Mitigation of Linear Accelerations and Shear Forces During Drop Head Simulated Falls

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ABSTRACT

The danger and risk associated with ice hockey has led to the development of new helmet technologies and testing protocols to minimize the risk of traumatic brain injuries or concussions. Researchers believe that understanding helmet performance across different impact locations and angles during head collisions helps inform helmet manufacturers in the development of helmet testing protocols for brain injury prevention. Based on these beliefs and concerns, this study examined the dynamic interaction of neck compliance, helmet location, and angle of impact in mitigating linear acceleration and shear forces. The results support the hypothesis that an increasing angle of impact decreases peak linear acceleration and increases shear force. Decreasing neck compliance, however, decreases peak linear acceleration and shear force for some helmet impact locations but not all of them. These results add to the literature by implementing a new helmet testing protocol to provide information beyond traditional measures of peak linear acceleration used in current helmet testing standards.

KEYWORDS

Accelerometers, Angular Acceleration, Brain Injuries, Concussions, Helmet Testing Protocols, Mitigation Of Acceleration, Peak Linear Acceleration, Risk Of Head Injuries, Shear Force, Sport Of Hockey

INTRODUCTION

Despite helmet technological improvements, injuries to the head and brain continue to occur. Researchers believe that training hockey players to develop stiffer necks may help mitigate accelerations induced to the head during impact. Researchers also believe that understanding helmet performance across different impact locations and angles during head collisions helps inform helmet manufacturers in the development of testing protocols for brain injury prevention.

Based on these beliefs and concerns, this study examined the relationship between neck surrogate compliance and neck strength for angles of flexion, extension and lateral flexion during static testing. The study also examined the dynamic interaction of neck compliance, helmet location, and angle of impact in mitigating linear acceleration and shear forces.

The first hypothesis of the study stated that increasing neck surrogate compliance increases the strength of the surrogate neck for different angles of flexion, extension and lateral flexion during static testing. The second hypothesis stated that higher neck compliance in combination with higher...
angle of impact generates a decrease in peak linear acceleration, but an increase in shear force across helmet impact locations during dynamic testing.

The results from the static data support the concept that higher neck compliance generates higher neck strength and greater tensile stiffness than lower neck compliance. The results from the dynamic data revealed a significant two-way interaction effect between angle of impact and helmet impact location on measures of peak linear acceleration. The dynamic data results also revealed a significant three-way interaction effect among neck compliance, angle of impact, and location on measures of shear force.

These findings support existing literature and shed further light on the static and dynamic behaviors of helmets in mitigating linear acceleration and shear forces. These results provide information beyond just traditional measures of peak linear acceleration across helmet impact locations when assessing helmet performance.

BACKGROUND

The sport of ice hockey contains the highest incident of concussion and head injury per participant in all of sports (Kendall et al., 2012). In Canada, for example, 3.78% of sport-related emergency room visits in a year related to head injuries experienced by people while playing ice hockey. Among these head injuries, concussions seemed to be the most prevalent type of head injury (Wennberg & Tator, 2003). A concussion or mild traumatic brain injury (mTBI) is “an alteration in brain function, or evidence of brain pathology, caused by an external force” (Menon, Schwab, Wright, & Maas, 2010, p.1637).

The elevated incident of concussions in the sport of ice hockey relates to the high level of impact forces to the head experienced by individuals while playing the sport (Post, Oeur, Hoshizaki, & Gilchrist, 2011; Wennberg & Tator, 2003). These impacts forces result in either linear or rotational accelerations affecting the brain matter and consequently producing concussions (Meaney & Smith, 2011). Linear acceleration refers to a vector quantity representing the rate of change of linear velocity over time measured in units of g (Gimbel & Hoshizaki, 2008). A g unit signifies a multiple of the acceleration due to gravity (Post, Oeur, Hoshizaki, & Gilchrist, 2011). Angular acceleration, on the other hand, refers to a vector quantity representing the change in angular velocity over time measured in radians per second squared (McLean & Anderson, 1997).

Peak linear acceleration represents the most frequent measure used to assess head injuries and helmet performance in the sport of ice hockey. The magnitude of the linear accelerations seems to indicate the severity of the head injury due to the impact (Gurdjian et al., 1968). The magnitude of the rotational accelerations, on the other hand, seems to be more associated with high levels of tissue strain and brain damage (King, Yang, Zhang, & Hadry, 2003).

Although researchers more often associate peak linear acceleration to traumatic focal injuries/skull fractures and rotational accelerations to brain deformation and tissue shearing, concussive head impacts experienced by ice hockey players in the real world, also depend on the ability of the helmet material properties to mitigate shear forces. A shear force refers to “a force applied parallel to a surface, causing internal deformation in an angular direction” (Hamill, Knutzen, & Derrick, 2015, p. 40). Shear force measures, however, do not form part of traditional helmet testing protocol measures for head injury prevention. Shear forces do cause rotation and generate angular accelerations known to be more associated with intercranial tissue damage (Halldin & Kleiven, 2013). This rationale suggests that the risk of sustaining a concussion also depends on the ability of the helmet material to mitigate shear force impact (Gennarelli, 1982; Post et al., 2011), which
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