ESTABLISHING EVIDENCE OF RELIABILITY AND VALIDITY FOR THE USE OF A PNEUMATIC HELMET IMPACT SYSTEM

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Helmets are the main form of head protection used in hockey. Concussions, however, still pose a significant health threat to hockey players. While researchers have used pneumatic impactors to simulate on-ice head impact injury mechanisms responsible for concussions, evidence of reliability and validity for the use of these impactors' acceleration measures are needed to simulate head impact injuries accurately. The purpose of this study was to provide evidence of reliability and validity for the use of a new pneumatic helmet horizontal impact system to measure linear acceleration. The results provide evidence of reliability (ICC=.787-.875, p < .0001) and concurrent-related validity (ICC=.852-.949, p < .0001) when using the new impactor to measure linear acceleration applied to the headform. These outcomes suggest that the new impactor complies to the helmet testing standards.

KEY WORDS: concussion, helmet impact system, impact biomechanics.

INTRODUCTION: Ice hockey is a high-speed collision sport with an inherent risk of injuries. Most troubling of all are injuries to the brain, which can cause severe neurological dysfunction and even death (Post, Oeur, Hoshizaki, & Gilchrist, 2011). Helmets are the primary form of head and brain protection in ice hockey. Research has shown that helmets are effective at decreasing the forces applied to the head resulting in a reduced instance of skull fractures and clinical incidence of injury (Kis et al., 2013). There is little evidence, however, indicating helmets are effective at preventing mild traumatic brain injuries or concussions from biomechanical forces to the head or torso. This lack of evidence may be due to helmet designers compromising their helmets' ability to prevent injuries in favour of comfort and appearance (Zerpa, Carlson, Elyasi, Przysucha, & Hoshizaki, 2016). Current helmet evaluation protocols are based off a single large impact, determining if the helmet passes or fails (Carlson et al., 2016). Testing is conducted using a surrogate headform with a helmet mounted on it. The headform contains an array of accelerometers and is designed to mimic the response of a typical human head during a collision. The helmet impact testing protocols are based on the peak linear acceleration experienced by the headform upon impact. The maximum linear acceleration accepted during this testing protocol is set around 275-300 g from a drop height of 1.5 meters. "The unit g is used for any linear acceleration analysis and is a multiple of acceleration due to gravity (g = 9.81 m/s^2)" (Carlson et al., 2016, p. 391). The helmet is determined to be appropriately protective if the recorded peak linear acceleration is below the threshold value during the impact. Current standard specifications for helmet testing are based off a drop height mechanism to assess the ability of the helmet to prevent a head injury. It has been proposed, however, that a linear horizontal impactor may more closely emulate on ice impacts believed to be responsible for concussions. This type of impactor also allows the headform to move post impact (National Operating Committee on Standards for Athletic Equipment, 2006). Introducing new impactor designs could improve current helmet testing standards and decrease the chance of injuries to the head during collisions.

When introducing a new design to measure helmet performance, the impactor must follow NOCSAE testing procedures. Evidence of reliability and validity for the impact acceleration measures must also be provided before using the impactor for further research. Evidence of reliability can be obtained by examining the internal consistency of the instrument from repeated trials (Furr & Bacharach, 2008). The split-half method estimates reliability by creating two parallel subsets of equal size from one sample, then correlating the scores from the two subsets to provide an estimate of the instrument's test reliability (Furr & Bacharach, 2008). Evidence of validity can be attained by comparing the new impactor acceleration measures to previously validated acceleration measures from a standard device (Cronbach & Meehl, 1955). This type of validation relates to concurrent evidence of validity or the degree to which an instrument's measures are correlated with another relevant instrument's measures as the primary test of interest (Furr & Bacharach, 2008). Based on this rationale, the purpose of this study is to provide evidence of reliability and validity for the use of a new pneumatic helmet impact system to quantify peak linear acceleration across different helmet impact locations.

