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

Stephen Carlson[1], Carlos Zerpa[1], Thomas Hoshizaki[1], Siamak Elyasi[2], Glen Paterson[1], Eryk Przysucha[1] and Paolo Sanzo[1]

School of Kinesiology, Lakehead University, Thunder Bay, Canada[1]
Faculty of Engineering, Lakehead University, Thunder Bay, Canada[2]

Head and brain injuries pose a significant threat to the health and well being of athletes. Helmets used in contact sports have proven to be effective in managing linear accelerations applied to the brain. One form of evaluating helmet performance is through the simulation of head impacts acceleration measures using a free-fall drop system and head surrogates (i.e., headforms). The purpose of this study was to provide evidence of reliability and validity for the use of a new helmet drop system to measure linear acceleration for future helmet impact research. Concurrent-related evidence of validity was observed (ICC=0.844-0.952, $p<0.005$) and the system was shown to be highly reliable (ICC=0.922, $p<0.005$) in measuring linear accelerations applied to the head, suggesting it can be used to accurately and consistently measure linear acceleration in future research.

KEY WORDS: Concussion, Helmet Impact System, Drop Testing

INTRODUCTION: The inherent risk of injury in contact sports has lead to the development of new technologies and equipment to prevent injuries. Most concerning of all injuries are those incurred to the head and brain, which can lead to severe neurological dysfunction and even death (Post, Oeur, Hoshizaki, & Gilchrist, 2011). In most contact sports, helmets are the primary form of head and brain protection. As research indicates, helmets have been very effective in reducing the occurrence of head and brain injuries, especially those traumatic in nature (Hoshizaki & Chartrand, 1995). Concussion injuries produced by biomechanics forces applied to the head, however, still occur. These concussion incidents suggest that further development of helmet technology and testing protocols are needed. Current helmet testing and evaluation protocols entail a pass or fail criteria based on a single and large impact (Post et al., 2011). The helmet testing is accomplished by using a surrogate “headform” with the helmet mounted on it. The headform is instrumented with accelerometers and it is designed to respond closely to an actual human head during an impact. The helmet impacts during testing protocols are measured based on peak linear accelerations felt by the headform (Post et al., 2011). The maximum value of linear acceleration allowed during this testing protocol is set around 275-300g from a drop height of 1.5 meters, which is an accepted threshold value obtained from skull fracture data of human cadaver research (Gurdjian, Roberts, & Thomas, 1966). The unit “g” is used for any linear acceleration analysis and is simply a multiple of the acceleration due to gravity ($g=9.81m/s^2$). If the measured peak linear acceleration is less than the threshold value during the impact, the helmet is deemed appropriately protective. There is, however, a need to introduce new rig designs to improve helmet testing standards as a possible avenue to reduce the risk of injuries to the head. When introducing a new rig design to measure helmet performance, it is crucial to comply with The National Operating Committee on Standards for Athletic Equipment (NOCSAE) testing protocols and provide evidence of reliability and validity for the use of the instrument measures. This validation process can be accomplished by providing concurrent-related evidence of validity to assess the accuracy of the measures obtained from the new device when compared to previously validated measures from a standard device (Cronbach & Meehl, 1955). Evidence of reliability, on the other hand, can be obtained by examining the consistency of the instrument measures from repeated trials (Nath, 2013). Based on this rationale, the purpose of this study was to provide evidence of reliability and validity for the use of a new helmet drop system to measure linear acceleration for future helmet impact research.

METHOD: A NOCSAE headform designed by Hodgson (1975) to simulate the dynamic response that a human head experiences during impacts was used for this study. The headform included an array of accelerometer sensors to measure the impact acceleration in the anterior-posterior, superior-inferior and the left-right directions as implemented in previous research (McAllister, 2013; NOCSAE, 2011). The headform was mounted on a mechanical neckform. The neckform was attached to a drop carriage and it was used to simulate the dynamic response of a human neck during impacts. The drop carriage was mounted on a frictionless railing system, which behaved as free falling. The weight of the headform, neck and drop carriage was 30.6 kg and remained the same throughout the testing protocol. A 110-volts AC winch with a wire connected to a magnetic plate controlled by an electronic unit was used to elevate the drop carriage to the correct drop height prior to each impact. Upon release, a switch was pressed on the electronic unit and the drop carriage freely dropped on a steel anvil with a circular impact surface (Gimbel & Hoshizaki, 2008). The rig was mounted on rubber matting and bolted into the floor to minimize noise and vibration caused during impact. This rig as depicted in Figure 1 was constructed by students from Lakehead University Mechanical Engineering Department in conjunction with the School of Kinesiology staff.

