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# A SYSTEM FOR ASSESSING CERVICAL READINESS USING ANALYTICS AND NON-INVASIVE EVALUATION (CRANE)

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Current cervical spine assessment methodologies focus solely on subjective measures, such as pain reports, and range-of-motion (ROM) testing that only measures maximum head excursion and reach (i.e., not dynamic motion). Due to report bias and the potential for negative outcomes of self-reported pain, current clinical assessment methods fail to provide valid, reliable data for medical practitioners to effectively manage long-term cervical health. Furthermore, commercial systems capable of quantitative assessment of cervical spine function are generally sparse and often immature. This paper highlights both the need and a path towards a clinical tool for objective measurement of cervical spine health and functionality. Lastly, a novel solution concept is presented to objectively assess Cervical Readiness using Analytics and Non-invasive Evaluation (CRANE). This solution concept combines cervical spine instrumentation, novel virtual reality (VR) game-based test protocols, robust analytical algorithms, and intuitive presentation of health metrics.

Neck pain and cervical spine injury are known mission degraders across the spectrum of military personnel. Such pain and inury is a undisputed source of increased cost in terms of preventative actions, healthcare treatment, and negative impact on productivity (Hauret, Jones, Bullock, Canham-Chervak, & Canada, 2010). Managing and mitigating long-term health risks associated with Naval aviation is especially problematic. Although the rapid onset of catastrophic injuries to the neck from extreme loading (i.e., high G-forces combined with heavy helmets) continues to be a risk (Harrison, Coffey, Albert, & Fischer, 2015), clinicians often lack the information and tools necessary to properly diagnose, treat, or prevent cervical spine injuries. The inherent negative consequences for aviators that admit to neck injuries or pain is also an exacerbating factor. For example, injury or pain that could lead to performance degradation can result in medical grounding and a "duty not including flying" (DNIF) status. Although some aviators may disclose information during annual clinical visits, others may either seek treatment from private providers or seek no treatment at all. In addition, current clinical tests intended to assess cervical spine health (e.g., range of motion [ROM] tests) have been questioned with respect to their validly, reliability, and overall practicality for clinical use (Jordan, 2000). Unfortunately, most potential solutions (1) neglect the cervical spine by focusing on the lumbar or thoracic spine, (2) lack quantitative data to support physician assessment and patient anamnesis, or (3) are confined to research prototypes that have not undergone clinical trials (Yang, Su, & Guo, 2012).

There are obvious risks with undiagnosed acute and chronic cervical spine injuries. Minor chronic pain can lead to distraction and reduced cognitive abilities, which can impact decision-making during critical phases of operations (Apkarian et al., 2004). Severe injuries that limit ROM or function could thus hinder the aviator's ability to perform effectively. Both situations negatively impact aviator readiness and add unnecessary risk to the mission, and these risks are not isolated to aviators. Ground-based operators and support personnel also experience cervical spine health risks and are exposed to similar point of care testing (POCT) consequences. Fortunately, recent advances in wearable sensor technologies (e.g., inertial measurement units [IMUs]) have made it possible to obtain data for developing motion models that can characterize human behaviors and proclivities. Similarly, advanced predictive analytic methods leveraging machine learning can identify subtle patterns in longitudinal data. This proceedings paper outlines the need and path forward toward a medical material solution that allows clinicians to more accurately diagnose injury and utilize preventative care to maintain healthy cervical function or reduce the likelihood of injury progression.

## Approach

With no immediate solution present, this paper will describe a novel method and medical material solution for objectively assessing cervical spine neck function. This approach focuses primarily on a clinical medicine application, though some approaches and research may generalize to continuous assessment of aviator spine health and performance. This overarching objective is supported by three subsidiary topics of discussion: (1) application to the military clinical use case, (2) a review of current sensing components and solutions, (3) an investigation of data modeling techniques and prototype development. Each of these research areas will be discussed in the following section.

