# The Influence of Neck Stiffness on Head Impact Dynamics in Rear Body-First Falls

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## Summary

A body-first fall is described as a fall where a body part (e.g., shoulder, back) contacts the ground or surface prior to head contact. Body-first backward falls are a common cause of head trauma, resulting in injuries from concussions to severe traumatic brain injuries. Backward falls generate rotational forces during head impact, a key contributor to brain injury [1]. This study examines how neck stiffness affects head impact kinematics in body-first backward falls, focusing on peak rotational acceleration and the associated risk of brain injury. Using a 95th percentile Hybrid III headform mounted on an unbiased neck form with a neck spring apparatus, varying neck stiffness and impact velocities were simulated. Results showed that high spring tension led to a disproportionate increase in rotational head acceleration, thus increasing the risk of concussive injury. This research informs the development of safer protective equipment and training programs.

## Introduction

Body-first backward falls result in rotational forces during head impact, which contribute to the risk of brain injury. Recent studies identify neck stiffness during a body-first fall can significantly influence head impact kinematics and the risk of brain injury [2]. This study investigates the influence of neck stiffness on head impact kinematics during body-first backward falls.

## Methods

This research used a 95th percentile adult male Hybrid III headform mounted on an unbiased neck form within the uOttawa neck spring apparatus (UONSA). The unbiased neck form allows for free rotation in all planes. The UONSA was designed to simulate muscle activation by setting spring tensions to represent different levels of muscle contraction. There are three muscle groups represented by springs on the UONSA: upper trapezius, splenius capitis, and sternocleidomastoid muscle groups [2]. Two impact velocities (3.5 m/s, 5.0 m/s) and two neck muscle stiffnesses (low, high) were investigated. The low (25%) and high (100%) maximal voluntary contraction forces were used to represent neck stiffness by adjusting the spring tension of the UONSA. A 6.5 cm vertical offset was used to represent the average distance between the upper back and the back of the head in adult males for the body-first falls. The headform was dropped using a monorail system and guided onto the MEP anvil. The upper back was the first point of contact, represented with a piece of vinyl nitrile foam which represented the compliance of the back. Peak resultant head linear acceleration and peak resultant head rotational acceleration were measured using a 3-2-2-2 accelerometer array within the headform.

## Results and Discussion

Linear acceleration decreased during body-first falls while rotational acceleration increased during body-first falls (Table 1). The highest peak resultant rotational acceleration, 22596 rad/s$^2$(±377.86), was reported for the highest velocity and highest neck stiffness (Table 1). In body-first rear impacts, high muscle tension resulted in very high rotational acceleration, reflecting a high risk for brain injury. Future research will include the influence of neck and head posture on the relationship between neck muscle strength, impact velocity, and head impact kinematics for body-first falls.

## Conclusions

This research demonstrated a nonlinear relationship between impact velocity and neck stiffness for peak linear and rotational impact accelerations for body-first backward falls. Notably, linear accelerations decrease while rotational accelerations increase during these falls, which is significant given that rotational acceleration is highly correlated with concussion risk [1]. These findings emphasize the need for head protection testing and brain trauma research to account for these biomechanical patterns. This research contributes to a better understanding of the biomechanics of body-first backward falls to inform the development of safer protective equipment, and effective training programs for athletes to prevent injury.

## References

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**Table 1:** Mean linear and rotational acceleration values.

| | | Direct low neck stiffness (±SD) | Direct high neck stiffness (±SD) | Body-first low neck stiffness (±SD) | Body-first high neck stiffness (±SD) |
|---|---|---|---|---|---|
| 3.5 m/s | Linear acc. (g) | 101.7 (±0.96) | 102.3 (±1.6) | 95.3 (±2.99) | 81.9 (±4.65) |
| | Rotational acc. (rad/s$^2$) | 9148 (±273) | 10634 (±307.2) | 15281 (±656.72) | 16693 (±1261.56) |
| 5.0 m/s | Linear acc. (g) | 168.1 (±5.27) | 168.4 (±0.75) | 161.4 (±6.15) | 150.5 (±3.04) |
| | Rotational acc. (rad/s$^2$) | 15469 (±2336.08) | 15352 (±134.34) | 14980 (±1526.84) | 22597 (±377.86) |