Helmets in Sport: Fact and Fallacy

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Abstract
Head injuries and the prevention of both the short-term and long-term consequences have received heightened awareness in recent years. Education and legislative efforts have promoted both appropriate treatment of concussion and pushed the use of helmets for protection from head injuries. Current scientific data would suggest that helmets are effective at decreasing the risk of serious head injuries. However there is no evidence to suggest that helmets are protective against concussive injuries or the long-term impact of repetitive head trauma.

Introduction
With the increasing attention being given to the potential dangers of concussions and repetitive head impacts, interest in helmet technology has increased also. While this attention has led to advances, it is also leading to widespread misinformation about the ability of helmets to protect athletes from head injuries. Media reports and manufacturer claims have contributed to this issue with false claims and misunderstood reports. This is highlighted in recent lawsuits against helmet manufacturers, in reports suggesting that most National Football League players are not wearing “concussion proof helmets” and players have extra protection to decrease the chances of repeated concussions.

An understanding of the protective capabilities and deficiencies in helmets is the best way to ensure athletes have the correct information.

Helmet Types and Standards
It is important in the discussion of helmets to clarify the type of helmet or head protection being studied or used. Traditionally helmet design includes an outer shell and an inner liner (23). These structures and materials are designed to absorb and disperse energy during head contact (23). Helmets also have a variety of features for comfort and restraint. Other types of headgear such as soft padded helmets commonly referred to as padded headgears have no outer shell (23).

Helmets can be classified also as single-impact use or multiple impacts. For example, American football helmets are designed for repetitive/repeat exposure, whereas most bicycle helmets are designed for only a single significant impact.

There are multiple testing and standards organizations both in the United States and Internationally. Testing standards vary somewhat by the type of helmet and the testing organization. A recent review summarizes the most well-known organizations and their sports helmet certification (23). It is interesting to note that specific helmet requirements may vary by organization even for the same sport (23).

Most testing standards involve a measure of impact (23,25). This classically involves dropping the helmet (and usually a headform) from a specified height (23,25,34). The Wayne State Tolerance curve was developed, based on these measurements, to determine the failure thresholds, both force load and time of application, for the human skull (25). This information is the basis on which most standards are measured. Although these laboratory data measuring linear acceleration were applied initially to skull fracture thresholds, it was used later to measure risk of moderate to severe traumatic brain injury (25). Newer systems have been proposed, and although they have given us increased insight into the forces involved in head impacts, they have yet to be examined fully in their ability to improve on current standards and more importantly patient outcomes (3,4,17,20,33,36).

The most well known of these is the summation of tests for analysis of risk (STAR) evaluation system developed at Virginia Tech University (36). This system used field-collected data points on head acceleration and translated this information into a new testing procedure for helmets. Instead of a single or a few drop test configurations, the STAR system uses 24 drop test configurations. Data from 32 concussions in the collection period also were used to assess concussion risk based on these measurements. While they found the overall forces involved in concussive injuries higher than subconcussive injuries, there is still a wide variation in forces for both concussive and subconcussive forces as previously reported. The Virginia Tech Helmet Rating™ recently was released based on these data and findings. While the STAR measurement system is a step forward in measuring a helmet's ability to disperse forces, the STAR
value calculation is still theoretical, and clinical outcomes, i.e., concussion rates by helmet rating, have yet to be studied. The National Operating Committee on Standards for Athletic Equipment recently released a statement cautioning parents, players, coaches, and athletic directors about the limitations of the STAR evaluation (28).

What Helmets Do Well?

Biomechanics Laboratory data clearly show that helmets, including padded headgear, are generally good at distributing impact forces (3,15,18,23,33,34). The forces measured and attenuated in testing consist of both linear and rotational components. This is a result of not only the impact absorption of the material but also the ability of the helmet to spread the force over a greater surface area. Helmets therefore have the potential to decrease injuries caused by such forces. These types of injuries include skull fractures, cerebral contusions, and intracranial bleeding. However most testing data rely heavily on linear force measurement, and although newer data are attempting to quantify the affect on rotational forces, the magnitude of the effect remains largely unknown (23,35). Additionally because each head impact/injury is an almost infinitely unique combination of both linear and rotational forces, it can be difficult to extrapolate laboratory data to real-world safety.

Clinical studies Overall studies seem to point to a positive effect of helmets on serious head injury (2,10,40). The quantification of this effect is extremely difficult to determine given the majority of data are from case-controlled epidemiological studies. These types of studies are generally good at quantifying a positive or negative effect of an intervention, but data on the magnitude of the effect must be interpreted cautiously.

