Analysis of Cerebral Concussion Frequency With the Most Commonly Used Models of Football Helmets

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Abstract: *Data on helmet models used and occurrence of cerebral concussions over five seasons were collected from a representative sample of college football teams including a total of 8,312 player-seasons and 618,596 athlete-exposures to the possibility of being injured in a game or practice. Results showed that players with a history of concussion any time during the previous 5 years were six times as likely to suffer a new concussion as those with no previous history. In light of previous studies showing cognitive deficits for up to 30 days following even minor head injuries, and the growing awareness of "second impact" fatalities, these data support a need for reconsideration of the common practice of immediate return to play following non-loss-of-consciousness head injuries. Results on concussion frequency in ten models of football helmets indicated a significantly lower than expected frequency in the Riddell M155 and a significantly higher frequency in the Bike Air Power. All other models performed within expectations. This study demonstrates the need for monitoring on-the-field performance of football helmets through continuing epidemiological studies to supplement laboratory test data, which cannot duplicate all the factors involved in actual helmet performance.*

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Cerebral concussion is a common injury among football players,[1,5,20] being the fifth most common injury in college football.[20] Reducing the number and severity of head injuries, including cerebral concussions, is the principal purpose of the football helmet. Over the past 25 years, there have been several studies reporting the incidence of concussions in football players, but few studies have looked specifically at concussion rates in players wearing different brands and models of football helmets. During the 1969 high school football season in North Carolina, Robey et al[16] found essentially no difference in second and third degree concussions among brands of padded helmets or among brands of suspension helmets, but the players wearing suspension helmets had lower rates of concussion overall. Data collected by the National Athletic Injury/Illness Reporting System from a sample of high school and college teams during the 1975–1977 seasons indicated no difference in cerebral concussion rates in 13 brands of football helmets.[4] More recently, in a study combining data from the NCAA's Injury Surveillance System and from the Athletic Injury Monitoring System, it was reported that there were no differences in concussion rates among brands of football helmets in a sample of college teams during three of the four seasons studied.[21] It was uncertain whether the differences in concussion rates found in the fourth year were due to real differences in protective ability among the brands of helmet or due to a statistical aberration in that year's data.

This report on cerebral concussion in the most commonly used models of football helmets is based on data collected during a 5-year prospective study of football injuries in a national sample of college football teams conducted by the Athletic Injury Monitoring System (AIMS) operated by Exercise Research Associates of Oregon (ExRA). The results of the descriptive analyses of these data are used to address issues concerning recurrence of head injuries and monitoring on-the-field performance of football helmets.

Subjects and Methods

The data used for this study were collected during five seasons (1986–1990) by AIMS. AIMS meets the major criteria for reliable studies of sports injury rates outlined in 1987 by the American Orthopaedic Society for Sports Medicine.[18] The total AIMS sample was a stratified, proportionally representative sample, based on geographic region and size of athletic program, of all NCAA and NAIA intercollegiate football teams, and was approximately a 5% sample of all these teams. The subset of data used for this report included all the teams from which complete data were available on brands and models of football helmets used, constituting an approximately 3% sample of all NCAA and NAIA football teams, and was proportionally representative by geographic region and size of program.

The study population included all intercollegiate football players at these institutions. The geographic region by program size distribution of this sample is presented in Table 1. A χ^2 test of goodness-of-fit comparing this distribution with the distribution expected based on NCAA and NAIA members sponsoring football during the period of this study showed no significant difference between the sample distribution and the actual distribution (calculated $\chi^2 = 15.2$; critical value = 19.7, $\alpha = .05$, df = 11). The results therefore are gener-

Table 1.—Distribution of Helmet Study Sample

	East*	South	Midwest	West	Totals
NCAA Division I	7	12	8	7	34
NCAA Division II and NAIA Division I	5	8	9	8	30
NCAA Division III and NAIA Division II	10	0	14	5	29
Totals	22	20	31	20	93

*East: ME, NH, VT, MA, RI, CT, NY, PA, NJ, DE, MD, WV; South: VA, KY, TN, NC, SC, GA, FL, AL, MS, AR, LA, OK, TX; Midwest: OH, MI, IN, IL, WI, MN, IA, MO, ND, SD, NE, KS; West: MT, WY, CO, NM, AZ, UT, ID, NV, WA, OR, CA, AK, HI. Ratio of NCAA to NAIA teams, this sample: 2.9:1; 1986–1990 actual: 3.1:1.

alizable to the total population of intercollegiate football teams.

