



FUTURE OF SPORTS HELMETS

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Declaration

I declare that this written submission represents my ideas in my own words and where other ideas or words are included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea / data / fact / source in my submission. I understand that any violation of the above will cause for disciplinary action by the institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.



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Approval Sheet

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Future of Sports Helmets

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Abstract

The report studies sports helmets and presents a synthesis of research based information and opinions. A review of the literature shows that helmets play an important role in head injury prevention and control. Helmets have been shown to be very efficacious and effective in a range of sports and in preventing specific head injury risks, especially moderate to severe head injury. The report emphasizes the importance of helmet standards and the need for further development. There are calls for helmets that address the needs of competitive (elite) athletes separate to helmets for recreational athletes. Deficiencies in the evidence base for head injury risks and helmet efficacy and effectiveness were identified in some sports. A need to evaluate helmet performance in oblique impacts and incorporate this into standards is also a part of this report. There are emerging opportunities within helmet technology to improve impact performance or to measure impact exposure. In helmet technology as it matures may provide critical information on the severity of the impact, the location of the injured athlete, for example, motorcyclists, and assist in the retrieval and immediate, as well as the long-term medical management of the athlete. It was identified that athletes, families and sports organizations can benefit from access to information on helmet performance. The importance of selecting the appropriate sized helmet and ensuring that the helmet and visor were adjusted and restrained optimally was emphasized. The translation pathway from the science to new and better helmets is the development of appropriate helmet standards and the requirement for only helmets to be used that are certified to those standards.

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A. Introduction

This report presents a detailed summary of the research done on existing and future technologies for helmet design. One of the aims of the research was to identify and highlight helmet topics that required research, policy and/or practical attention. A summary of these topics is also provided. Helmets or padded headgear are used extensively in a wide range of sports where there are head impact hazards and injury risks. Helmets have been found to be very successful in some applications, for example, reducing moderate to severe head injuries, and less so in others. Some reasons for this include research ethics considerations, research design, insufficient funding, immature technology, helmet design and performance versus the sports requirements, standards and deficiencies in bio-mechanical knowledge and tools. In the past decade, there has been a much greater focus on resolving these issues, with some success, and many new opportunities for preventing head and brain injury have been developed. Much of this is presented below. This report summarizes head and brain injury risk, helmet performance and target areas for helmet development.

B. Importance Of Helmets

B.1 Function Of Helmets

A helmet is a form of protective gear worn to protect the head. More specifically, a helmet complements the skull in protecting the human brain. [15]

Studies have shown that wearing a helmet can reduce the risk of a serious brain injury and death because during a fall or collision, most of the impact energy is absorbed by the helmet, rather than your head and brain. [Table 1]



Fig A.1. Motorcycle Helmet. Source [10]



Fig A.2. American Football Helmet. Source [8]



Fig A.3. Equestrian Sports Helmet. Source [9]