Recreation sports, bicycling, skiing, and snowboarding, have data supporting helmet use to reduce the risk of serious head injury (2,10,40). A 2009 Cochrane review, using five case-control studies, found helmets to be 63% to 88% effective in reducing the risk of serious head and facial injuries (44). Although these data have been criticized by some, the large reduction in injury points toward an overall positive effect of bicycle helmets on serious head injury. As stated previously, however, the magnitude of the effect should be interpreted with caution.

Similarly a review found a significant decrease, 15% to 60%, in risk of serious head injury in skiing and snowboarding (40). These studies also were case controls, and several of the articles in this review used ski patrol data as the surrogate for serious head injury. While ski patrol assessments have been found to be useful in classifying some injuries, a recent study suggested there was poor correlation between ski patrol assessment and final hospital diagnosis (31). Interest in this small sample physician correlation was poor as well. Despite this, it is likely that helmets in these sports do decrease the risk of serious head injury, but the size of the effect may have been overestimated by these studies.

American football carries a significant risk of head injuries and accounts for the majority of sport-related catastrophic injuries in the United States (11,27). The modern football helmet, not surprisingly, performs better than its leather predecessors in biomechanical testing, although a recent study did find leather helmets to have similar impact protection in game-simulated impacts (34). Leather helmets were replaced largely by more modern helmets in the early 1950s, and helmet technology has not changed significantly since the 1980s. According to the National Center for Sports Injury Research, brain injury-related fatalities decrease from 128 (1961 to 1970) to 32 (2001 to 2010) (27). This number has been relatively stable, though slowly decreasing, since 1981 (27). This coincides with some improvement in helmet technology, but significant rule changes were instituted also in this time frame. The decrease in fatalities is likely related to both improved helmets and these changes, but it is unclear how much of the effect should be attributed to each. Since 1984, brain-related injuries with incomplete recovery have been relatively stable, averaging about 6 per year (range, 2 to 16), but there were several spikes in the past few years with 12 injuries occurring in each of 2007 and 2008 and 16 occurring in 2011 (27). These injuries almost are seen exclusively in high school and college athletes. This most likely is due to the increased numbers of participants versus professionals.

Other helmeted sports, ice hockey, and to a lesser degree, rugby and soccer have generally overall lower risk of fatal or incomplete recovery (11,23). There are some epidemiologic data suggesting helmet effectiveness and no reported fatalities in Sweden since 1963 when mandatory helmets were introduced, but helmet introduction in hockey also coincided with an increase in facial injuries and concussion (5). There have been few direct head injury-related deaths reported since 1983 in high school or college ice hockey (27). There are little data on fatal or incomplete recovered head injury in soccer and rugby with the small number of soccer deaths almost all related to a goal falling over onto a participant (27). Rugby-related data and headgear have focused thus far on concussive injuries, and headgear has an unknown effect on serious head injuries (19,21,24).

What Helmets Do Not Do Well?

Biomechanics Several recent lawsuits against the helmet manufactures have brought to the forefront the issue of helmets and concussions. While the details of the lawsuit are not pertinent to this discussion, the cases center around claims that helmets helped prevent concussion.

There are two important anatomic issues that may limit a helmet’s ability to protect against concussive injury. First brain tissue has very little resistance and deforms easily to shear forces (25). Based on our current understanding of concussion, it is these shear forces that contribute most to concussive injury (25). Secondly the brain is a free-floating structure, making it susceptible to injury from these forces (25).

Current biomechanical data have yet to elucidate a clear concussive threshold (13,14,15,35,36). Helmets in general have some ability to decrease rotational as well as linear forces (23,37). As previously discussed, because each individual head impact represents a unique combination of forces, measurement even with in-helmet technology can be difficult. Interestingly, current clinical symptoms associated with concussion do not correlate well with biomechanical
data as well, suggesting that an exact threshold may not be clinically relevant in the care of a concussed athlete (7,12).

This information makes engineering a helmet that can decrease these forces difficult to design. Current biomechanical studies in the literature often refer to a concussion threshold or subconcussive impacts. Currently we can only define a concussive or subconcussive impact based on a clinical exam, i.e., did the impact cause a concussion, making laboratory data discussion of subconcussive measurements difficult to interpret. In-helmet technology force measurement has margins of error that may contribute our inability to collect data accurately (20). Additionally, because it is thought generally that concussions may be underreported, (18) field-based data may not capture all data in regards to concussive injuries. Although it is necessary to some degree for research to make an assumption based on the best known data, in reality, there may be errors related to the assumptions given our significant gaps in understanding the forces involved in concussive injuries.

