P. David Halstead[1,2], Cherie F. Alexander[1], Edward M. Cook[1], Robert C. Drew[2]

Hockey Headgear and the Adequacy of Current Designs and Standards

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ABSTRACT: Technology has surpassed the requirements of hockey headgear standards in use today; however, very few helmets have improved in design/performance. The CSA and ASTM hockey headgear standards are two of the least demanding standards in use and should be updated to account for new materials, a variety of hazards, and use conditions. The design of the helmet should also be investigated to reduce the amount of rotational and possibly cervical injuries. This paper will demonstrate where the current standards need updating and will present theories on how to reduce some of the injuries that plague the sport today.

KEYWORDS: hockey, helmet, standards, impact energies, pass/fail limits, hazards, temperature, geometry.

Head injury rates in collegiate, and potentially other levels, of ice hockey are on the rise [1]. The risk of a young player receiving a head injury during his career as a hockey player is significant [2]. Many of these head injuries may only be preventable through proper education of coaches, players, parents, officials and the sanctioning bodies that establish the rules of play. Regulatory changes, good officiating, and programs such Heads Up Hockey which reflect current understanding of injury mechanics may be the only prevention of many of the head, neck, and other injuries, prevalent in the sport today.

In regard to player's head protection, hockey helmets have changed very little over the past 10-15 years; yet, during that time frame many advances have been made in understanding of how head injuries occur and how their incidences, or their magnitude, can be reduced. Also there have been remarkable strides in developing better materials to attenuate shock. Therefore, the current standards should be revised to account for all the advances and encourage the industry to keep up with technology.

In addition to the technological advances, one needs to recognize all the aspects of the sport that can result in injuries to the head. First of all, hockey is a collision sport. The energy levels that hockey players face upon impacting a variety of obstacles can

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[1] Laboratory Director, Graduate Research Assistant, and Laboratory Technician, respectively, Sports Biomechanics Impact Research Lab, Department of Industrial Engineering, University of Tennessee, Knoxville, TN 37996.
[2] Technical Director and Administrative Director, respectively, Southern Impact Research Center, 1817 Ailor Avenue, Knoxville, TN 37921.

result in higher levels than the typical American football or lacrosse player faces. This is primarily due to the higher velocity attainable on skates and the “rigid” structures that can be struck by a player. Hockey is not a “soft” sport in terms of the hazards encountered. These hazards include the ice, the boards, the goals, the puck, or even another player’s stick, skates, and other equipment.

Variations In The Standards

Headgear standards were put into effect to ensure that the consumer is getting a helmet that meets the minimum requirements, thought to offer some protection against certain types of head injuries. At present all energy management criteria is based only on linear acceleration, a known mechanism of brain injury. Since there are several different activities that can result in either multiple or single impacts and a diversity of hazards, a variety of helmets and standards have been created specifically for a particular activity. A list of standards for several different helmets is provided below:

- Ice Hockey Helmets (CAN/CSA Z262.1-M 90)
- ASTM Performance Specification For Ice Hockey Helmets (F1045-90a)
- ASTM Test Method For Shock-Attenuation Characteristics Of Protective Headgear For Football (F429-92)
- ASTM Specification For Headgear Used In Horse Sports And Horseback Riding (F1163-90a)
- ASTM Specification For Protective Headgear Used In Bicycling (F1447-94)
- ASTM Specifications For Helmets Used In Recreational Roller Skating (F1751)
- ASTM Specification For Protective Headgear Used In Skateboarding (F1492-93)
- SNELL Motorcycle 1990 (M90)
- NOCSAE Performance Specification For Newly Manufactured Football Helmets (NOCSAE DOC.002-96)
- NOCSAE Method Of Impact Test And Performance Requirements For Lacrosse Helmets And Faceguards (NOCSAE Lacrosse)

Since the main reason for contemporary helmets is to minimize the risk of those head injuries that are known to occur from linear accelerations, the standards for similar activities should have similar impact energies (typically determined by the impact velocity and the mass of the headform). However, this is not the case as shown below (Table 1).

TABLE 1--*Comparison between impact energies and pass/fail limits for various standards.*

STANDARD	IMPACT ENERGIES (J)	PASS/FAIL LIMIT (g's)
CSA Z262.1	40	275
F1045-90a	51	300
F429-92	62	300
F1163-90a	90	300
F1447-94	96	300
F1751	96	300
F1492-93	52	300
M90	150	300
NOCSAE DOC.002-96[3]	115	215
NOCSAE Lacrosse[3]	115	215

One might be deceived by the apparent strenuous pass/fail requirements of the CSA standard when compared to several other standards which allow up to 25 more g's; however, these standards cannot be directly compared due to the differences in impact energies. The CSA standard has the lowest impact energy of all the standards, even though all of the other standards listed in Table 1, with the exception of F1045-90a, NOCSAE DOC.002-96[4], and NOCSAE Lacrosse, utilize the same drop system and headform. In fact, the ASTM roller skating helmet standard, F1751, has an impact energy that is nearly 2 1/2 times greater than the CSA hockey helmet standard; although, the pass/fail limit is only 25 g's higher.