	Injury risk		Severe TBI	Helmet		Target future injury reduction
	All head injuries—as proportion of all injuries and/or rate	Concussion—as proportion of all injuries and/or rate		Benefit	Evidence strength	
Football (soccer)	4–20% all levels	3% all levels UEFA: 0.06/1000 h Boys high school: 0.59 per 1000 A–E (comp) College male 1.08 per 1000 A–E (comp)	Minimal risk	63% reduction concussion	One population study, limited laboratory studies	Goal keepers
Rugby	14–25% 8.1/1000 h (youth).	5–15% 6.9/1000 h (youth)	Minimal risk	None. Positive trend with novel design	Multiple well-designed laboratory and population studies	Concussion
American Football	6.6/1000 h (pro) H/F 12% (high school) H/F 8% NCAA	4.1/1000 h (pro) 6.1% Boys high school: 1.55 per 1000 A–E (comp) College male 3.02 per 1000 A–E (comp)	Medium risk=7 catastrophic head injuries per annum US College/High School	74% decrease in fatalities and 84% reduction in serious head injury since 1976.	Multiple well-designed laboratory and population studies	Concussion
Projectile Sports	3–25% cricket 11% baseball	Baseball—Boys high school: 0.05 per 1000 athletic exp (overall) 0.0043/1000 hrs (elite) Cricket: 1.5/1000 h 15%	Minimal risk	Not quantified	Laboratory studies, limited population studies	Facial injury in cricket
Equestrian	19–48%	0.1 to 4.2 per 1000 rides	High risk	Not quantified, but large	Laboratory studies, limited population studies	Severe and fatal head injury
Bicycle	General: 54 H/F/N ED pres per 100 000 population (with helmet) Road race: 0.59 per 100 000 km (with helmet)	Not quantified	Medium risk	63–88% reduction HI	Multiple well-designed laboratory and population studies	Severe and fatal head injury and concussion
Alpine Sports	15–30% (all levels) 2010 Winter Olympics—17%	9.6% skiers 14.7% snow boards (high school and college) 0.05/1000 h (elite) 2010 Winter Olympics—17 per 1000 competitors	High risk	15–60% reduction HI	Multiple well-designed laboratory and population studies	Severe head injury in competitive snow sports Concussion in all snow sports

NCAA, National Collegiate Athletic Association; TBI, traumatic brain injury.

Table 1. Summary of head injury risks, helmet benefits and areas for future injury reduction
Source [20]

B.2 Head Injuries In Sports

If we define a direct fatality as one occurring directly from participation in the skills of a sport, as opposed to an indirect fatality which is one caused by systemic failure as a result of exertion while participating in a sport, head injury is the most frequent direct cause of death in sport. Furthermore, injury to the head takes on a singular importance when we realize the brain is neither capable of regeneration nor, unlike many other body parts and organs, of transplantation. Every effort must be made to protect the athlete's head as injury can lead to dementia, epilepsy, paralysis, and death.



Fig B.2. Head Collision during a Football Match. Source [13]

B.3 Injury recognition

Recognition of a head injury is easy if the athlete has loss of consciousness. It is the far more frequent head injuries in which there is no loss of consciousness but rather only a transient loss of alertness that are much more difficult to recognize. More than 90% of all cerebral concussions fall into this most mild category where there has not been a loss of consciousness but rather only a brief period of post-traumatic amnesia or loss of mental alertness, because the dreaded second impact syndrome can occur after a grade I concussion, just as it can after more serious. head injuries, it becomes very important to recognize all grades of concussion.

Two major types of head injuries involve :

- Severe Head Injury
- Concussion

Others may involve Oro-facial injuries (projectile sports eg. Cricket)

C. Bio-mechanics Of Head Injuries

C.1 Types of Head Injuries

C.1a Concussion

Concussion is derived from the Latin 'concussus' which means "to shake violently". Initially it was thought to produce only a temporary disturbance of brain function due to neuronal, chemical, or neuroelectrical changes without gross structural damage. Structural damage with loss of brain cells does occur with some concussions. The most common athletic head injury is concussion, with one in five high school American football players suffering one annually. Furthermore, the risk of sustaining a concussion in football is four to six times greater for the player who has sustained a previous concussion. It can occur with direct head trauma in collisions or falls, or may occur without a direct blow to the head when sufficient force is applied to the brain, as in a whiplash injury.

Concussion is an injury risk because of its frequency as well as the short- and long-term neurocognitive consequences on brain health and function.

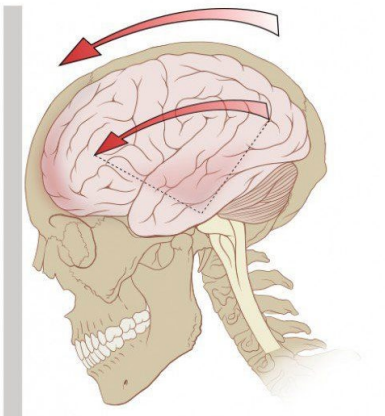


Fig C.1a. Concussion. Source [11]

C.1b Severe Head Injury

A head injury is any sort of injury to your brain, skull, or scalp. This can range from a mild bump or bruise to a traumatic brain injury. Common head injuries include skull fractures, and scalp wounds. The consequences and treatments vary greatly, depending on what caused the head injury and how severe it is.

