A Pain in the Neck: A Modeling Analysis for Design Limitations of Head Supported Mass

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Head supported mass, including helmets, night vision, communications, and other attachments, is a two-edged sword. Though such technologies generally increase survivability, there are functional, occupational limits to how much mass may be borne effectively and safely. The chronic effects of an increased head supported mass include acute and degenerative cervical spine injuries. During the late 1990s and early 2000s, a series of Army sponsored research projects examined the combined effect of increased head supported mass and cyclical loading on cervical spine injuries in helicopter pilots. However, these studies were limited to helicopter pilot exposure and only tracked the dynamics of the head and neck. To fully understand the role this increased mass plays in chronic cervical spine injuries, we assessed the sensitivity of intervertebral stresses to the location and magnitude of the head supported mass using the Duke University Human Neck Model (DUHNM). The DUHNM is a finite element model equipped with active musculature and anatomically accurate stiffness of spinal units, and has been validated against human response in the mid-sagittal plane for neck tension, compression, flexion, and extension.

The methodology for this study is separated into a static component, to analyze effects of increased cervical muscle activation that counteracts the head supported mass, and a dynamic component, to analyze the inertial effects of head supported mass. The static methodology placed masses of 3kg and 5kg, 50mm and 100mm away from the center of gravity (CG) of the head at angles of 0, 30, and 90 degrees from the transverse plane passing through the head CG. An optimization algorithm was used to determine the lowest cervical muscle activation state required to maintain a stable, upright, head position. The maximum intervertebral forces and moments for each scenario in equilibrium were extracted and compared using the combined Nij criterion developed by the National Highway and Traffic Safety Administration (NHTSA). For the dynamic methodology, the region of interest also included head supported mass from 0 to 5kg at locations 0-100mm from the head center of gravity in the vertical and horizontal directions. Simulations include the effects of walking (~1g-1Hz sinusoidal input), jumping from low height (4g-100ms half sine input), and parachute drops (~10g-50ms half sine input) on maximum neck forces and moments and were also compared using the combined Nij criterion from NHTSA.

For static scenarios, it has been shown that tensed cervical muscular alone can reach 40-45 percent of compressive neck tolerances. Extreme scenarios show increasing mass as well as the distance in the X direction from the center of gravity can nearly double maximum intervertebral forces, and quadruple maximum intervertebral moments. Incorporating both repeated impact response from occupational loads (jumping, waling, etc.) and increased head supported mass can increase the compressive loads beyond muscular response. Based on these simulations, we provide design guidance envelopes for head supported mass and center of gravity location in terms of career longevity and assumed occupational scenarios for head supported mass under repeated impact loading.