The ASTM hockey helmet standard is also misleading. Although the impact energy is higher than that of the CSA hockey helmet standard, the impact surface is a somewhat compliant modular elastomer programmer instead of the steel anvil used in the CSA standard. Another difference between the ASTM and CSA hockey helmet standards is the headforms. The ASTM standard specifies a headform with geometries significantly different from those specified for the headform utilized in the CSA standard. Moreover both the CSA and ASTM hockey helmet standards need to be updated to include the more rigorous testing that many other helmets already have to endure. The authors believe these recommendations will not result in helmets significantly different in appearance, mass, or cost.

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[3] The pass/fail limit for NOCSAE standards is determined by the severity index rather than peak acceleration; however, its 1200 SI pass/fail limit is approximately 215 peak g's, in a typical helmet impact.

[4] The pass/fail limit for NOCSAE standards is significantly lower than other standards in part because a humanoid anthropometric headform is utilized which attenuates some of the impact energy as opposed to the other identified standards that use metallic headforms that effectively transmit all the input to the measurement transducer.

Recommended Hockey Helmet Standard Revisions

In addition to the fact these standards need to include more strenuous impacts to fall in line with the performance requirements of similar sports, there are several other issues that need to be addressed. For instance, the CSA Z262.1 standard does not include high temperature conditioning even though the temperature inside the helmet during play has been casually measured by the authors and found to range from 41 °C to 43 °C (105 °F to 110 °F)[5].

An example where both the CSA and the ASTM hockey helmet standards need to be updated involves the specifications on the chin strap/retention system. Although faceguards are not technically part of the helmet and are evaluated using different standards, the full-face faceguard (typically mandated for ages 18 and under) has a direct effect on the helmet's performance because the chinstrap is attached to the faceguard itself. This arrangement results in a direct transfer of the impact to the wearer's head and jaw structures. Neither standard has a means to measure these forces. Neither standard has an effective helmet position/stability requirement such as the "roll off" requirement used in some standards. In this type of test the helmet is fitted to a headform, a load is typically applied to some edge of the helmet, and the helmet's ability to remain in place is measured.

Also neither hockey helmet standard accounts for many of the obvious hazards involved in hockey. Hockey pucks can be projected at very high speeds; yet, the CSA and ASTM hockey helmet standards call for no such projectile impact tests. In addition, given the fact that hockey can include impacts involving the goals, another player's stick, skates, or other equipment; the helmets should be tested on a hazard anvil that simulates impacts other than on a flat surface.

Recommendations For Product Improvement

In conjunction with revisions to the standards, manufacturers need to make improvements in the design of hockey helmets. Three basic aspects of hockey helmet design that can be improved are impact attenuation, external geometry, and fit/comfort.

In the area of impact attenuation, the authors acknowledge that many, and perhaps most mild head injuries, may never be prevented by changes to the helmet. However, rotationally induced injuries (possibly the primary cause of "mild" head injuries including some levels of concussion) that are the result of a helmet impact are directly affected by the helmet's ability to attenuate linear acceleration. Therefore, if the linear acceleration resulting from a helmet impact can be reduced, the rotational acceleration can also be reduced. In conjunction with improving the helmet's ability to attenuate energy, the authors are convinced that the helmet must remain as light as possible without sacrificing performance. Presently there are several exemplars such as bicycle, roller-skating, and lacrosse helmets which are required to attenuate significantly more impact energy (see Table 1) than hockey helmets yet many are significantly lighter. A weight comparison for several types of helmets and for the same helmets as typically used in play has been

[5] Several hockey players were instrumented with a small thermocouple placed in the area around a vent, not in direct contact with the head, helmet interior lining, or shell.

provided in Figures 1 and 2 respectively. It can be argued that the typical bicycle or roller skating helmet is designed with less coverage and for a limited amount of impacts. While this is true, there are several “bicycle” helmets that are designed and manufactured for repeated impacts and “full” coverage.