Head injuries may be either closed or open. A closed head injury is any injury that doesn't break the skull. An open (penetrating) head injury is one in which something breaks the scalp and skull and enters the brain. It can be hard to assess how serious a head injury is just by looking. Some minor head injuries bleed a lot, while some major injuries don't bleed at all. It's important to treat all head injuries seriously and get them assessed by a doctor.

Severe head injury is a risk because of the health consequences to the individual and the economic effects for society.

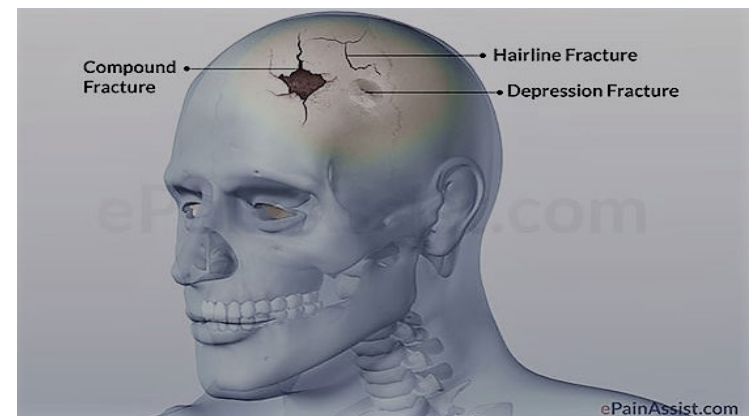


Fig C.1b. Head Injury. Source [12]

The technical expertise behind the design of high quality helmets is based on an understanding of what happens to the head in the event of an accident. This section describes what happens in the event of an accident, and then explains how a helmet works to reduce this effect.

C.2 The Structure

An appreciation of the anatomy of the head is important in understanding the mechanism of injuries to the head and brain. Briefly, the important anatomical information about the head to note is the following:

- The brain is enclosed within a rigid skull.
- The brain “sits” on bones that make up the base of the skull.
- The spinal cord passes through a hole in the underside of the brain.
- Under the skull, adhering to the bones, is a tough tissue called the dura that surround the brain.
- Between the brain and the dura is a space containing cerebrospinal fluid that protects the brain tissue from mechanical shock.
- The brain “floats” in the cerebrospinal fluid but it can only move about 1 millimetre in any direction. The skull is covered by the scalp, which provides some additional protection.

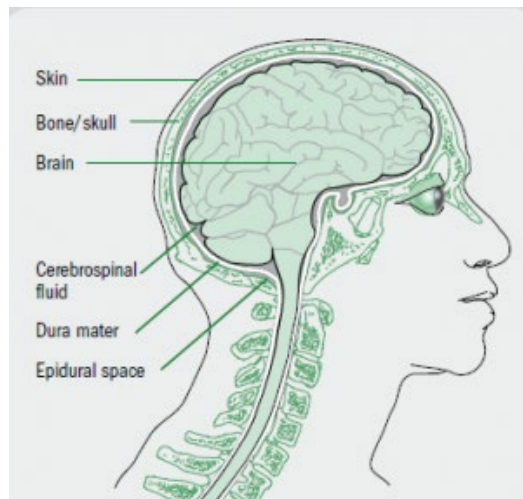


Fig C.2. Structure of Nervous System. Source [19]

