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NHRC has an integrated laboratory and field study to document neck/back fatigue profiles in female military helicopter pilots. Subsequent to a 3-hr flight mission, subjects will undergo initial neck and back strength evaluation using the MedEx. Subsequently, an 8-week neck/back strengthening program will be conducted followed by another neck/back evaluation and 3-hr flight mission. Validation of a repeated jolt impact platform at the U.S. Army Aeromedical Research Laboratory, will also be conducted to ascertain if neck/back muscles fatigue at same rate as in helicopter operations. NHRC has evaluated all equipment and software needed for in-flight monitoring of pilots using portable, miniaturized video/EMG recording systems. Initial analyses of laboratory studies indicate neck strength is greater during rotations to the left. It was observed that lumbar muscle activation is associated with neck fatigue. EMG amplitude asymmetry is evident for both cervical and lumbar paraspinals during extension and flexion suggesting there is uneven strength profiles for neck/back muscles. This asymmetry may be the basis for neck/back fatigue reported by military pilots after prolonged flights. Neck/back strengthening programs may minimize uneven strength profiles and enhance pilot performance in helicopter operations.

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INTRODUCTION

The number of women entering naval aviation is increasing, and a large number will be assigned to helicopter squadrons. The rotary-wing community has documented a number of occupational ailments due to: 1) cockpit ergonomics, 2) helmet (mass/design), 3) peripherals on the helmet, 4) repeated jolt impact, and 5) muscle fatigue leading to soft tissue injury. These ailments are reported mainly in the neck, lumbar, and upper sacral regions.[1] In a recent study titled "Aviator Back Syndrome and Putative Pathology and Etiology," only 2 of 60 subjects studied were women.[2] Results obtained in males are unlikely to be generalized to females because of the differences in physical characteristics.

Women have been generally characterized by increased flexibility and decreased strength relative to men.[3] Anecdotal data from civilian auto accidents indicate that female accident victims suffer more chronic neck and back injury due to their increased flexibility.

There are no reported neck and back fatigue profiles of female military rotary-wing pilots wearing various helmet configurations. In addition, the effects of exercises that could be used to strengthen neck and back muscles and minimize soft tissue injury in the helicopter environment have not been scientifically evaluated. Thus, with the increasing number of female pilots participating in rotary-wing military operations, there is a requirement to develop a database of female neck and back fatigue profiles with various helmet configurations. The proposed research will result in the development of a database documenting the effects of various helmet configurations and repeated jolt impact profiles on the genesis of neck and back fatigue. In addition, the database can be used to assist in evaluation of methodologies to minimize neck and back strain that may lead to long-term soft tissue injuries in female rotary-wing pilots. Data from these studies will permit transition of the neck and back strengthening paradigms to the civilian sector so as to minimize neck and back injuries in women.

Although research has been conducted evaluating the effect of various air combat maneuvers (ACM) on neck and back function in men with various helmets and mask configurations, there is still no experimental methodology nor guidance available to assess the degree of hazard posed by head/helmet mounted systems.[4] The combined use of the proposed in-flight electromyograms (EMGs) and video recording of head movements may become a new methodology to evaluate the muscle fatigue or injury potential of various headgear on military aircrew.

The Naval Health Research Center (NHRC) has conducted laboratory and in-flight studies evaluating neck and back fatigue profiles in

male pilots. Surface EMGs have been successfully recorded on military pilots in fixed-wing aircraft and helicopters using new solid-state recording technology. In addition, NHRC has developed the capability of recording surface EMGs simultaneously with video images. This capability enables the biomechanical modeling of in-flight responses of the head, neck, and back. Surface EMGs also have been recorded from Navy pilots exercising on various exercising equipment (e.g., MedEx) specifically designed to strengthen various muscle groups.

EMGs are complex electrical signals associated with muscle contraction.[5] The frequency and amplitude characteristics are determined by various patterns of motor unit activation.[6] Extensive studies have been conducted correlating the decrease in the frequency and an increase in amplitude of the EMG with fatigue.[7,8,9] Current investigations are quantifying the changes in the various components of the waveform of the EMG as the muscle fatigues during concentric and eccentric contractions.[10] EMGs have been used to assess neck and back muscle fatigue, however, until recently, it was not possible to record EMGs during flight in high performance military aircraft. The first U.S. study on in-flight EMGs reported by NHRC was made possible by using a small recorder and amplifier (Mega, LTD) that is battery-driven and is capable of recording four muscles simultaneously. That system is presently being modified to record acceleration signals in addition to the EMGs.