## Discussion

### Military Clinical Use Case

Navy aviators and other military personnel operate in unique, demanding environments in which they are subjected to a wide range of forces that can result in acute injuries and lead to either long-term or permanent disabilities. Forces on the cervical spine are a combination of (1) static axial forces related to head-mounted weight (i.e., wearing a helmet with additional equipment such as night vision goggles [NVGs]), make-shift counter weights, or helmet mounted displays; and (2) dynamic torsion forces related to head-turning (e.g., “check-six” maneuver), often with flexion or extension, to perform in-cockpit tasks or outside scanning across a wide range of g-force situations. Although treatment costs and disability compensation are significant financial issues, a potentially greater issue is the risk of aviators performing missions while experiencing cervical pain or restricted ROM that could either distract or prevent them from successfully completing their mission.

Unfortunately, military clinicians often lack sufficient information to effectively manage aviator cervical health for three reasons: (1) measurement frequency, (2) measurement validity, and (3) measurement reliability. Formal cervical spine assessment typically only occurs during annual flight physicals or when pain is reported. Outside of these events, aviators who experience cervical pain or injury may not report symptoms to medical practitioners (hence foregoing examination or treatment). Many military aviators avoid disclosing medical information that could jeopardize their careers and result in medical grounding (i.e., DNIF). Consequently, some aviators manage their symptoms outside of the military clinic, either through private clinicians or pain medication using over the counter (OTC) medications. This situation exacerbates the military neck health epidemic by figuratively blinding medical practitioners to aviator cervical health status. Considering the nature of the cervical spine issue (i.e., repeated stressors and impact loads over long periods of time), designing a clinical diagnostic system on a single, crude ROM measure seems extremely suboptimal.

The other current limitation to effectively managing aviator cervical spine health is a lack of validity and reliability in the primary means of measurement, which is typically the ROM test. Past research has concluded that this ROM test is limited in that it only measures static range and is not sensitive to the dynamic aspects of cervical spine function, such as linear and rotational acceleration (Youdas, 1991). Currently, no commercial off the shelf (COTS) sensor system exists to objectively measure cervical spine health. Reliance on a relatively crude method such as the ROM test makes it vulnerable to patients "gaming" the test and enduring pain associated with uncomfortable motions. Consequently, medical researchers are limited in the models they can develop using only head excursion data, as opposed to using dynamic kinematic data. Furthermore, the single set of data obtained from the ROM test administered during the annual clinical visit limits the ability to conduct longitudinal assessments of cervical health, which would help medical practitioners diagnose, treat, and ideally prevent neck injury. More importantly, data obtained from the ROM test can be systematically biased due to the strong motivation for aviators to not reveal cervical issues. To address this challenge, an objective sensing solution must be developed to integrate within existing military clinical workflows, which normally consists of period health assessment (PHA) questionnaires, in-person ROM tests, and intermittent health exams as requested by the servicemember. The results of these assessments would need to interface with current and future U.S. military’s electronic health record systems, such as the Armed Forces Health Longitudinal Technology Application (ALTHA) and the Military Healthcare System GENESIS.

## Review of Current Spine Sensing Solutions

The concept of objective spine health monitoring is relatively new. Despite the relative nascency, COTS sensing systems do exist; however, these systems primarily focus on the thoracic or lumbar sections of the spine (Rodgers, Pai, & Conroy, 2015). Fortunately, the increasing demand for highly functional and data-driven technology has led to increased research on wearable sensors designed for human use. To support the overarching objective of improving aviator cervical spine health through non-invasive evaluation, this article will briefly examine current spine sensing solutions and the requisite components. Most research or commercial sensing systems utilize one or more of the following sensors: accelerometers, gyroscopes, magnetometers, or electromyography sensors (EMG). These Micro-Electro-Mechanical Systems

(MEMS) components can be fused to create inertial or motion-tracking sensors, such as IMUs. Although these sensors are prevalent in numerous electrical technologies (automobiles, aircraft, smartphones), their uses for human monitoring applications are still relativley new. EMG is a technique for recording and evaluating the electrical activity produce by skeletal muscles. This activity can be collected either invasively or non-invasively through the use intramuscular or surface EMG (sEMG), respectively. Paired with various temporal and spectral analytical techniques, EMG can be used to detect muscle fatigue, muscle dysfunction, and muscle activity.