C.3 The Mechanism of Head Injuries

For example,

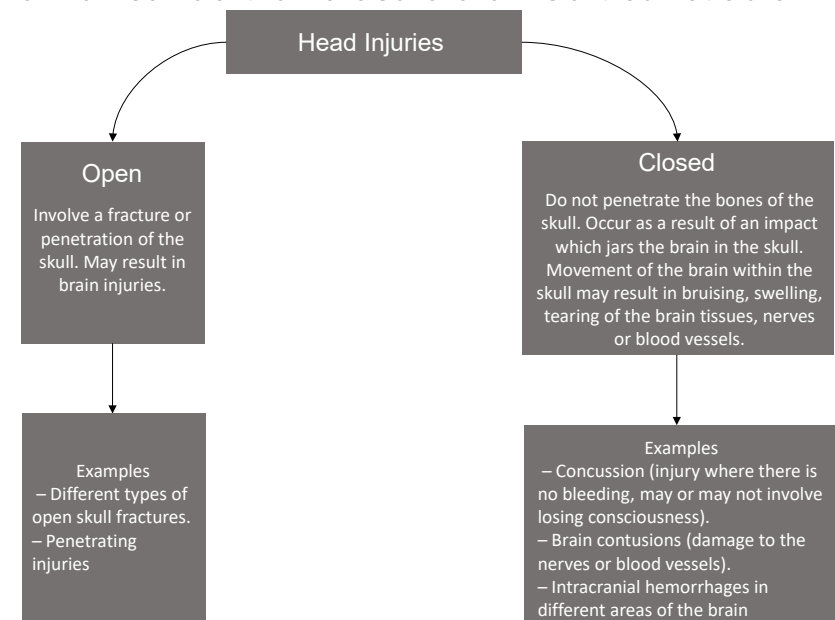
During a motorcycle or bicycle crash there are two principal mechanisms of injury to the brain –

- Through direct contact
- Through acceleration–deceleration

Each mechanism causes different types of injuries.

When a motorcycle or bicycle is involved in a collision, the rider is often thrown from the cycle. If the rider’s head hits an object, such as the ground, the head’s forward motion is stopped, but the brain, having its own mass, continues to move forward until it strikes the inside of the skull. It then rebounds, striking the opposite side of the skull. This type of injury can result in anything from a minor head injury, such as concussion, to a fatal head injury.

Motorcycle riders who do not wear a helmet run a much higher risk of sustaining any of these head and traumatic brain injuries, or a combination of them. Helmets create an additional layer for the head and thus protect the wearer from some of the more severe forms of traumatic brain injury.



Flowchart C.3a. Types of Head Injuries. Source [19]

Motorcycle and equestrian accidents' statistics using data from Germany, Canada and Finland found the most common impact situation to be an oblique impact with an average angle to the ground of 30°. A pure radial impact will cause linear acceleration of the head while a pure tangential impact around the head's center of gravity will cause rotational acceleration of the head. In reality, pure radial impacts are very rare and would mainly cause skull fractures and injuries secondary to those. It is more likely that an oblique impact will occur that gives rise to linear and rotational head acceleration. The human brain is sensitive to rotational motion. Current helmets are, through energy absorbing liners, optimized to reduce the linear acceleration of the head and related injuries, such as skull fractures. A study by Mertz et al (1997) estimated a 5% risk of skull fractures for a peak acceleration of 180 gravities (g) and a 40% risk of fractures for 250 g. Since rotational motion is not included in any current

helmet testing standard, it is not known to what extent the current helmets reduce the rotational accelerations during a head impact. The bulk modulus of brain tissue is roughly 105 times larger than the shear modulus. Thus, the brain tissue can be considered as a fluid in the sense that its primary mode of deformation is shear. Therefore, rotational acceleration may be a better indicator of traumatic brain injury risk than linear acceleration; the most common severe injuries such as subdural hemorrhage and diffuse axonal injury are more easily caused by rotational head motion. However, these occur when the head is subjected to a severe impact. A typical helmet can reduce the impact force and as a result also reduce the magnitude of the rotational loads applied to the brain. Similar considerations need to be given to the mechanisms of concussion and design of helmets to prevent concussion. No generally accepted thresholds exist for rotationally induced brain injuries,

D. Working and Structure - Helmets

D.1 How a helmet works

A helmet aims to reduce the risk of serious head and brain injuries by reducing the impact of a force or collision to the head.

