Full90Sports

White Paper, 2nd edition, August 2004

Introduction to 2nd edition

Progress in the understanding of head injuries in soccer has been dramatic since the release of our first White Paper in February 2003. It has been established and accepted that concussions occur in soccer at a much higher rate than was previously suspected, and potential methods for reducing concussion incidence and severity are being investigated more thoroughly and more scientifically than in the past. Soccer governing bodies have recognized that many players are concerned about head injuries, and soft padded headbands are now allowed for use by all major soccer groups. However, despite this dramatic progress, much work remains to be done.

Soccer remains the most popular organized sport in the world. Because the head is used as a deliberate physical offensive weapon in soccer, there is significant risk of head injuries. Any protective device that is used to reduce the risk of head injury must allow the game to be played without modification – the device must not alter the act of heading, it must not provide an advantage to any player, and it must not itself be injurious to any player.

While the act of heading seldom causes a concussion if the player is prepared for the impact, the result of years of heading is still under debate. Other types of impacts – head to head, head to ground, head to goal post – are known to cause concussions, and there may be long-term negative affects as well. Any protection offered to players must mitigate the forces of these incidental contacts without altering the method or result of heading.

A few commercial products that make a variety of claims about head protection have been introduced recently. One independent study[1] concluded that none of the available products provided significant benefits against heading impacts, but no incidental impacts were conducted, and the authors concluded that "...the headbands may play a role in decreasing impact for more forceful blows." Other tests show that at least one available product (Full90™ Performance Headguard) provides important reductions in both linear and rotational acceleration in more severe impacts such as collisions between players and falls to the ground. If GAMBIT is correct (see Measuring Impact Forces, below), these force reductions could lead to reduction of the probability of concussion, including the possibility of prevention of some minor concussions and severity reduction of others.

The results of these tests of the Full90™ Performance Headguard show conclusively that head protection can be provided in soccer without changing the game. FIFA, USSF, and NFHS have published statements specifically allowing the use of soft padded headbands by all soccer players, so there is no barrier to the wearing of qualifying products such as Full90. In response to the medical research, recent FIFA and US Soccer clarifications to Law 4, numerous state associations, leagues, and clubs have either mandated the use of head protection or promoted its use in 2005.

Is There a Head Injury Problem in Soccer?

There are unquestionably head injuries in soccer and some of them are quite severe. Attend just about any competitive tournament during the season, and you will see a sports medicine tent staffed by emergency medical personnel. It is typical for them to attend to at least one head injury during each tournament – usually a concussion-type injury.

It has been suggested that improved rule enforcement by coaches and referees would end the head injury issue in soccer. If players would just follow the rules, it is said, there would be no more head injuries. However, Fuller[2], in reviewing films of FIFA tournaments and having a panel of referees decide whether on-field penalty calls related to head/neck injuries were

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[1] Naunheim R et al, "Does Soccer Headgear Attenuate the Impact When Heading the Soccer Ball?" Acad Emergency Med 2003; 10(1):85-90.
[2] Fuller CW, et al, "An Assessment of Football (soccer) Referees' Decisions in Incidents Leading to Player Injuries," Am J Sports Medicine2004; 32:17S-22S.

correct, found that on-field foul calls were made in only 40% of the injurious situations, and the review panel identified 49% of the injury plays as fouls. Either way, over half of the plays that led to head/neck injuries were not considered to have been related to foul play, so even perfect rule enforcement by the referees would account for less than half of the head/neck injuries.

The U.S Consumer Product Safety Commission (CPSC) estimates that there are thousands of soccer-related concussions in the US every year. Recent NCAA data show that the number of participants in NCAA college soccer grew by 257% between 1981 and 2001. Additional data from the Sporting Goods Manufacturers Association (SGMA) show that the rate of concussions among soccer players increased nearly twice as much as the rate of participation during 1994-2002. Because of the difficulty and confusion surrounding the diagnosis of concussions, these numbers must be viewed as estimates, but they point out clearly that head injuries in soccer are a growing concern. Additional interest occurred in 2003 when former English star forward Jeff Astle died at a relatively young age from "industrial disease." The coroner concluded that Mr. Astle's death was caused by accelerated brain deterioration as a result of frequent heading of a soccer ball early in his life. No one knows how many of these impacts were actually concussions.

