditions that put them at significant risk for musculoskeletal injury. Improved technology and assistive exoskeletons have increased soldier head supported mass (HSM), and it is believed current HSM requirements exceeds functional occupational limits of what can be borne safely, contributing to cervical spine (C-spine) musculoskeletal injury risk. A subset of these functional limits has been investigated through the lens of helicopter and fixed wing aviation pilot HSM with respect to two specific scenarios, vibrational loading and high G events. These studies used both experimental and modeling approaches to develop HSM design criterion. Our overall objective for this project is to determine the chronic effects of repeated loading with HSM and to assess intervertebral stresses through biomechanics modeling to provide mitigation strategies for the effects of HSM on the modifiable musculoskeletal cervical spine characteristics military personnel. Determining the effects of HSM on musculoskeletal and neuromuscular functional joint stability characteristics will drive the design of chronic injury prevention programs, equipment design guidelines, and other potential injury countermeasures. These targeted injury prevention programs and design guidance can lead to a reduction of musculoskeletal injuries to soldiers from repetitive loading and increase operational effectiveness, lengthening military careers, and improving post-military health.

## 2. Keywords:

Head supported mass; cervical spine; musculoskeletal injury

## 3. Accomplishments:

### What were the major goals of the project?

#### Specific Aims

- Specific Aim 1: Survey the injury epidemiology, cervical spine strength and flexibility, and current cervical spine radiology of SFCS and physically active non-military personnel.
- Specific Aim 2: Obtain head/neck kinematics and flexion/extension electromyography data of a cohort of SFCS personnel during a number of relevant simulated military scenarios.
- Specific Aim 3: Implement the experimental kinematic and EMG data into a validated hybrid finite element – multibody head/neck model to determine intervertebral stiffnesses during these simulated military scenarios with varying levels and positions of head supported mass.

(See Table below for important activities and the status of each of task)

### What was accomplished under these goals?

**TABLE.** Specific Aims Status

Specific Aim 1	Site	Site
<b>Major Task 1 – Injury epidemiology, cervical spine strength and flexibility testing of military and non-military personnel</b>	Atrium Health	USAARL
University and Military IRB/HRPO Approval (all Atrium Health Major Tasks)	Completed	Completed
Testing of military and non-military personnel begins.	Ongoing	Ongoing
Testing of military and non-military personnel completed.	73%	4%
Data analysis and final report completed.	Ongoing	Ongoing
<b>Major Task 2 – Cervical spine musculoskeletal imaging</b>	Atrium Health	Duke University
Musculoskeletal imaging (MRI) begins.	Not Initiated	Ongoing
Musculoskeletal imaging (magnetic resonance imaging) completed.	N/A	33%

Data analysis and final report completed.	Not Initiated	Not Initiated
<b>Specific Aim 2</b>	<b>Site</b>	<b>Site</b>
<b>Major Task 1 – <i>In vivo</i> data collection of kinematic and electromyographic data with and without head supported mass (laboratory data collection)</b>	Atrium Health	Duke University
Laboratory testing of kinematic/electromyographic data with and without head supported mass begins.	Ongoing	Ongoing
Laboratory testing of kinematic/electromyographic data with and without head supported mass completed.	33%	33%
In field testing of kinematic data for events that cannot be replicated in a lab (parachute openings and helicopter flights) using small in-ear accelerometers.	N/A	100%
Data analysis and final report completed.	N/A	Ongoing
<b>Specific Aim 3</b>	<b>Site</b>	<b>Site</b>
<b>Major Task 1 – Calculation of intervertebral stresses during military relevant scenarios</b>		Duke University
Run static optimizations to determine muscle activations and peak intervertebral stresses from maintaining a stable upright head position both with and without HSM.		Completed
Prepare, package, and transfer kinematic and EMG data collected from field and/or lab based dismounted Soldier studies under varied HSM conditions in preparation for DUHNM simulations.		Ongoing
Run DUHNM simulations replicating each experimental participant scenario with data from Specific Aim 2 using HSM values of the head gear in the experiments. Simulations will be run as experimental trials are conducted.		40%
Run DUHNM simulations as experimental trials are completed replicating each experimental scenario with a range of HSM magnitudes and CG locations.		30%
Final report completed and peak intervertebral stresses calculated from each of the simulations.		Ongoing
<b>Major Task 2 – Creation of HSM design and injury criteria</b>	NA	Duke University
Calculate an average repetitive loading intervertebral stress exposure for each participant by combining information of HSM exposure from Specific Aim 1 with stresses determined in Specific Aim 3.		40%
Combine the injury history and musculoskeletal imaging results of each patient from Specific Aim 1, with the calculated repetitive loading intervertebral stress exposure for each participant calculated in Specific Aim 3 to create both an injury risk survival curve and a SN repetitive loading failure curve.		20%
Use the intervertebral stresses calculated for the range of HSM values and CG locations in comparison to the injury criteria built in Specific Aim 3 to develop a design criterion (HSM magnitude and CG location) for helmet manufacturers that accounts for repetitive loading injuries.		10%
Use the intervertebral stresses calculated for the range of HSM values and CG locations in comparison to the injury criteria built in Specific Aim 3 to update and/or validate interim guidelines for acceptable HSM design criterion (HSM magnitude and CG location) specifically for dismounted military populations.		10%
Data analysis and final report completed.		5%