A helmet works in three ways:

- It reduces the deceleration of the skull, and hence the brain movement, by managing the impact. The soft material incorporated in the helmet absorbs some of the impact and therefore the head comes to a halt more slowly. This means that the brain does not hit the skull with such great force.
- It spreads the forces of the impact over a greater surface area so that they are not concentrated on particular areas of the skull.
- It prevents direct contact between the skull and the impacting object by acting as a mechanical barrier between the head and the object.

However there is little evidence for what helmets do to reduce rotational acceleration of the brain (as mentioned above).

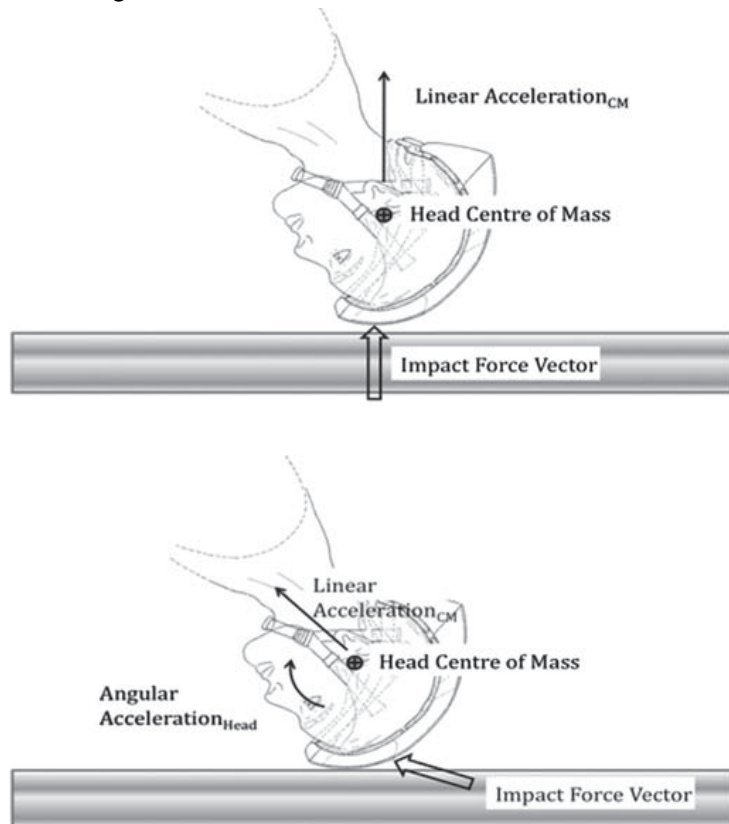


Fig C.3b. Mechanics of Head Injury. Source [20]

D.2 Typical Structure Of Helmets

Little has changed in helmet safety design during the past 30 years. The three functions mentioned are achieved by combining the properties of four basic components of the helmet that are described below -

i. The shell

This is the strong outer surface of the helmet that distributes the impact over a large surface area, and therefore lessens the force before it reaches the head. Although the shell is tough, it is designed to compress when it hits anything hard. It provides protection against penetration by small, sharp and high speed objects and it also protects the padding inside the helmet from abrasions and knocks during daily use. These requirements mean that the shell must be hard, usually with a smooth exterior finish.

ii. The impact-absorbing liner

This is made of a soft, crushable padded material – usually expanded polystyrene, commonly called “Styrofoam”. This dense layer cushions and absorbs the shock as the helmet stops and the head tries to continue moving.

iii. The comfort padding

This is the soft foam-and-cloth layer that sits next to the head. It helps keep the head comfortable and the helmet fitting snugly.

iv. The retention system, or chin strap

This is the mechanism that keeps the helmet on the head in a crash. A strap is connected to each side of the shell. Chin and neck straps, which are specifically designed to keep the helmet on during an impact, must be correctly used for the helmet to function as it is designed to.

Sometimes helmets are also provided with a face shield.