EMGs of Navy pilots exercising to fatigue have been analyzed utilizing a "moving window" spectral technique. These analyses demonstrated that as muscles fatigue, there is an increase in amplitude (RMS) and a decrease in frequency. Interestingly, in some subjects, the RMS values decrease before the subject fatigues indicating that other muscle groups are being recruited and also that the isolated RMS of single muscle groups may be an early indicator of fatigue.[11]

These studies also indicated neck muscle fatigue is associated with an increasing recruitment of lumbar musculature. Therefore, neck fatigue which triggers increased lumbar muscle activity, may be a major predisposing cause of low-back pain in Navy pilots.[12] Thus, neck fatigue in female pilots caused by the flight helmets and associated attachments (e.g., night vision goggles [NVG]) during prolonged helicopter flights, may indirectly fatigue their lumbar regions.

Associated with its studies in this area, NHRC has visited U.S. Army Aeromedical Research Laboratory (USAARL) at Ft. Rucker, Alabama. A study at USAARL will be conducted utilizing their repeated jolt impact platform (RJIP) that can be programmed to mimic specific-military helicopter repeated jolt impact profiles.

Utilizing the RJIP, it will be possible to evaluate in-flight fatigue-inducing properties of various helmet configurations in the laboratory.

NHRC has also identified an exercise system (MedEx) that is able to selectively isolate neck and back muscles for strengthening, either in an anterior/posterior or rotational plane. The ability to record EMGs simultaneously with active neck and back exercise was also evaluated. Initial analyses indicate that surface EMGs can be recorded simultaneously with exercise, and subsequent analysis of the EMGs indicated the predicted decrease in frequency and rise in amplitude correlated with fatigue. The MedEx equipment is housed in the Department of Orthopedics at University of California, San Diego. This equipment will be used to isolate and strengthen various muscle groups (e.g., neck or back). However, the long-term thrust of this research will be to arrive at an inexpensive, flexible exercise routine that can be used by Naval aviation personnel aboard ship.

NHRC has conducted earlier studies in which neck and back fatigue profiles were evaluated by having pilots exercise on MedEx equipment. During these studies, EMGs and force movements were conducted. Initial analysis indicated that the neck and back muscles do not bilaterally fire (contract) at the same level. A functional bilateral asymmetry exists between the right and left neck and back muscles during back or neck extension and flexion. This finding indicates that there may be selective muscle sites on the neck and back which would predispose them to fatigue, leading to soft tissue injury and permanent alteration of neck/back vertebral column or musculature (e.g., soft tissue injury).

The challenges facing the Navy with an increasing number of female pilots participating in flight operations is reflected in the Amelia program.[13] This program surveyed 343 female aviators in terms of their unique equipment requirements for flight operations. The number one problem facing female pilots was the design and weight of the flight helmet. The helmet significantly contributes to neck and back fatigue. In addition, the fatigue-inducing effect of the helmet may be enhanced by the vibrating environment of the helicopter.[14]

Due to the lack of biomedical information concerning females in the military flight community, it is advisable to determine the predisposing factors affecting the onset and magnitude of cervical/back fatigue that may lead to soft tissue injury and/or permanent injury. Moreover, there is a need to determine if effective and inexpensive intervention procedures can be designed and employed to minimize the incidental rate of cervical/back injuries.

METHODS

To study the above mentioned areas, laboratory and field studies have been proposed. In study 1, the in-flight/field study has the following components:

Study 1

(1) In-flight study to quantify the amount of skeletal muscle fatigue.
(2) Lab study in which female helicopter pilots will undergo an extensive training program to strengthen neck and back muscles.
(3) In-flight study in which female helicopter pilots will repeat flight maneuvers conducted in Phase 1 in order to ascertain effectiveness of neck and back training protocols.

The overall research question will be to ascertain if specific neck and back strengthening programs will minimize the rate of skeletal muscle fatigue in neck and back muscles of female helicopter pilots while conducting flight operations.