Dr. Delaney et al[3] at McGill University found that more than 60% of college-level soccer players reported concussion symptoms (headache, nausea, dizziness, amnesia, light sensitivity, etc) during a single season. Some support for the reported high frequency of concussions was provided by Sallis[4], who concluded that 40% of players are concussed each year, and that 10% of them received a concussion in their most recent game. Although the percentage at other levels of play may be different, these data indicate that head injuries in soccer are more frequent than previously thought.

<u>If Concussions Are So Frequent, Why Do We Hear So Little About Them?</u>

Concussions may be the most misunderstood and misdiagnosed injury in the sports world. A concussion does <u>not</u> have to be fatal; it does <u>not</u> require loss of consciousness; there may <u>not</u> be any outward symptoms; a concussion may even occur with <u>no</u> impact to the head. The current definition of concussion is "a traumatically induced alteration in brain function manifested by an alteration of awareness or consciousness." Symptoms such as dizziness, confusion, or even just a headache, which are changes in awareness, can mean that a concussion has occurred. Admittedly headaches may derive from other sources; concussion headaches can be differentiated from stress headaches[5] by observing deficits in simple reaction time. In general, stress headaches can be alleviated by aspirin or Tylenol, while concussion headaches cannot. Although head impacts are a common cause of concussions, sudden movement of the head can also generate a concussion, as in shaken baby syndrome and whiplash.

Because there are usually no visible markers when a concussion occurs, many people believe there is also no injury. Players are often urged to "shake it off," or "get back in the game." "Having your bell rung" and "getting a ding" are mild forms of concussion, and if they are not properly addressed they can lead to more serious damage. A person who has had one concussion is about four times as likely to have a second one as a person who has never been concussed, and the following concussion is likely to be more severe than the first one. Also, although the reasons are not understood, women are more likely to be concussed by a particular incident than men. Symptoms may be so subtle that a coach or trainer does not notice them; in fact, even the concussed individual may not know that he has been injured,

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[3] Delaney JS, Lacroix VJ, et al, "Concussions Among University Football and Soccer Players," Clin J Sport Med 2002; 12(6):331-338.
[4] Sallis RE and Jones KD, "The Incidence of Concussion in College Soccer Players," Med and Sci in Sports and Exercise 2003; 35(5).
[5] Makdissi M et al, "Differentiating Concussion from Post-Traumatic Headaches in Australian Footballers – A Pilot Study," Med and Sci in Sports and Exercise 2003; 35(5).

particularly with delayed-onset symptoms that may not appear until the next day. Even when mild symptoms are noticed, neither the coach nor the player may want a substitute in the game, so the injured player re-enters action immediately, risking much more serious injury. McCrea discovered in a recent project[6] that the three most common reasons that players did not report head injuries to coaches or trainers were (a) Didn't think the injury was serious enough to report, (b) Didn't want to leave the game, and (c) Didn't know the symptoms were indicative of a concussion. Delaney[7] in his study found that 80% of the concussions were unreported or unnoticed.

While brain functions may recover completely with rest after a concussion, apparently heightened susceptibility to injury does not. After a minor concussion, a person may feel completely normal after a week, doing everything he did before the concussion, but he is still more likely to incur another concussion than if he had not had the first one. If a second concussion is received before the brain has healed from the first one, the second one, no matter how minor the impact seems, may be catastrophic. This is referred to as Second Impact Syndrome, or "talk and die." This is a rare occurrence, but has happened enough to warn us to take great care to avoid a second concussion shortly after a first one.