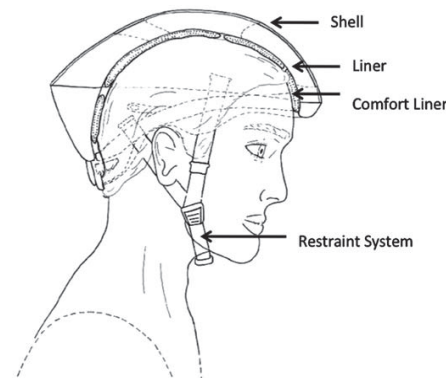


Fig D.2a. Parts of helmet. Source [20]

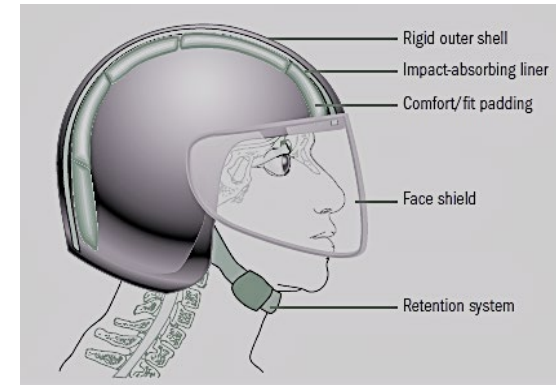


Fig D.2b. Helmet with Face Shield. Source [19]

D.3 Materials

Outer shell

- Lower price plastics are generally Composites
- Premium cost materials include Fiberglass along with Kevlar / Carbon Fiber. Lexan is a bullet proof glass which may also be used. It is less expensive, however heavy in weight.

Fiberglass crushes during impact and thus provides better protection. Most manufacturers use Kevlar or Carbon fiber along with Fiberglass to reduce cost.

Impact-absorbing Liner

This layer is generally made from EPS (expanded polystyrene foam) to distribute the impact and deform to reduce the impact on the head. A new element—Koroyd, is being tested to replace Styrofoam as it is believed to be 30% safer because it can absorb more impact. Koroyd is made by welding tiny tubes together so that when the helmet hits something, these tubes break and absorb the impact, keeping your head safe from injury.

Comfort Padding

Comfort padding is generally foam lined with fabric to provide a snug fit. Sometimes inflatable liners are used in helmets to achieve proper fit for various head sizes.

The face shield and chin straps and generally moulded in Polycarbonate.

E.1 Sports Helmets

i. Headgear in football

Football is the only contact sport where the participants purposefully use their unprotected head to control and advance the ball; despite this, the risk of concussion and severe head injury is low. Laboratory studies testing headgear to reduce concussion and severe head injuries in head-to-head and ball-to-head situations are inconclusive. Headbands reduce linear acceleration very modestly; however, there is no protection against rotational acceleration of the brain. A cross-sectional, non-randomized study using a symptom based definition found that concussion frequency was significantly (2.7 times) higher among youth players who did not wear headgear compared with those who did. However, this is the only, very weak, evidence that headgear protects the brain while playing football

ii. Headgear in rugby football

There is a definite risk of concussion in rugby football and a very low risk of moderate to severe head injury. To date, high-quality laboratory and randomized control studies of headgear have not shown that current designs are likely at a player population level or an individual player level to prevent concussion or head injury. There may be other reasons why players wear headgear, for example, comfort and protection against very superficial injury. The Rugby Headgear Study and associated research identified a strong trend in protective performance for the 'modified headgear'. This headgear was constructed from thicker and denser foam than a standard headgear and performed better in laboratory tests. In the randomized control trial, there was a non-significant reduction of 59% compared with no headgear in head injury (including concussion) leading to at least one missed games. This result indicates the direction that rugby headgear might take to improve its performance and the importance of well-designed research in informing helmet development and assessing helmet efficacy.