A few of the most notable COTS sensing systems include the following: the Xsens various inertial motion tracking modules (Xsens Technologies B.V., The Netherlands); Delsys's Trigno platfrom (Delsys, Inc., Natick, Massachusetts), which combines the capabilities of EMG and IMU into one unit; dorsaVi's ViSafe, ViPerform, and ViMove inertial tracking platform (dorsaVi Ltd., Australia), which provide solutions for occupational, athletic, and clinical applications; and StrongArm's wearble inertial harness and FUSE platform (StrongArm Technologies, Inc Brooklyn, NY, U.S.). Despite dissimilar wearble form factors and data dashboards, these technologies all leverage inertial measurement through the use of MEMS for healthcare, occupational, and athletic applications. A description of a detailed review of these technologies is not within the scope of this paper; however, such a review reveals that there are few technologies specifically designed for the spine or for clinical environments, and precisely zero mature solutions that are designed specifically for clinical measurement of cervical spine function. Most sensing efforts specifically focused on the cervical spine have been confined to basic research settings, such as academia (Papi, Koh, & McGregor, 2017).

**Data Modeling and Protoype Solution**

Implementation of medical devices is the clinical setting is often limited or slowed by necessary supporting infrastructure for device operation (Lukas, et al., 2007). Cervical spine measurement devices, such as the CRANE solution, need to provide accurate clinical assessments through a lightweight form factor with little supporting architecture. Thus, effective solutions would leverage MEMS sensors (e.g., IMU, EMG) without the need for room-based motion tracking of the neck for functional assessment. IMUs can be used to provide orientation and 6 degree of freedom (6-DOF) accelerations of the head and torso while sEMG electrodes are placed bilaterally to track muscle activity on key neck extension and neck flexion muscles during clinical assessment tasks. Tasks would include both standard clinical assessments (i.e., ROM) as well as VR-aided functional tasks (e.g. simulated air-to-air combat). Although the quantification of cervical spine disorder using motion measure has not been heavily researched, empirical examinations of other areas spinal regions has been completed (Marras et al., 1999)

Over the course of a POCT assessment, the IMU/EMG instrumentation and VR-system would collect fine-grained head-torso kinematics and muscle activity data. Raw data can be processed to calculate secondary features such as head trajectory, head acceleration, head jerk, and neck muscle activation patterns and characteristics. Over multiple POCT sessions, the CRANE system would allow for longitudinal tracking of cervical spine functionality. Long-term and chronic overuse injuries often emerge after extended periods of untreated sub-symptomatic states, gradually accumulating soft-tissue damage until significant functional deficits are exhibited (Salmon, Harrison & Neary, 2011). Analysis of minute deviations in cervical spine trajectories and fatigue characteristics over time may be indicative of injury development. Clinical insights supported by objective data would aim to supplement current clinical assessments and provide early detection of movement-pain compensation (and potentially injury development) within the POCT environment.

