The Effect of Neck Stiffness and Impact Velocity on Neck Kinematics for Body-first Lateral Impacts

N. Samuel[1], A. Hughes[1], A. Azadi[1], T.B. Hoshizaki
[1]Neurotrauma Impact Science Laboratory, The University of Ottawa, Ottawa, Canada
Email: nsamu011@uottawa.ca

SUMMARY

A body-first impact occurs when a body part other than the head absorbs the initial external force during an impact. This type of impact transfers forces through the body to the neck and head, resulting in complex biomechanical interactions. Body-first impacts are common in sports collisions (e.g., athletes hitting the ground shoulder-first) and vehicular crashes. Injury prevention strategies include increasing neck stiffness but tend to overlook the kinematic responses of the neck. This study explores how neck stiffness and impact velocity influence neck kinematics during shoulder-first impacts. This research will inform injury prevention strategies and protective equipment design.

INTRODUCTION

During body-first impacts, neck muscles play a large role in absorbing and distributing forces, reducing the risk of head and neck injuries. Shoulder-first impacts, specifically, transmit forces through the shoulder to the cervical spine and head, generating complex kinematic responses that affect angular and translational head motions. The human neck allows for an extensive range of motion in several planes comprising ligaments, tendons, muscle tissue and intervertebral discs [1]. These motions influence the risk for brain injuries (TBI) that can contribute to neurodegenerative brain diseases such as chronic traumatic encephalopathy (CTE) highlighting the need for a better understanding of neck stiffness and resulting kinematics of the neck during impacts.

METHODS

Using video analysis, data was collected from 47 shoulder-first impacts in professional hockey games. These impacts were reconstructed using a Hybrid III headform, the University of Ottawa Neck Spring Apparatus, high-speed cameras (1000 fps), and a 3-2-2-2 acceleration array. Neck kinematics were obtained from lateral, body-first impacts tested across three velocities (3 m/s, 5 m/s, 7 m/s) and three neck stiffness levels (low, medium, high) representing 25%, 75%, and 100% of maximum voluntary contraction. Video annotations were conducted using Kinovea software, marking surrogate neck discs: D5 (representing C6/C7), D3 (representing C4/C5), D1 (representing C1/C2), and the center of gravity of the head.

RESULTS AND DISCUSSION

Angular, parallel, and perpendicular disc displacements and velocities provided kinematic responses across stiffness and velocity conditions. High neck stiffness reduced overall motion and promoted earlier stabilization, particularly in the lower neck (D5), redistributing forces upward. At high neck stiffness across velocities, D1 absorbed the majority of translational forces, displaying the highest perpendicular velocity peaks. At an impact velocity of 5 m/s with high neck stiffness, D5 stabilized earlier at frame 10 with a perpendicular velocity of 2.6 m/s, while D3 reached 4.3 m/s. In contrast, D1 maintained a higher perpendicular velocity of 6 m/s, as it absorbed the majority of the forces at this velocity. At an impact velocity of 5 m/s with medium neck stiffness, D5 exhibited a perpendicular velocity of 4.2 m/s at frame 10, while D3 maintained a velocity of 5.5 m/s. D1 reached a perpendicular velocity of 6.6 m/s. D3 functioned as a transitional zone, transferring forces between D5 and D1. Increasing impact velocity amplified kinematic responses, with higher velocities generating pronounced angular, parallel, and perpendicular motions across all regions of the neck. These results demonstrated that neck kinematics during body- first impacts were affected by both neck stiffness and impact velocity.

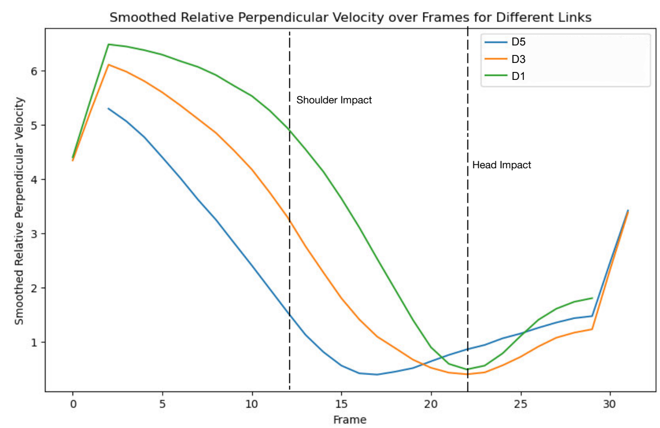

Figure 1: Perpendicular velocity at 5 m/s under high neck stiffness across frames for different cervical neck regions.

CONCLUSIONS

This study examines the influence of neck stiffness and impact velocity on cervical spine kinematics during body-first impacts. Increased neck stiffness reduces overall motion but redistributes forces to the upper cervical spine, while higher impact velocities amplify kinematic responses. These findings provide valuable insights into the biomechanical mechanisms underlying neck injuries in high-risk environments, such as contact sports and automotive crashes.

REFERENCES

[1] Siegmund, G.P et al. (2007). Electromyography of superficial and deep neck muscles during isometric, voluntary, and reflex contractions. Journal of Biomechanical Engineering, 129(1), 66-77.