iii. Cycle helmets

Head injuries are the cause of death in 69%–93% of the fatalities in bicycle accidents. However, bicycle safety helmets have been shown to be effective in all epidemiological studies. Current cycle helmet design

provides good protection although certain political lobbying organizations have been claiming the opposite. The typical large vents seen in bicycle helmets do not cause excessive pressures on the skull. Furthermore, the long extensions at the front and rear of cycle helmets do not cause excessive rotation of the head. Even so, bicycle safety helmets can still be susceptible to improvement and especially the coverage at the side of the head can be improved. This could easily be done by changing the test lines in future test standards. A further improvement in the rotational protection of bicycle helmets could be obtained by including an oblique helmet test and rotational head motion measurement in future test standards. Nevertheless, the difference between not wearing a bicycle helmet and wearing a helmet in terms of accident outcome is much greater than wearing an optimal helmet. Thus, increasing helmet wearing rates to high levels (80% and above) through mandatory helmet laws and/or public safety campaigns is also a critical step to protect cyclists.

iv. Projectile sports

As presented in table 1, there is a risk of head and facial injury in sports with projectiles, such as cricket, baseball and ice hockey. Over the past two decades, cricket helmet use has come to be the norm, despite there not being rigorous evaluation of their performance. Concerns have been expressed about the possibility of cricket balls breaching the helmet's face guard and causing eye and facial injuries. The standards for cricket helmets, unlike baseball, do not include impact tests for the helmet or the face guard that are representative of projectile impacts. Therefore, standards' development is one area of improvement. It has also been identified that correct helmet fit and adjustment of the restraint or face guard are essential in ensuring adequate performance.

v. Alpine sports

A recent systematic review based on 12 studies on recreational skiers/snowboarders concluded that skiers and snowboarders with a helmet were significantly less likely than those without a helmet to have a head injury, and that there was no evidence of an increased risk of neck injury. There is no data available from the competitive level. According to the International Ski Federation (FIS) regulations, the use of crash helmets is compulsory for all events, conforming to standards. However, the

question is whether these standards are appropriate, as they define performance requirements for use in recreational snow sports. It seems reasonable to assume that these requirements will be very different in World Cup skiing and snowboarding, where race speed may exceed 140 km/h down an icy course. Thus, there is a need to develop appropriate helmet standards for competitive skiers and snowboarders.

vi. American football

The incidence of concussion in American football is relatively high compared with other sports, owing largely to the high number of head impacts experienced. College and high school age athletes are exposed to as many as 1400 head impacts during a single playing season, mostly of relatively low magnitude. While the short-term effects of these repetitive impacts on the measures of brain function quantified by cognitive testing or neuro-imaging appear to be limited, less is known about the cumulative effect of head impacts over time; research on retired American football players has demonstrated a significant increase in the incidence of early onset dementia, potentially linked to repetitive head impacts. Current efforts are aimed at better monitoring of head impact exposure at different age levels, correlation of head impact bio-mechanics with clinical sequel surrounding concussion diagnosis, understanding the risk of brain injury due to rotational head motion following impact and the development of bio-fidelic test methods for reproducing head impacts in a laboratory.

E.2 Future of Sports Helmets and Standards

Sports helmets do an excellent job at preventing traumatic head injuries that they were designed to protect against. However, as research on concussions and repetitive brain trauma advances rapidly, there is a demand for helmet technology to provide increased protection against these injuries as well. By attenuating impact energy, current helmets do reduce the forces acting on the head that might lead to these less severe brain injuries, but helmets alone may not be able to prevent rotational motion of the head that is thought to be linked to the stretching of axons in the brain linked to concussion. Efforts to use helmet technology

in concussion prevention must not reduce their current protective capability against focal injury, nor add so much padding or weight as to make participation in the sport difficult.

Potential technology solutions for the prevention of brain injury should rely on research identifying the mechanism of sports-related brain trauma. Both single impact and repetitive impacts should be considered. The use of non-linear anisotropic padding materials which react differently to attenuate varied energy input, helmet geometries and construction to reduce rotational acceleration of the head following impact, and alternative attachment mechanisms to improve helmet fit and also to more efficiently manage energy are all design options that have or are being employed in new helmet designs. Sports-specific or even position-specific helmets address differences among and within sports and consider different hazards that might be encountered and likely head impact energies and directions. Single impact versus multiple impact helmets and their construction using inexpensive, lightweight materials such as expanded polystyrene and expanded polypropylene highlight these approaches. Novel technologies and materials used must also be cost-effective when mass production is required.