Other Issues Related to Concussions

1. Field data. In order to measure the real protective capabilities of headgear, it is necessary to put the product on some people, and determine the difference in injury rates between those wearing the product and those not wearing it. All other variables must be kept as constant as possible to avoid unwanted confusion of data. Unfortunately, this simple straightforward test method will not provide sufficient information in this case. As we have noted, 80% of concussions are not diagnosed, most of them at the mild end of the concussion scale, because of the lack of visible symptoms. Major concussions are easy to detect; minor ones are problematic. Unfortunately, the type of soccer headgear that is allowed by the governing bodies must be the type that is most effective against relatively minor impacts – the ones that are often undetected. Football helmets work very well against more severe impacts, but football-type helmets are not acceptable in soccer because they are not "soft, padded headbands" and would significantly modify the way soccer is played. The soft padded headbands that are allowable to the governing bodies provide some protection against many minor impacts, but cannot prevent concussions from major collisions. Because of this disparity, any straightforward field test of soccer headgear will be biased against the headgear because many of the injuries that are being prevented or reduced by the headgear will not be included in the count of concussive incidents. It is possible, then, that headgear may prevent only a small percentage of the diagnosed concussions, suggesting moderate effectiveness, while it prevents or reduces the severity of a large percentage of the undiagnosed concussions. Until there is an accepted, simple and reliable method for diagnosing all concussions immediately at the sidelines, the validity of any report of the effectiveness of soccer headgear in actual field use must be questioned.

2. Improving detection of concussions. There is some progress in improving diagnostic thoroughness, although it may still be incomplete and relatively unavailable for some time. Pellman's team has published a series of articles[8] analyzing professional football game films to determine impact locations and velocities, calculating linear and rotational accelerations, and comparing the accelerations to the presence or absence of concussion. This work represents a

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[6] McCrea M et al, "Unreported Concussion in High School Football Players," Clin J Sport Medicine 2004; 14(1): 13-17.

[7] Delaney, op cit.

[8] Pellman EJ et al, "Concussion in Professional Football: Reconstruction of Game Impacts and Injuries," Neurosurgery 2003; 53(4): 799-812.

Pellman EJ et al, "Concussion in Professional Football: Location and Direction of Helmet Impacts – Part 2," Neurosurgery 2003; 53(6): 1328-1340.

Pellman EJ et al, "Concussion in Professional Football: Epidemiological Features of Game Injuries and Review of the Literature," Neurosurgery 2004; 54(1): 81-94.

giant early step in creating a quantitative and predictable link between impact forces and concussion probability.

Another step has been taken by Simbex, creators of the HIT System (Head Impact Telemetry System™) that uses accelerometers situated inside a player's football helmet to measure the magnitude of each head impact and transmit the data to an analysis system on the sidelines. If this system can be adapted to soccer, both with and without headgear, it will advance the reliability and completeness of product field testing.

3. Link to Alzheimer's, multiple sub-concussive impacts. For more than fifteen years there have been reports that soccer players who head the ball regularly are more prone to cognitive damage later in life than those who have not had repeated head impacts.[9] The phenomenon is similar to "punch-drunk" syndrome in former boxers. Although not all research reports support these findings, more data are being collected, and recent studies[10,11,12,1314] extend the theory to suggest that repetitive head injury and repeated concussions both increase the risk of Alzheimer's Disease, depression, other dementias, and possibly even Parkinson's Disease. If these links are substantiated by further studies, the need for head protection in athletics will be insurmountable.

4. Age dependence. In a study that may have profound implications on the future of participation in sports, Melvin Field and colleagues at the University of Pittsburgh found[15] that high school athletes require a longer recovery period from a concussion than older college athletes, even when the college athletes had more serious concussions and a more extensive history of prior concussions. If these findings are confirmed and extended to even younger children, return-to-play criteria must be adjusted for age level, and we may have to rethink the entire concept of allowing young children to participate in contact sports.