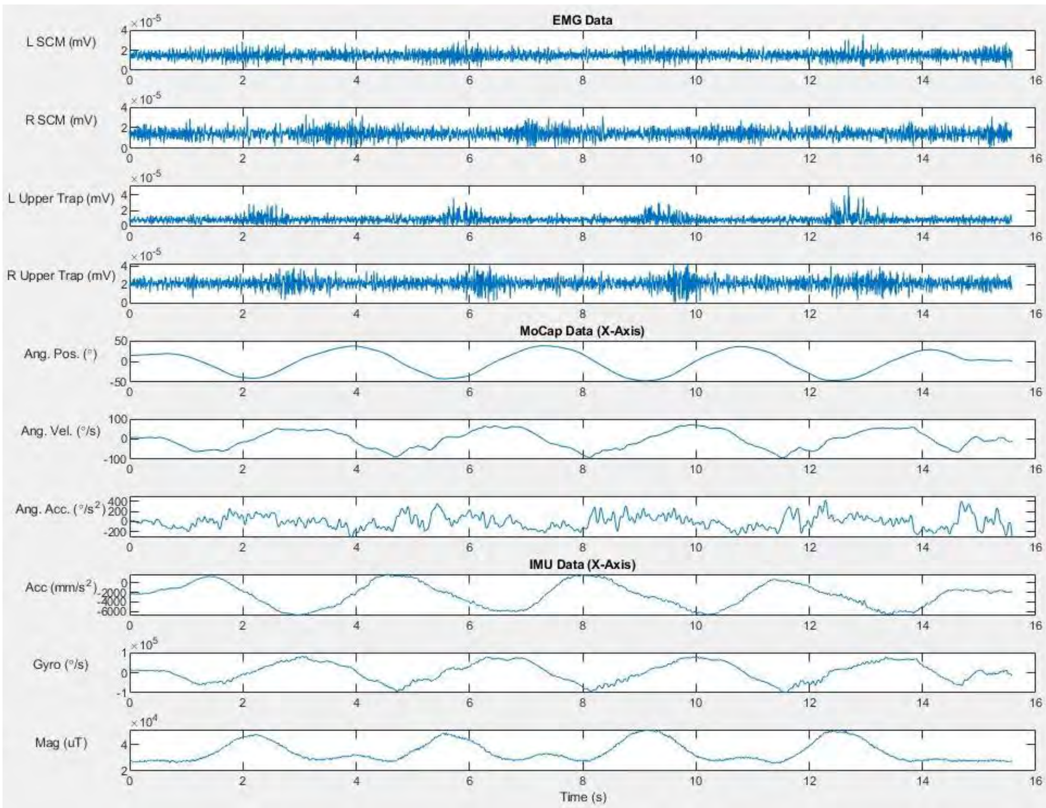


*Figure 1.* Signal outputs from the CRANE system's IMU and sEMG sensors over cycles of head circumduction. (Top-to-bottom) sEMG sensors tracked left-right sternocleidomastoid (SCM), and left-right upper trapezius. Although not part of the in situ CRANE system, motion-capture provides a reference for IMU-collected head kinematics, including position, velocity, acceleration, and orientation. Though complete 6-DOF motion is captured by the system, only X-axis motion components are depicted for brevity.

## Conclusion

Though this research intiative is still in its infancy, early research and development has shown a clear need for a medical material solution capable of objective cervical spine asesement. This article aims to provide a review of existing spine health monitoring capabilites along with a path forward towards cervical spine monitoring in military settings. The initial environment of interest is that of a military clinical environment (e.g., use of the solution during an annual flight physical), with a military clinician serving as the initial user. Outside of clinical use, a long-term objective is to pursue continous and longitudnial spine-health monitoring initiatives in operational settings, such as during long-duration flight missions. A gradual move toward continous monitoring is needed for myriad reasons. Clinical exams are certainly needed to diagnose and treat injury or illness; however, most of this treatment is reactive by nature, as oppossed to proactive. Quite simply, many aviators do not seek treament in the clinic until they are debilitated by often-irreversabile spine pain and damage. Additionally, modern aircraft expose the body to static and dynamic forces that were previously inconceivable. Although research examining short-term exposures is prevalent, the longitudnial effects of such forces and moments is relatively sparse. This article and supporting body of work hope to highlight current research gaps and ameliorate impediments to military spine health monitoring initiatives.

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