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THE RELATIONSHIP BETWEEN IMPACT CONDITION AND VELOCITY ON BRAIN TISSUE RESPONSE

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SUMMARY
Injury reconstruction is a well accepted method for investigating the relationship between the event causing brain injury and the resulting trauma to neural tissue. Understanding the effect of the impact characteristics and velocity on the brain deformations is important when interpreting brain stress and strain values obtained from reconstructions. A finite element model (UCDBTM) was used to evaluate brain tissue response under varying impact conditions using an unhelmeted Hybrid III headform. This study was designed to evaluate the relationship between impact conditions and corresponding brain tissue response variables. The results revealed that the dynamic response curve created by different impacting conditions significantly influenced the maximum principal strain and Von Mises stress of brain tissue, providing valuable insight in the limitations of accident reconstruction from descriptive data.

INTRODUCTION
Traumatic Brain Injuries (TBI) have decreased since the advent of helmet standards, however the incidence of mild Traumatic Brain Injuries (mTBI), also known as concussions, have not decreased and continue to be a concern in both recreational and professional sports. In an effort to understand these injuries, reconstructions employing finite element modeling are becoming more common in describing the parameters related to the resulting injury [1,2]. However, the influence of the parameters used to describe the accident, such as impact location and velocity on brain tissue deformation, is not well understood.

Previous researchers have proposed tolerance values for brain tissue response characteristics associated with sustaining mTBI using finite element modeling [3,4]. Threshold values for peak resultant linear and angular accelerations representing a 50% probability of sustaining mTBI have been estimated as 82g and 5900 rad/s² respectively [3]. More recently, Von Mises stress of 8.4 kPa and maximum principal strain of 0.21 or 0.26, depending on location within the brain tissue, were identified with 50% probability of concussion [4]. However, while this research did involve a variety of impact locations and velocities, they did not examine the influence of these factors on the brain tissue response.

Impact location has been shown to have an influence on the resulting brain response, and therefore resulting head injury [5]. Understanding how the dynamic response of the head form changes with varying impact conditions, and the subsequent resulting brain tissue responses are important in creating an accurate accident reconstruction and ultimately predicting the degree of risk of injury. While it is clear impact location, angle and velocity have a direct effect on the resulting brain tissue deformation, the relationship is not well understood.

METHODS
Impact reconstruction was performed on an unhelmeted Hybrid III headform fitted with a 3-2-2-2 accelerometer array [6]. Impacts were performed using a 13.1kg pneumatic linear impactor under two impact conditions (location and angle), at two impact velocities (5.5m/s and 6.5m/s). Impact conditions were a front impact with a positive elevation 15° (Front PE15) and a rear impact with a negative azimuth (Rear NA). These sites were based on the University of Ottawa Testing Protocol, [7]. Impacts were performed at 5.5m/s and 6.5m/s. The resulting dynamic response of the headform, specifically the x, y, and z components for both linear and angular acceleration was used as an input for the UCDBTM to determine the Von Mises stress and maximum principal strain in the brain tissue.

RESULTS AND DISCUSSION
The peak resultant linear acceleration (figure 1) and peak resultant angular acceleration (figure 2), are presented for each impact condition and velocity. The highest peak resultant linear and angular acceleration magnitudes were from the front impact condition at both 5.5m/s and 6.5m/s. The peak resultant linear acceleration created by the front impact condition was higher than the proposed concussive thresholds under both impact velocities, although the rear impact condition did not show linear accelerations beyond this tolerance [3,4]. All impact conditions created peak angular accelerations higher than the estimated thresholds of sustaining mTBI [3,4].

The peak Von Mises stress (Figure 3) and peak maximum principal strain (Figure 4), are presented for each impact condition and velocity. Resulting peak Von Mises stress for the front impact was 9.8 to 10.1 kPa and peak maximum principal strain was 0.19 to 0.2. In the case of the rear impact, resulting peak Von Mises stress was 7.9 to 10.3 kPa and peak maximum principal strain was 0.18 to 0.23. The highest response values resulted from the front impact at 5.5m/s, and from the rear impact condition at 6.5m/s. Each impact response value exceeds the tolerance thresholds for 50% probability of sustaining mTBI with the exception of maximum principal strain from rear impact at 5.5m/s [3,4]. These results indicate that the location and angle of impact play an important role in injury prediction.
Comparison between peak acceleration and tissue response variables showed low positive correlation between peak linear acceleration and Von Mises stress (0.49). However, when separated by the levels of impact velocity and impact condition different results were obtained. Peak resultant linear acceleration at 5.5m/s significantly correlated with Von Mises stress at both front (0.97) and rear (0.93) impact sites, and with maximum principal strain at front (0.97) and rear (0.91) impact sites. Similar results at 5.5m/s were seen for peak resultant angular accelerations and Von Mises stress (0.98), and maximum principal strain (0.98) for the rear impact condition. At 6.5m/s only the peak resultant linear acceleration showed a high negative correlation with maximum principal strain (-0.88) for the front impact site. These results support that when varying impact velocity and impact condition, the dynamic response of the head form may not reflect changes in brain tissue response.

The resulting comparative trends from this study are consistent with research findings of similar subject-based evaluations [8]. Using the UCDBTM, linear acceleration showed low correlations (0.20-0.52) with peak and average Von Mises stress and maximum principal strain [8]. These investigations indicated that linear acceleration is a poor predictor of tissue response when location of impact is not considered. However angular head accelerations showed good correlations with peak and average Von Mises stress (0.72-0.79) and maximum principal strain (0.70-0.75) outputs even if impact location was not considered [8]. This relationship was not revealed in this study. It must be noted that previous findings were based on simulated helmeted head impacts that did not include a rear impact site [8].

CONCLUSIONS
The results from this experiment suggest that the dynamic response curve of the head form created by different impacting conditions used in this study have a significant effect on brain tissue stress. Impact conditions involving location, direction and velocity all are important in predicting the effect of the impact on brain tissue stress. Further investigations will address the relationships between impact characteristics and brain tissue stress.

REFERENCES
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Figure 1: Peak resultant linear acceleration of Hybrid III headform under two impacting conditions and velocities

Figure 2: Peak resultant angular acceleration of Hybrid III headform under two impacting conditions and velocities

Figure 3: Von Mises stress of Hybrid III headform under two impacting conditions at two impact velocities

Figure 4: Maximum principal strain of Hybrid III headform under two impacting conditions at two impact velocities