5. Postural stability. Despite the variety of studies that have attempted to improve concussion diagnosis by searching for a strong correlation between concussions and symptoms, there is still no reliable way of determining the presence or severity of a concussion by looking at physical symptoms. Loss of consciousness was once considered to be necessary for a concussion to have occurred; cognitive deficits may be an accurate measure but they are difficult to assess quickly; amnesia duration has been suggested to be directly related to concussion severity. One correlation that has not been widely publicized is between concussion and postural stability. The idea was proposed in 2001[16] and appears to be a consistent link to concussions, but again it is difficult to determine objectively and quantitatively within a short time after impact. A position statement to be published by the National Athletic Trainers' Association (NATA) in September 2004 will stress that "postural-stability testing is recommended to assist in determining injury severity and readiness for return to play."[17]

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[9] Sortland O and Tysvaer AT, "Brain Damage in Former Association Football Players: An Evaluation by Cerebral Computed Tomography," Neuroradiology 1989; 31:44-48.

[10] Uryu K et al., "Repetitive Mild Brain Trauma Accelerates Aβ Deposition, Lipid Peroxidation, and Cognitive Impairment in a Transgenic Mouse Model of Alzheimer Amyloidosis," J Neuroscience 2002; 22(2): 446-454.

[11] Fleminger S et al., "Head Injury as a Risk Factor for Alzheimer's Disease: The Evidence 10 Years On; A Partial Replication," J Neurology Neurosurg and Psych 2003; 74:857-862.

[12] Bailes J et al., "Recurrent Sport-Related Concussion Linked to Clinical Depression," AANS Annual Meeting, April 2003.

[13] Plassman BL et al., "Documented Head Injury in Early Adulthood and Risk of Alzheimer's Disease and Other Dementias," Neurology 2000; 55:1158-1166.

[14] Guskiewicz AK et al., "No Evidence of Impaired Neurocognitive Performance in Collegiate Soccer Players," Am J Sports Med 2002; 30:157-162.

[15] Field M et al., "Does Age Play a Role in Recovery from Sports-Related Concussion? A Comparison of High School and Collegiate Athletes," J Pediatrics 2003; 142:546-553.

[16] Guskiewicz KM et al., "Postural Stability and Neuropsychological Deficits After Concussion in Collegiate Athletes," J Athl Train 2001; 36(3):263-273.

[17] "Athletic Trainers Urge that Concussions Not Be Taken Lightly," The NCAA News, 5 July 2004.

6. Computerized neuropsychological testing. As mentioned above, cognitive deficits appear to be directly linked to concussion severity; the difficulties are in conducting neuropsychological testing immediately following a head impact and in determining exactly what deficits are related to concussion type and severity. A number of test batteries, administered via computer, have been introduced in recent years[18] to compare post-concussion cognition with baseline pre-season cognition. Because of the difficulty in conducting immediate testing after injury, the current value of these systems is in determining concussion severity and recovery rather than in initial diagnosis.

7. Is the number of impacts proportional to late-life deficits? While there is still controversy about whether successive sub-concussive head impacts cause late-life mental deficits, one study[19] claims to have found not only a definite link between head impacts and cognitive problems, but even a direct quantitative association between the number of head impacts and the severity of late-life deficits. If additional studies confirm this relationship, it may be possible to predict how much heading should be acceptable in soccer.

8. Other issues. Two papers of interest were published in late 2003. One (Broglio[20]) is a variant on prior tests conducted at Washington University[21] in projecting a soccer ball against a headgear-protected device, and measuring the resultant forces. Broglio tested three products that had at one time been commercially available, by placing them on a force plate and shooting the ball at them at a determined speed. Unlike Naunheim, who found little or no impact reduction except at high speeds, Broglio determined that there was a significant reduction in peak impact force with all of the tested products.

Queen[22] looked at heading forces from a somewhat different point of view, creating a theoretical model of a soccer ball impacting a head, and investigating the contact time, ball size and pressure, and neck stiffness as they affect impact forces. Not surprisingly, she found that a more massive head and a stiffer neck reduced linear and angular acceleration. Ball pressure doesn't seem to be important, but a larger ball increases the contact time with the head. The importance of using an appropriately-sized ball for each age group is reinforced.

What Happens to the Brain When It Is Concussed?