Over a 5-year period, this study included a total of 93 team-seasons (an average of 19 teams per year) with a total of 8,312 player-seasons accumulating 618,596 athlete-exposures. An athlete-exposure (A-E) is one player taking part in one practice or one game, where he is exposed to the possibility of being injured. If a football team has 100 players that all take part in five practices in a given week, that team has 500 A-E for the week in practices. If 43 players actually participate in the game on Saturday, there are 43 game exposures and a total of 543 A-E for that team for the week.

Prior to the start of each football season the head athletic trainer at each participating school was sent copies of forms for reporting exposure and injury data, along with detailed instructions on how to use the forms. On a weekly basis throughout the season, from the first preseason practice until the final regular season or postseason game, the athletic trainers returned a form listing the number of practices and any games played during the week, and the number of players participating in each. They also returned separate forms detailing each football-related injury that kept a player from full participation for one day or more. The athletic trainers also were instructed to complete an injury form for any player evaluated for a suspected or diagnosed cerebral concussion, whether or not there was time-loss involved. Upon arrival at the ExRA office, each form was logged in and screened for completeness and consistency before being entered into a computer file for later analysis. In the case of missing data, or incomplete or inconsistent data on any form, the individual athletic trainer was contacted for clarification. During the 5 years of this study, 97.9% of the weekly forms were submitted.

For this study the athletic trainers also completed a form at the beginning of the season indicating the number of each brand and model of football helmet being worn by their team members. While brand data were available from all teams, for various reasons the athletic trainers from about one-fourth of the total sample of 125 team-seasons were not able to obtain complete data on the models of helmet used. This report therefore uses data only from the 93 team-seasons that provided complete helmet model data. The distribution of helmets in use by brand names was the same in the total sample and in the sample used for this report. During the last 3 years of this study the athletic trainers also indicated the number of players on the team who had a history of cerebral concussion any time during the 5 years prior to each season. This information was taken from the medical histories of the players. On the individual injury forms the athletic trainers provided information such as the type of injury, player position, the circumstances, type of playing surface being used, number of days away from participation, whether or not it required surgery and, if it was a head injury, whether or not a cerebral concussion was diagnosed, what degree based on AMA's Standard Nomenclature of Athletic Injuries,[2] and what brand and model of helmet was worn by the injured player. The statistical analyses for this report utilized the chi-square goodness-of-fit test with an $\alpha = .05$.

Results

Concussion Rates

Data for ten models of football helmets used in a total of 93 team-seasons during the 5-year period of this study are presented in Table 2. The left-hand column of figures shows the distribution of the different models of helmets in the sample. The next column shows the total number of athlete-exposures in practices and games for each model, with the next column displaying the number of cerebral concussions observed in this sample for each model. The third column from the right lists the number of cerebral concussions expected for each model if the distribution was the same as the distribution of athlete-exposures for each model, which would be the case if every model were doing an equivalent job of protecting the head. The rate of cerebral concussions per 1,000 A-E is given in the second column from the right.