Clinical data Clinical data related to concussions can be difficult to interpret. Concussion rates have been increasing in recent years, and it is unclear whether this is a true increase in incidence or an increase in reporting (18). Given our increase awareness of concussive injuries and significant educational and legislative efforts, the increase is likely in large part a reporting difference. This does however make older studies on helmets and concussion difficult to compare, and these increased rates would suggest that modern helmets do not provide significant protection from concussive injury. This is consistent with the findings of several recent expert summaries on concussion (18,22).

American football Early studies on concussion and football found mixed results on concussion incidence and helmet types (11,23). Both studies had significantly lower concussion rates than expected and had significant exposure bias for the helmet types used. They also likely had reporting/data collection bias based on their study designs. A smaller study looking at repeat concussion rates in athletes who purchased a polyurethane cover as added protection found increase concussion rates with those previously reporting a higher number of concussions being at greater risk (45). It is unlikely however that the cap increased rates, but as data has shown, previous concussion is a risk factor for subsequent injury (18).

The most controversial study on helmets and concussion reported a 31% (5.3 vs 7.6) decreased relative risk for players using the Riddell Revolution helmet (8). This study has been criticized for control group bias (newer vs older helmets), the use of neuropsychological testing as a diagnostic tool (not validated for this purpose) and industry ties.

No other current studies have looked at helmet type and concussion risk in American football.

Rugby and soccer There had been some suggestion of decreased concussion risk with the use of padded headgear in rugby and soccer (11). Studies however have shown mixed results, and all experience significant methodological flaws including small number of players using headgear, and study designs were not intended to determine effect of head gear on concussions (19,21). The only randomized trial found no difference in rates of concussion between rugby players who wore head gear and controls (24).

Other sports There is limited data relatively in other sports with regard to helmet use and concussion risk. As previously stated, an increase in facial and concussive injuries was reported in Sweden after the institution of mandatory helmet rules (5). It is unclear whether a more aggressive playing style or increased attention may have led to this increase.

Other Issues
Risk compensation This theory suggests that the protective value of helmets, or any protective equipment, may be limited by the tendency of the wearer to increase risk-taking behavior while wearing the equipment (30). This theory has been supported by studies showing bicyclist, skiers, and snowboarders tend to ride faster and on average engage in more risk-taking behavior than nonhelmet wearers (30,42). Additionally studies have not shown a decrease in fatalities in skiing and snowboarding despite increasing helmet wearing and no reduction in head injuries from cycling in countries where helmet laws were enacted (43). One could however interpret this alternatively to say that increased helmet use has not caused an increase in injuries. Additionally there is evidence that personality type, i.e., sensation seeking, may play a larger role in risk behavior than risk compensation (38,39,41). The value of any protective equipment is clearly limited by the circumstance under which it is used; however the effect of risk compensation on the protective effect of helmets is unknown.

Chronic traumatic encephalopathy Current case reports have described a neurodegenerative disease in athletes, mainly American football players, that presents with symptoms similar to tau-related dementias (47). Although little is known about the potential risk factors and causes of this condition, it is postulated that a combination of concussive and subconcussive blows causes a progressive cognitive decline and neurodegeneration generally years after an athlete has finished their career (47). There is some concern that modern helmets allow athletes to sustain these repetitive head impacts potentially increasing their risk for these conditions (6,9,46). This has been highlighted by the recent decision of the International Boxing Associations decision to ban headgear from Olympic competition. Given the current concern that it is the cumulative impact load, not individual concussive injury, that may lead to this condition, further studies are needed to define the role of helmets in protecting athletes from this condition.

Neck injuries Initial concerns that helmets may increase the risk of neck injury have not been supported in the literature. Studies of cycling, skiing, and snowboarding have found neither increased nor inconclusive evidence (1,16). Extrapolating from recreational motorsports, motorcycle, and all-terrain vehicle, there is no evidence that helmets increase the risk or cervical injury (26,29,32).

Conclusion
Helmets have shown the ability, both in the laboratory and clinically, to decrease the risk of serious head injury in some
circumstances. Because of study design limitations, the magnitude of this protection is difficult to quantify.

Current data do not suggest that modern helmets are protective against concussive injury. There are weak data that padded headgear may help in rugby and soccer; however further study is needed to determine whether this effect can be reproduced.

Researchers continue to look at better measurement methods and current data points to a combination of measurements and clinical data as a tool in understanding the forces involved in concussive injury. With continued research, these data may help engineers develop materials and designs to improve a helmet’s ability to protect against concussion.

References