Study 2

The validation of a RJIP as a model for simulating helicopter operations will be performed. Female pilots will be evaluated for onset of skeletal muscle fatigue of neck and back muscles while on the RJIP. The research question will be whether the rate of skeletal muscle fatigue on the RJIP is similar to that experienced by female pilots while undergoing helicopter flight operations.

RESULTS

Funds were received on 8 Dec 94.

Study 1: In-flight helicopter video/EMG recordings

To document the onset of in-flight fatigue, a portable lightweight system had to be designed that could simultaneously record video and EMG signals.

Design of a combined video/EMG recording system and initial testing has been completed. Three miniature cameras can be used in-flight and synchronized with the EMG signals to produce a simultaneous recording. The system weighs approximately 10 lbs and allows NHRC to perform three-dimensional analyses of head movement.

Analyses of preliminary video data has been accomplished with an innovative motion analyses program called MikroMak. These algorithms enable automatic targeting of various anatomical

algorithms enable automatic targeting of various anatomical landmarks and thus facilitates the rapid analyses of data. Therefore, it is possible to quantify the velocity and acceleration of the helmet/head during flight and correlate with EMGs over relatively long periods of time. Presently, corroboration between these measurements and those gathered by independent accelerometers placed on the helmet are being conducted.

Overall, NHRC has been able to design, develop, and test a portable camera video/EMG recording system for in-flight studies. The analysis program, MikroMak, facilitates analysis of large segments of motion data. To present, up to 30 seconds of continuous data has been analyzed. All software and hardware required for this study have been tested and are being used during in-flight studies.

Neck/back strength profile and 8-week laboratory training

Before commencing the proposed 8-week training program, an initial study using the MedEx equipment was conducted to evaluate the neck and back strength profiles of female helicopter pilots. EMGs were recorded during the evaluation to document the onset of fatigue.

Twelve female helicopter pilots were evaluated for neck and back strength. Subjects sat in a MedEx neck and back exercising machine and performed an initial static test (isometric), and a dynamic test (isokinetic). Surface EMGs were recorded from neck and lumbar musculature during the dynamic phase.

EMG and force data from these preliminary studies were analyzed using spectral techniques. These data indicate that neck strength is greater when female pilots rotate their head to the left than when they turn to the right. As neck fatigue develops, lumbar musculature is activated. Activation of lumbar musculature associated with neck fatigue was also seen in earlier studies using male subjects. Additional analyses of EMG signals during neck and back extension and flexion indicated an asymmetry between right and left paraspinals. The 8-week training program will begin in approximately 2 weeks.

Study 2: Validation of repeated jolt impact platform

NHRC is scheduled to begin studies using the RJIP at USAARL, Fort Rucker, Alabama the first quarter of fiscal year 1996. Scientific staff from Ft. Rucker recently visited NHRC and the research design for the study was mutually agreed upon. The design will consist of three different experiments using the RJIP. Each experiment will last three hours. Neck and back fatigue profiles will be quantified on female helicopter pilots while they participate in

the three different randomly scheduled experiments where they will wear a helmet with and without NVG.

In addition, USAARL will send EMG data gathered from previous RJIP studies using male volunteers so that NHRC staff can conduct additional spectral analyses.

CONCLUSIONS

NHRC has developed a coordinated in-flight/laboratory study to evaluate the strength profiles of the neck and back muscles of U.S. Navy female helicopter pilots. The initial analysis of the data from laboratory experiments indicate that neck muscle strength during right rotation and left rotation may be significantly different. In practical terms, this rotation of neck muscle to the right may induce more rapid fatigue which could trigger lumbar muscle activation. This integrated electrokinesiology of the neck and back muscles suggests that helmet loading will lead to muscle fatigue and subsequent soft tissue injury. Once these early observations are substantiated by the upcoming studies, it is possible that various exercise countermeasures could be instituted to minimize the onset of neck/back skeletal muscle fatigue.

Future work will be geared towards developing simple but robust scientific analyses of the various EMG's to pinpoint which muscle groups are the weakest and to design specific exercise protocols. Feature extraction techniques will be utilized to develop an easy-to-use analytical tool that can be distributed Navy-wide. In addition, inexpensive exercise regimens are being developed which include the integration of small electronic sensors that will be able to document the duration of the specific neck and back exercises.

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