A. Linear acceleration. If you push the center of a uniform object on a frictionless surface, it will move in the direction of the force you apply. As long as you are pushing directly at the center of mass of the object, it will not twist, or roll, or do anything except move smoothly in a straight line. If the object is moving smoothly, then hits an obstacle, it will decelerate at a rate dependent on the magnitude of the stopping force. If it hits a brick wall, it will stop quite suddenly, but if it hits a pillow it will slow down more gradually as it compresses the pillow until it stops or the pillow cannot compress anymore. The rate of stopping in this case is called linear acceleration (or deceleration).

If a person's head is moving smoothly, then hits another head of equal mass and hardness, both heads will stop almost immediately. This may cause discomfort and bruising on the outside of the head, but what happens on the inside? Because the brain is not firmly mounted to the inside of the skull, it will try to continue moving even when the skull stops; it's somewhat like shaking a tube that has a marble in it. If the tube and marble are moving smoothly together, then the tube is stopped, the marble will continue to move until it is stopped by the wall of the tube. In the head, the brain continues to move until it hits the inner wall of the skull at the point of impact, potentially causing something akin to a bruise on

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[18] For example, ImPACT, CogSport, Headminders, and others.

[19] Matser JT et al., "A Dose-Response Relation of Headers and Concussions with Cognitive Impairment in Professional Soccer Players," J Clin Exp Neuropsychology 2001; 23(6):770-774.

[20] Broglio SP et al., "The Efficacy of Soccer Headgear," J Athl Train 2003; 38(3): 220-224.

[21] Naunheim RS et al., "Does Soccer Headgear Attenuate the Impact When Heading a Soccer Ball?" Acad Emerg Med 2003; 10:85-90.

[22] Queen RM et al., "Theoretical Study of the Effect of Ball Properties on Impact Force in Soccer Heading," Med & Sci in Sports & Exercise 2003; 35(12):2069-2076.

the brain at the impact site. Then, as a reaction to this motion, the brain may rebound away from the impact point and strike the opposite side of the skull, causing another bruising injury. Injury at the impact site is called "coup" injury, and at the opposite side is called "contracoup." These are the types of injuries that are most common when the head is linearly accelerated.

B. Rotational acceleration. If we take the same object on a frictionless surface, and push it tangentially, it may still move slightly linearly, but most of its motion will be rotational – it will rotate around its center depending on the magnitude of the tangential force. It will continue to spin until it is forced to stop by some external force. Going back to our marble in a tube, if the tube is spinning with the marble at its center, the marble spins along with the tube. If the spinning of the tube is reduced slowly, the marble may peacefully come to rest inside the tube. However, if the tube is stopped suddenly, the marble will tend to continue spinning after the tube stops. How soon the marble will stop spinning depends on the frictional force between the marble and the inside of the tube.

The head is tethered to the body by the neck, so the head can move only a short distance linearly before the neck forces it to twist, applying rotational movement. When the head moves in a rotational manner, the brain tries to follow along with the motion of the skull. If the skull is stopped suddenly, the brain tends to continue to spin. As we said, the brain is not firmly attached to the inside of the skull; it is attached by blood vessels and other relatively soft connections that were not designed to withstand the spinning of the brain inside the skull. If the skull is stopped very suddenly, some of the soft connections may be broken, and this may occur all the way around the brain. In addition, the inside of the skull is not smooth, but has sharp points and ridges that can cut into the brain as it rotates inside the skull. To make matters worse, the brain, being somewhat viscous, does not all stop at the same time. When the outside of the brain stops, the inside wants to continue spinning, causing stretching and deformation at different depths inside the brain. Brain cells are very sensitive to bending and stretching, and are easily damaged when this happens, causing dispersed damage throughout the brain, called "diffuse axonal injury," or DAI. It is believed that damage caused by rotational acceleration is more severe than that caused by linear acceleration, in part because rotational acceleration may affect the entire brain while linear acceleration usually affects only the impact site and possibly the opposite side. This suggests that much of our effort should be put into managing rotational acceleration, even though it is not nearly as well understood as linear acceleration.