The helmet models included are those that comprised at least 2% of the helmets in use in the sample and had at least five for the expected value of the number of concussions. This eliminated four models that together accounted for only 4% of the total athlete-exposures in the sample. This step was taken to avoid violating the assumption that observed values are normally distributed around the expected value in the χ^2 test, which is a potential problem when expected values fall below five.[10]

The distribution of observed cerebral concussions in Table 2 does not

Table 2.—Cerebral Concussion Rates for Ten Football Helmet Models During a 5-Year Period in a Total of 93 Team-Seasons

Helmet Model	No. in Use N (%)	No. of Athlete-Exposures	No. of Concussions Observed	No. of Concussions Expected	Rate/1000 A-E	Standardized Residuals
Bike Air Power*	3,058 (36.8)	217,241	115	86.04	0.53	3.12
Bike Pro Air*	1,822 (21.9)	130,988	81	51.88	0.62	4.04
Riddell M155	1,083 (13.0)	90,299	15	35.76	0.17	−3.47
Riddell WD1	649 (7.8)	48,846	12	19.35	0.25	−1.67
Riddell VSR3	370 (4.5)	29,501	6	11.68	0.20	−1.66
Riddell PAC-3	392 (4.7)	27,341	5	10.83	0.18	−1.77
Riddell VSR1	287 (3.5)	23,031	4	9.12	0.17	−1.70
Riddell AF2	223 (2.7)	18,206	3	7.21	0.16	−1.57
AHI Air Power*	254 (3.1)	17,914	3	7.09	0.17	−1.54
MaxPro Super Pro	174 (2.1)	15,229	1	6.03	0.07	−2.05
Totals	8,312	618,596	245	244.99		

*Note: The Bike helmet line was purchased by American Helmet, Inc., in 1987, and AHI subsequently changed some components of the Air Power model, thus making it a "new" model. The AHI Air Power is therefore analyzed here as a separate helmet model. The Bike Pro Air was replaced after 1989 by a new model, the AHI Pro Air II, and there were not enough AHI Pro Air II helmets used in this sample to be able to include in this analysis. (There were only 4860 A-E and no concussions reported in the AHI Pro Air II.)

fall within the expected range based on number of A-E for each model of football helmet ($\chi^2 = 58.7$, compared to a critical value of 16.9, $\alpha = .05$, df = 9). A χ^2 test will tell whether or not a set of results fall within an expected distribution range, but it will not indicate which categories, in this case helmet models, are contributing most significantly to the results. To identify the major contributors to this significant χ^2 value, standardized residuals were calculated for each model, and are presented in the right-hand column of Table 2. Major contributors to a significant χ^2 value are those categories (or helmet models) with a standardized residual having an absolute value of 2.00 or more.[8,11] The Bike Air Power and Pro Air models have positive values greater than 2.00, indicating they have significantly more observed cerebral concussions than would be expected based on the number of exposures for these models, while the Riddell M155 and the MaxPro Super Pro have negative values greater than 2.00, indicating they have significantly fewer than the expected number of cerebral concussions. (Because of the relatively low number of helmets in use and exposures for the MaxPro Super Pro, and only a single observed cerebral concussion in that model, until more data become available for this model, it is probably best not to draw any immediate conclusions regarding the MaxPro Super Pro.) All other models appear to fall within expected ranges based on the number of exposures. Separate analyses indicated there were no significant effects on the distribution of concussions based on player position or on the type of play (rush, pass, kick) at the time of injury.