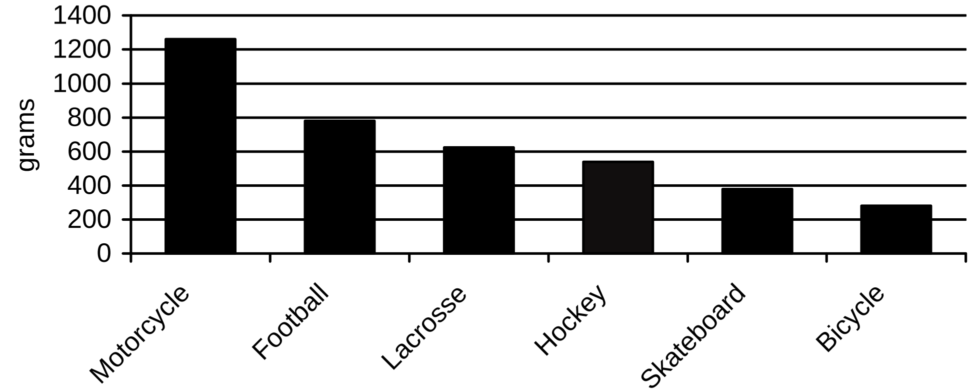

FIGURE 1—*Typical weight comparison for several types of helmets.*

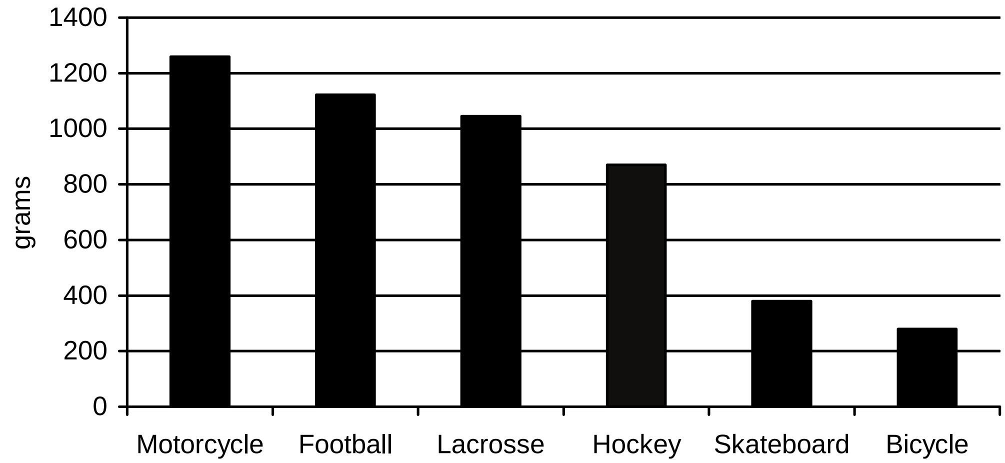

FIGURE 2—*Typical weight comparison for several types of helmets as typically worn with face protectors, shields, etc.*

Of more direct comparison is the lacrosse helmet. Due to the similarities in the activities, several ice hockey helmets were tested in accordance with the NOCSAE lacrosse standard. The results are reflected in Table 2 and Figure 3 below.

TABLE 2—*Results of various hockey helmets tested to the CSA Z262.1 and NOCSAE standards.*

	#1	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**
CSA 262.1 275 g's	FAIL	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS
NOCSAE 1200 SI	FAIL	FAIL	FAIL	PASS	FAIL	FAIL	FAIL	FAIL	FAIL

As can be seen only one of the ice hockey helmets tested was able to meet these requirements. Further the most significant results may be the apparent degradation of ice hockey helmet performance when tested at high temperature as we recommend (see Figure 3 below).

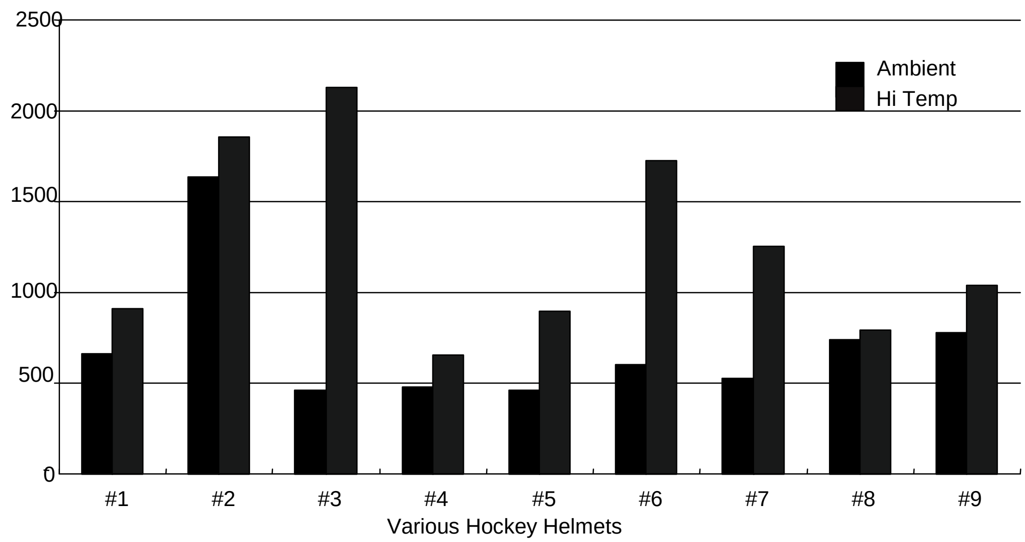

FIGURE 3—*Comparison of hockey helmet performance at ambient and high temperature-side impacts.*