C. Injury thresholds. It is not possible to say whether a given impact will result in a concussion in a particular person. Skull thickness, skull curvature, mass of impacting object, shape and density of the impacting object, direction of impact – many factors are involved, and there are so many variables that it is impossible to define a precise threshold of impact magnitude at which concussions begin to occur. It is believed that linear acceleration, which is fairly well understood, begins causing concussions within a wide band centered at about 78 g (gravitational units). However, some people may withstand much higher impacts without injury, while others may be concussed at much lower levels. All we really know is that concussions are more likely to occur as the impact energy increases. Rotational acceleration is more mysterious than linear acceleration, so the gray area in which a concussion may begin to occur is even wider. It has been suggested that the center of the threshold zone may occur at about 7000 radians per second squared, but some concussions have been observed at rotational accelerations as low as 2500 r/s2. The uncertainly when both linear and rotational acceleration are present is even greater.

Measuring Impact Forces

Although determination of reduction in concussion incidence and severity is impossible to determine with current diagnostic methods, it is possible to measure the reduction in forces reaching the head in typical soccer impacts. Equipment that is normally used in testing of other kinds of protective helmets is insufficient for two reasons: (1) Headforms used in testing of bicycle, equestrian, and hockey helmets are made of titanium metal, which is considerably harder than a human head. Titanium is fine in looking for a single catastrophic impact, but does not give reasonable results in lower level impacts of the type seen in soccer; and (2) The accelerometers, processing electronics and software for measuring catastrophic impacts measure only linear acceleration, while rotational acceleration must also be measured for soccer head injury purposes. As a result, the testing that is required for soccer-type impacts is more sophisticated and expensive than that for catastrophic impacts, and few laboratories are capable of conducting the tests required.

Two types of headforms are appropriate for soccer head impact testing – those referred to as Hybrid III, which have been used for many years in automobile crash testing; and National Operating Committee on Standards for Athletic Equipment (NOCSAE) headforms, as are used in testing football helmets. A 2-2-2-3 array of accelerometers is necessary to measure both linear and rotational acceleration, and the analysis electronics must be capable of processing the additional accelerometer channels. Software must calculate GAMBIT[23] (Generalized Acceleration Model for Brain Injury Threshold) by combining linear and rotational acceleration into a single factor related to concussion probability.

In the laboratory, a Hybrid III or NOCSAE headform is firmly fixed to a horizontal platform. A second identical headform is mounted on a drop system that allows it to drop in essentially frictionless free-fall from a fixed height onto the fixed headform, approximating a head to head impact. The accelerometer array in the falling headform registers the impact forces and calculates GAMBIT for that particular impact. A soccer headguard is then placed on the falling headform as it would be worn in actual use, and the drop is repeated, this time with the headguard cushioning the impact. By measuring the reduction in impact forces when the headguard is in place, the laboratory effectiveness of the headguard can be calculated.

The fixed headform is then replaced by a hard rubber pad that responds to impact similarly to natural turf, and the test is repeated to simulate a fall onto the ground. A third drop is conducted, this time with a steel post simulating a goal post as the impact surface.

Results of Full90 Testing

Tests as described above have been carried out repeatedly with Full90 headguards, and it has been determined that in impacts that are typical of those encountered in soccer, both linear and rotational accelerations are reduced by approximately 20% in head to head impacts, by about 30% in head to ground impacts, and by up to 50% in head to goal post impacts that are most injurious of the three types. In many cases, Full90 headguards reduce the forces to less than the amounts believed to cause concussions, and in other cases they reduce the forces to a level that lessens the severity of concussions. No head protection can prevent all injuries, and severe injuries may still be incurred while wearing Full90 headguards correctly. However, we believe that Full90 headguards provide significant force reductions in many impact situations that arise in soccer.

Full90 has performed impact testing on over fifty different materials, and uses only the best performing materials in its products. Additional materials are tested as they become available, and promising materials undergo thorough laboratory evaluation before being used in prototype samples for consideration in production. Full90 also tests random samples of complete products from production to ensure that quality requirements are consistently satisfied.

[23] Newman JA, "A Generalized Model for Brain Injury Threshold (GAMBIT)," International Conference on the Biomechanics of Impact (IRCOBI), 1986.