As new helmet technologies emerge with the intent of also addressing concussion prevention, laboratory testing and standards development for these helmets should be based on realistic loading conditions for that sport. Technology to monitor head impact exposure on the playing field, including head impact frequency, magnitude and direction (impact location), is used together with clinical diagnosis of concussion injury to develop risk curves for sustaining concussion based on variables including head linear acceleration, rotational acceleration, impact duration and impact location. These data can be used to develop standard test methodologies and to inform helmet technology developments. On-field monitoring technologies should measure head motion rather than just helmet motion during impacts to correlate better with injury mechanisms. Navigation sensors can also be made a part of the newly developed helmets to track the location of athletes in long distance races and to provide quick information if the athlete has met with an accident.

These sensors can also be a part of helmets designed for recreation sports.

Advances in helmet technology alone may not and are not likely to eliminate concussions in sport. Opportunities to reduce the incidence and severity of concussions in sport will emerge from the coupling of (a) appropriate education and rules (enhancement and enforcement) to minimize repetitive head impacts in sports and (b) novel helmet materials, geometries and designs based on emerging scientific data that elucidate the mechanisms of sports-related concussion.

E.3 Manufactures and Helmet Development

Manufacturers rely on scientific data, standards, market research, input from sports organizations and individuals in the development of helmets. They also rely on their in-house design and engineering expertise. Helmet manufacturers and developers support the need for relevant helmet standards. From their perspective, standards provide the benchmarks for helmet performance, provide a fair playing field and access to markets. There is recognition of the differing requirements of competitive (elite) and recreational athletes, children and adults and a desire to supply products to those markets. However, the development costs for new helmets are considerable and these need to be factored into the thoughts of sporting organizations, standards committees and athletes, when there are calls for 'better' helmets. One section of the competitive sports helmet market where there has been progress is in motor sports, where helmets have been designed to protect athletes under extreme impact conditions. New shell and liner materials with properties optimized to minimize head and brain loads in radial, tangential and oblique impacts are always under consideration. Of these, some will emerge within new products.

F. Conclusion

Following conclusions were drawn from this research on existing and future helmets -

- Helmets play an important role in head injury prevention and control. Helmets have been shown to be very efficacious and effective in a range of sports and in preventing specific head injury risks, especially moderate to severe head injury.

- Helmet standards are important and there needs to be further development.
- Helmets for competitive (elite) athletes and separately for recreational athletes need to be designed and developed.
- Helmets for children, adults and older athletes, because of the differing human tolerance to impacts and impact profiles, need to be designed and developed.
- Deficiencies in the evidence base for head injury risks and helmet efficacy and effectiveness were identified in some sports and need to be worked on.
- There are difficulties in designing helmets that are suitable to prevent severe head injuries and concussion.
- There is need to evaluate helmet performance in oblique impacts using in-helmet technology and incorporate this into standards.

There are many knowledge deficits that can be addressed through research, including improving the bio-mechanical understanding of the impacts that athletes are exposed to, and higher-quality studies of helmet efficacy and effectiveness across many sports. The emerging opportunities of in-helmet technology to improve impact performance or to measure impact exposure should be developed. In-helmet technology as it matures may provide critical information on the severity of the impact, the location of the injured athlete, for eg, snowboarder, and assist in the retrieval and immediate, as well as the long-term, medical management of the athlete.

Finally, because of the high cost to the manufacturer to develop a new helmet, it is imperative that there is a broad stakeholder consensus on the need for new helmets. These costs may be on a higher end for a new product and may involve retooling and other fixed production costs. The additional benefit of reaching and communicating a consensus is that products will be developed that meet strategic injury prevention objectives. The translation pathway from the science and the consensus to new and better helmets is the development of appropriate helmet standards and the requirement for only helmets to be used that are certified to those standards.

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