Improvements in external geometry must also be considered in future product development. Current ice hockey helmets are somewhat square in geometry with many external ridges and features. While it is understood that a certain "tradition" in headgear appearance may be desirable, player protection must be the primary design consideration. Of particular concern, are the large nearly flat surfaces typical in the crown area. This geometry poses two potential problems. The first and most clearly understood involves impact performance/energy attenuation in the crown area. Flat surfaces on helmets simply are not as effective at spreading, deflecting, or attenuating impact energies.

The second concern is not as well understood but is based on solid scientific evidence involving the injury mechanics of cervical quadriplegia due to axial load. While the authors believe that no helmet can prevent this type of injury, it is conceivable that this relatively large, flat, sometimes nearly concave crown geometry may result in an increased risk of this injury. This assertion is based upon an understanding of the injury mechanics as described by Torg [3] and the potential for neck entrapment as described by

McElhaney [4]. It is feared that the relatively rare combination of circumstances necessary for this injury to occur may present themselves more frequently due to this "flat" helmet geometry. It should also be noted, however, that Bishop et al. [5] evaluated hockey helmets and the risk of axial load. The results of that study showed that helmets had no significant effect in axial loading

Ice hockey helmets are typically two shell halves that slide together, front to back. This interaction of the shell halves is the primary adjustment in most helmets. The lining components are typically arranged to complement this action or at least not interfere with the adjustment.

In recent years some more complex systems for fit and adjustment have come into use. There is at least one helmet that uses external dials to adjust a "fitting" system inside the helmet. Some helmets are adjusted by the use of soft "fit" foam to conform to the head. Unfortunately none of these fitting systems seem to keep the helmet in place on the head when it may be needed the most. It appears they were developed as a sales tool to keep purchasing decisions simple, and minimize inventory. Keeping cost low and use simple are important, but not at the expense of proper fit and retention. None of the hockey helmets tested could be made to fit the humanoid headforms, or test subjects in a way that inspired confidence in the helmet's ability to stay in place. None of the helmets had any sort of "undercut" to keep the helmet snug on the lower half of the head (that area below the reference plane). Fitting systems, retention systems, and harness adjustments similar to those used in headgear for horse sports, bicycling, or motorcycles should be considered. These systems must be simple to use, not compromise the structural integrity of the outer shell (as the two piece approach does), and be comfortable. The lack of comfort in the authors' opinions is the main reason for improper adjustment. Even the referees, who should be the last line of defense against improper fit, have helmets on their heads that are not properly fitted or retained on the head. Poor fit can be dangerous and compromise the function of the helmet. Improper fit can also complicate critical decisions made by emergency personnel during on-ice triage and preparation for transport in the event of an emergency.

Conclusions

While it is true that today's hockey helmets have done a reasonable job of preventing many injuries, including some brain injuries, the technology to improve the performance and evaluation of ice hockey helmets is readily available. Standards should be improved as soon as possible. International, national, and other standards making bodies should strive to put the best interest of the ice hockey player first and foremost. Efforts should be made to resist any lobbying by those who seem more concerned with manufacturing retooling costs or inventions than player safety.

The fact is, standards are the primary driving force to improve product performance in this market. Even if more protective helmets are constructed and made available, if they look different or cost slightly more they could be failures in this market just because "they look different." Additional marketing efforts to demonstrate the improvements these designs may offer only further increases the cost and may expose the manufacturer to additional litigation risk if he tries to point out potential added safety benefits. The purchaser will ask, “Do they all meet the same standard?” If the answer is yes then the low performance, traditional look, low budget product will likely prevail. It is incumbent upon the standards making bodies to ever increase the performance requirements if the epidemiology and measurement techniques indicate that tougher standards can make a difference.

The authors believe that the evidence is clear. Hockey headgear performance can be significantly improved without increases in cost or compromises in appearance, weight, or wearability. While it is true there is much still left unknown regarding mechanics of injury, measurement of helmet effectiveness, etc., there is solid evidence that high quality helmets that meet a more demanding standard can make a difference in both short and long term quality of life, for those who would wear them [6].

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