METHODS: The pneumatic linear impactor (depicted in Figure 1) was built through the collaboration of the School of Kinesiology and Mechanical Engineering Department at Lakehead University. The impactor was designed to generate impacts up to 7 m/s and consisted of the main assembly, an impactor rod, and a linear bearing table. The main assembly contained a 13.1 kg impactor rod and a 3-gallon compressed air tank. The pressure was manipulated using a digital pressure gauge. When the appropriate pressure was achieved, the pressurized air was released via a ball valve. The pressurized air then propelled the impactor rod into a helmeted medium sized NOCSAE headform designed by Hodgson (1975) to simulate the impact response that a human head would experience. The headform contained six accelerometers measuring the linear acceleration felt at impact in the superior-inferior, anterior-posterior, and left-right directions (Zerpa et al., 2016). The headform was fixed on a mechanical neckform designed to simulate the impact response of a human neck. The neckform was then secured on the linear bearing table, positioned to impact the front, side, or rear locations as defined by NOCSAE standards (Walsh, Rousseau, & Hoshizaki, 2011). For the reliability and validity analyses, a hockey helmet with a dual density vinyl-nitrate liner was fitted to the headform as per manufacturer instructions. The helmet position on the headform was further standardized by ensuring a 5.5 cm distance from the brim of the helmet to the bridge of the nose on the headform. All impacts were applied at an angle perpendicular to the headform surface, with no vertical or horizontal rotation being applied to the impact vector. The air in the tank was pressurized to 40 psi, to achieve the required impact velocity of the impactor rod. Once the pressure was achieved, the pressurized air was released, propelling the impactor rod into the impact helmet site with an average velocity of 4.39 m/s. After impact, the headform travelled 0.49 m before being stopped. For each impact site, the linear acceleration data were quantified by the accelerometers sensors mounted in the headform and were fed into an analog to digital converter interfaced to commercial software package called POWERLAB.

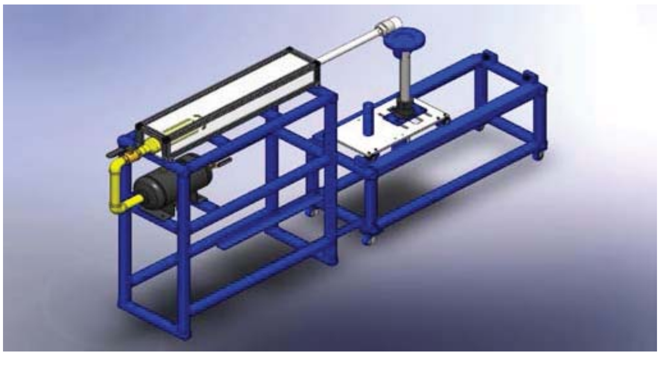

Figure 1: New Pneumatic Impactor System

The resultant linear acceleration was computed using the software calculation module in POWERLAB. A 1000 Hz low pass filter was applied to reduce noise levels. The data were obtained at a rate of 20,000 Hz for each acceleration input channel composed of 12-bit data. Each helmet location was tested in successive order ensuring all impacts were completed on the helmet before proceeding to the subsequent location (Carlson et al., 2016). The order of the impacts was front, side, and rear. To provide evidence of reliability, a protocol similar to Carlson et al. (2016) was used in which the helmet mounted on the headform was subjected to 100 impacts for each helmet location using the linear impactor. The split-half method was used to split the data into even and odd trials for the peak linear acceleration measures across impact locations (i.e., front, side, and rear). Even and odd trials acceleration measures were correlated using intraclass correlations (ICC) to provide evidence of reliability of the acceleration scores across impact locations. To provide evidence of validation for the use of the horizontal impactor, similar impacts were simulated by mounting the NOCSAE headform with the helmet on a standard vertical drop rig, which was attached to a 30.6 kg drop carriage. The drop carriage was raised to a height of 0.98 m and dropped with an impact velocity of 4.39 m/s vertically onto an impact anvil at the base of the vertical drop rig. It is important to highlight that the horizontal and vertical impactor systems had different mechanical structures and impact mechanisms. The standard vertical drop system uses a dual rail guiding track and a free-fall mechanism to produce the impact velocity whereas the pneumatic impactor uses compressed air to generate the required velocity. To be able to compare both systems, the same impact velocity, helmet and impact anvil materials were used. The design difference between the two systems, however, produced a systematic error when comparing the acceleration measures across impact locations. That is, there was a consistent error difference in measures of linear acceleration between both systems for each impact across helmet locations (Carlson et al., 2016). To compensate for the systematic error, the acceleration measures from the horizontal impactor were put under the same scale as the vertical impactor. After scaling was completed, an ICC analysis was applied to compare 25 randomly selected pneumatic trials to 25 randomly selected drop trials to examine the relationship between these acceleration measures and provide evidence of concurrent-related validity.