**Major Activities:** During this reporting (June 1, 2022 – December 16, 2022) we have continued to hold biweekly meetings with all research groups including the Partner PI (United States Army Aeromedical Research Laboratory (USAARL)) and Duke University. We've also have had monthly discussions with with USASOC where participants have been recruited and tested. In addition, we have completed the following:

- We have enrolled and tested 102 subjects at USASOC which brings our total to 147 total subjects enrolled at the USASOC site (not including June 15 testing). Twelve individuals from the USASOC site have been enrolled in the subject testing at the Duke University (kinematic/EMG/MRI testing).
- Subject testing was initiated at Atrium Health (Charlotte, NC). We have enrolled and tested 139 subjects at Atrium Health (Charlotte, NC) which brings our total to 139 subjects enrolled at the Atrium Health site.
- Subject testing was initiated at USAARL. USAARL has reported testing six subjects at their site which brings their total to six individuals enrolled at the USAARL site.
- Four operators used the DASHR earpiece accelerometer over 5 individual periods of up to 5 hours from 1/25/2023-2/3/2023. The operators performed typical operational ground tasks during this period including running and jumping.
- Modeling at the Duke University Injury Biomechanics Laboratory (under the direction of Dr. Dale Bass) was initiated based on the data collected (kinematics/EMG/MRI).
- A twelve month no cost extension was requested and approved. The no cost extension begins June 1, 2023 and ends May 31, 2024.

**What opportunities for training and professional development has the project provided?**

Nothing to report

**How were the results disseminated to communities of interest?**

Nothing to report

**What do you plan to do during the next reporting period to accomplish the goals? *If this is the final***

We will continue to meet every two weeks as a research group (Atrium Health, Duke University, USASOC, and USAARL) to discuss progress, concerns, and action items. This will be particularly important for enrollment to complete the cohorts at all three test locations. We will work with USAARL to increase enrollment in the non-SFCS military group by investigating opportunities to test at USASOC and locations identified by USAARL. We will continue two monthly visits to USASOC for human subject testing of SFCS and non-SFCS (as appropriate) and conduct testing of SFCS at Duke University for the kinematic, EMG, and MRI data collection. We will continue human subject testing at Atrium Health (Charlotte, NC) for the civilian control group and initiate MRIs of civilian controls (August 1, 2023).

**4. Impact:**

**What was the impact on the development of the principal discipline(s) of the project?**

Nothing to report

**What was the impact on other disciplines?**

Nothing to report

**What was the impact on technology transfer?**

Nothing to report

**What was the impact on society beyond science and technology?**

Nothing to report

**5. Changes/Problems:**

**Changes in approach and reasons for change**

Nothing to report

**Actual or anticipated problems or delays and actions or plans to resolve them**

We anticipate having difficulty with completing enrollment in military non-SFCS group that is to be enrolled at USAARL. They are currently working on alternative locations for enrollment and testing and have been in touch with two different groups. An IRB amendment is under review at this time. Even with these alternative subject pools, we anticipate they will have difficulty with enrollment and testing both the number and ages necessary for matching the SFCS group at USASOC. We will work with USAARL to help them with this enrollment. We have been notified that Dr. Dale Bass is leaving Duke University. He and his team are responsible for kinematic/EMG/MRI testing of SFCS from USASOC (Specific Aim 1, Major Task 2 and Specific Aim 2, Major Task 1) and all of the modeling (Specific Aim 3 (all Major Tasks)). We are working with Dr. Bass on how to seamlessly complete these tasks as he relocates to Wayne State University. This includes regularly meetings and discussions with Duke University. The no cost extension approved includes Duke University effort.

**Changes that had a significant impact on expenditures**

Nothing to report

**Significant changes in use or care of human subjects, vertebrate animals, biohazards, and/or select agents**

**Significant changes in use or care of human subjects**

Nothing to report

**Significant changes in use or care of vertebrate animals.**

Nothing to report

**Significant changes in use of biohazards and/or select agents**

Nothing to report

**6. Products: *L***

**Publications, conference papers, and presentations**

Nothing to report

**Journal publications.**

Nothing to report

**Books or other non-periodical, one-time publications.**

Nothing to report

**Other publications, conference papers, and presentations.**

Nothing to report

**Website(s) or other Internet site(s)**

Nothing to report

**Technologies or techniques**

Nothing to report

**Inventions, patent applications, and/or licenses**

Nothing to report

**Other Products**

Nothing to report

**7. Participants & Other Collaborating Organizations**

What individuals have worked on the project?

***Atrium Health***

Name	Title	Effort	Person Months
			Cal
Timothy Sell	Principal Investigator	15%	1.8
Ryan Zerega	Clinical Research Coordinator	60%	7.2
Richard Taylor	Clinical Research Specialist	75%	9.0

***Duke University***

Name	Title	Effort	Person Months
			Cal
Cameron 'Dale' Bass	Principal Investigator	20%	2.40
Jason Kait	Research Engineer	32%	3.84
Joos Op Eynde	Graduate Student	50%	6.00

Has there been a change in the active other support of the PD/PI(s) or senior/key personnel since the last reporting period?

Nothing to report

What other organizations were involved as partners?

**8. Special Reporting Requirements**

QUAD CHARTS:

**9. Appendices:**

None