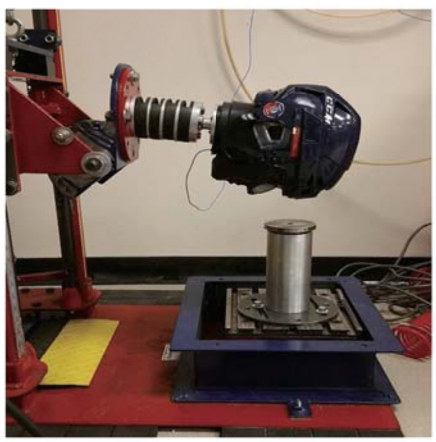

Figure1: New Drop System

Three CCM Vector V08 helmets with VN attenuation liner were used during the testing to provide evidence of validity. Each helmet was properly fitted on the headform prior to each drop by following helmet fitting instructions as defined by NOCSAE standards (NOCSAE, 2014). Between each impact, the helmet being tested was switched with another helmet to allow ample time for the helmet to rebound to its resting state. Each helmet was impacted three times, similar to the research protocol used by Oeur, Hoshizaki, and Gilchrist in 2012. This protocol included 5 locations as defined in NOCSAE drop test standards (Walsh, Rousseau, & Hoshizaki, 2011) at a velocity of 4.5m/s. These locations included: front, front boss, side, rear boss, and rear. For each impact location, the linear acceleration data in the x, y, and z directions captured by the accelerometers sensors mounted in the headform was fed into an analog to digital amplifier unit and processed via a commercial software package called POWERLAB. Resultant acceleration was computed using the software calculation module and a 1000 Hz low pass filter was implemented to minimize noise levels. The data was collected at a sampling rate of 20,000 Hz. Each helmet location was tested in sequential order, ensuring that all impacts to each helmet were completed before moving to the next location. The order of impacts was as follows: front,

front boss, side, rear boss, followed by rear as defined by NOCSAE standards. A total of 45 impacts were applied on each of the three helmets. The same protocol was conducted on a standard NOCSAE drop system at the University of Ottawa and identical helmets were used. Although identical protocols were used to compare both systems, it is important to highlight that both drop systems have different mechanical structures. The new drop system uses a two rail guiding track whereas the standard system uses a monorail guiding track. This design difference between the two drop systems creates a systematic error. That is, a consistent error difference between both systems for each impact location. To compensate for the systematic error, the acceleration measures obtained from the new drop system were put under the same scale as the standard system before comparisons were made. After scaling was completed, an intra-class correlation (ICC) analysis was implemented to examine the relationship between the acceleration measures of the new drop system and standard NOCSAE drop system to provide concurrent-related evidence of validity. To provide evidence of reliability, a fourth identical helmet was used. The helmet was impacted 100 times at the rear location with an inbound velocity of 3.13 m/s. This velocity was achieved by raising the drop carriage to a height of 50cm. The split-half method was used to examine the reliability of the acceleration measures obtained from the new drop system. This method is used when the results from a single measure is randomly divided into two equal halves. The two equal halves are then correlated using ICC to determine reliability of the scores from the measure (Nath, 2013).

Results: Table 1 shows the ICC results obtained when comparing the scaled acceleration measures of the new drop system to the acceleration measures of the standard NOCSAE drop system. The ICC analysis revealed strong significant correlations between the acceleration measures obtained from both systems across all helmet impact locations tested. The ICC values across all helmet location tested range from ICC= 0.84 for the front boss location to as high as ICC=0.95 for the rear boss location. These findings provide evidence of concurrent validity for the use of the new drop system as a valid tool for helmet testing.

Table 1
Results Provide Evidence of Validity for the Use of the New Drop System

Location	System	Mean (g)	SD (g)	ICC	Sig.
Front	New_System	149.33	14.24	0.92	0.0001
	NOCSAE_Standard	149.33	14.23		
Front Boss	New_System	151.01	11.92	0.84	0.002
	NOCSAE_Standard	153.04	14.66		
Side	New_System	125.10	8.25	0.93	0.0001
	NOCSAE_Standard	125.10	8.25		
Rear Boss	New_System	149.58	12.56	0.95	0.0001
	NOCSAE_Standard	149.57	12.56		
Rear	New_System	114.47	7.21	0.93	0.0001
	NOCSAE_Standard	114.46	7.20		

Table 2 offers a summary of the results obtained from 100 impacts at the rear location of the helmet to provide evidence of reliability. A mean of 86.44g was observed over 100 impacts with a standard deviation of 3.03g. ICC values were calculated using the split-half method and the results revealed a strong significant correlation (ICC=0.992, $p<0.005$), which provides evidence of reliability across replications of the test when using the new drop system.

Table 2
Results to Provide Evidence of Reliability for the Use of the New Drop System

Location	Mean (g)	SD (g)	ICC	Sig.
Rear	86.44	3.02	0.922	0.0001

DISCUSSION: It is well documented in the literature that in order to use the measures obtained from an instrument and make inferences from the instrument measures, it is crucial to provide evidence of reliability and validity (Cronbach & Meehl, 1955; Kane, 2006; Nath, 2013). The results of this study indicate that the new drop system is reliable across replications of accelerations measures during helmet impact testing. The new drop system is also comparable to a standard NOCSAE drop system as strong ICC correlations were obtained from the ICC analyses. This evidence of concurrent validity indicates that the new drop system can be used for helmet impact testing because it complies with NOCSAE standards. The new drop system, however, has advantage over current standard NOCSAE drop systems because it allows the researcher to include the mass of the torso in conjunction with the mass of the head to examine the effect of upper body weight on helmet performance.

CONCLUSION: The purpose of this study was to provide evidence of reliability and validity for the use of a new helmet drop system to measure linear acceleration for future helmet impact research. These findings provide evidence that the new drop system measures of linear acceleration are accurate and precise to conduct further research for helmet testing and simulated injury reconstructions in sports. The results obtained from the new system when measuring impact acceleration may also have implications on helmet design and standards for impact testing.

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