RESULTS: Table 1 offers a summary of the results obtained from 100 impacts to the front, side, and rear locations to provide evidence of reliability. The front impact site experienced the highest peak linear acceleration with an average of 97.29 g with a standard deviation of 5.72 g, while the side location experienced the lowest mean peak linear acceleration at 85.67 g with a standard deviation of 5.75 g. The ICC values were calculated using the split-half method and are displayed in Table 1. These results provide evidence of reliability across replications trials when using the new pneumatic horizontal impact system.

Table 1
ICC for Peak Linear Acceleration Across Impact Locations to Provide Evidence of Reliability

Location	Mean (g)	SD (g)	ICC	Sig.
Front	97.29	5.72	.86	.0001
Side	85.67	5.75	.79	.0001
Rear	88.86	5.40	.81	.0001

Table 2 displays the ICC results when comparing the scaled acceleration data of the new pneumatic horizontal impact system to the acceleration data of the vertical standard NOCSAE drop system. Strong significant correlations were revealed from the ICC analysis between the acceleration measures taken from both systems across all helmet impact locations tested. The ICC values across all helmet locations tested range from ICC= .85 for the side location to ICC= .95 for the front location. These findings offer proof of concurrent validity for the use of the pneumatic impactor as a valid tool for helmet testing.

Table 2
ICC for Peak Linear Acceleration Across Impact Locations to Provide Evidence of Validity

Location	System	Mean (g)	SD (g)	ICC	Sig.
Front	Pneumatic System	97.15	5.33	.95	.0001
	NOCSAE Standard	95.97	7.39		
Side	Pneumatic System	86.08	4.40	.85	.0001
	NOCSAE Standard	86.71	2.52		
Rear	Pneumatic System	92.18	2.06	.88	.0001
	NOCSAE Standard	91.50	1.46		

DISCUSSION: To use the measures provided by an instrument and make inferences from those measures, providing proof of reliability and validity is essential (Cronbach & Meehl, 1955). The findings of this study suggest that the new horizontal pneumatic impact system is consistent across the three impact locations tested based on the measures of peak linear acceleration. Regarding the validity evidence, the new impactor is comparable to a standard NOCSAE drop system. As the results indicate, strong ICC correlations were achieved when comparing both systems in measures of linear impact acceleration across helmet impact locations. This proof of concurrent validity suggests that the new pneumatic impacting system can be used for future helmet impact research. A limitation of the new horizontal impactor is that the pressure is released manually, adding some degree of variability to the data. A solution to this is retrofitting the impactor with a solenoid valve, which may provide higher consistency across replications.

CONCLUSION: The objective of this study was to provide evidence of reliability and validity for the use of a new pneumatic horizontal impactor when measuring peak linear acceleration. The findings of this study offer verification that the impactor can produce reliable and valid linear acceleration measures and therefore can be used to conduct future helmet testing research and simulate injury reconstruction in hockey or other sports.

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