There is one potential concern about the data set presented in Table 2 that could have an impact on the results shown. Many teams use more than one model of helmet, and if one assumes that all the first-string players use one model and lower-string players have been given different models, which may or may not be the case on a given team, then the model being used by starters could be receiving more exposures at a greater "intensity" than other models for that team. This, in turn, could tend to skew or bias the results of analyses such as those in Table 2. To determine whether any model was affected by this potential source of bias, a subset of data was assembled utilizing only teams that used one model on at least 90% of their players. This had the practical effect of eliminating all models from the data set except the three predominant models being used by the teams in the sample: The Bike Air Power, the Bike Pro Air, and the Riddell M155. Twenty-three team-seasons remained in this restricted subsample and each of the remaining models averaged a minimum of 97.5% "pure" sample. In other words, only one or two players on a given team would not be wearing the particular model of helmet used by all the other players on the team. There were representatives of all three divisions and all four geographic regions in this subset. While the four geographic regions remained proportionally representative of the national distribution, Division I teams were slightly overrepresented and Division III teams were somewhat under-represented. The additional analysis for this subset of "pure" helmet model data is presented in Table 3. The χ^2 test again shows a significant result. The calculated χ^2 value is 14.4, compared to a critical value of 6.0, $\alpha = .05$, df = 2. Table 3 shows there apparently was a biasing effect present for the Bike Pro Air model, possibly due to the above noted potential for nonrandom distribution of the model. It now falls well within the expected range of cerebral concussions, and even shows a tendency to have fewer than the expected number of concussions. However, based on the standardized residuals, the Bike Air Power continues to show a significantly higher number of cerebral concussions than expected based on the number of exposures for this model, and the Riddell M155 shows a significantly lower than expected number of concussions. Across both sets of analyses (Tables 2 and 3) the Bike Air Power and the Riddell M155 show little change in their respective concussion rates per 1,000 A-E, and the absolute values of the standardized residuals remain well above 2.00.

Further confirmation of these results were provided when game situations were isolated, to eliminate any potential bias from the range of intensities present during practices. This third set of analyses were done using only game concussions and game exposures, where the intensity of exposure should be fairly uniform. The overall results are essentially the same as those shown in Table 3 except, as noted in previous reports for all injuries,[19,20,22] the rates of concussions/1,000 A-E are considerably higher during games (Bike Air Power 4.64; Bike Pro Air 1.80; Riddell M155 0.38). These results continued to show the Bike Pro Air with fewer than the expected number of cerebral concussions, but within the expected range if all models were providing equal protection. Again, based on the standardized residuals, the Bike Air Power showed significantly more than the expected number of concussions, while the Riddell M155 showed significantly fewer concussions.

During the period of this study the Bike Air Power helmet was one of the oldest models on the market, having first become available in about 1975. Although manufacturers normally do not release their sales figures, it is apparent from these data that the Bike Air Power model was one of the predominant models used by college football teams during this period. (It is generally believed that the percentages of the various models in use at the high school level differ considerably from those at the college level.) Because the Bike Air Power had been available for a longer period, it is possible that, if there were a higher proportion of older Air Power helmets in this sample and if one assumes older helmets do not protect as well as newer helmets, it might affect these results. To investigate this possibility, the data were examined to see if the proportion of concussions occurring in old versus new helmets was different for the Air Power model compared with the others. The results of these analyses showed that there were no significant differences among the models in the proportion of concussions recorded in old, new, or reconditioned helmets. This also held true when history of previous concussion was factored into the analyses.

Reinjury

Data from the last 3 years of this study allowed a look at the impact of a history of cerebral concussion within the previous 5 years on the risk of sustaining another concus-

Table 3.—Cerebral Concussion Rates for Three Football Helmet Models from 25 Team-Seasons That Used a Single Model of Helmet

Helmet model	No. of Athlete-Exposures	No. of Concussions Observed	No. of Concussions Expected	Rate/1000 A-E	Standardized Residuals
Bike Air Power	109,531	59	43.65	0.54	2.32
Bike Pro Air	36,094	11	14.39	0.30	−0.89
Riddell M155	45,047	6	17.96	0.13	−2.82
Totals	190,672	76	76.00		

sion. During this period 2.1% of the players with no previous history of cerebral concussion suffered a new concussion, while 12.2% of the players with a previous history suffered a new concussion (Table 4). Thus, those players with a history of cerebral concussion any time during the previous 5 years were six times as likely to incur a new concussion. Further analyses showed that this result was not affected by player position or type of play at the time of injury. The proportion of concussions across all player positions was not significantly different for those with a history of previous concussions and for those with no history of concussion. Based on written communication from RM Campbell of the NCAA Staff in April 1993, there also were no significant differences in the proportion of concussions during different types of plays during games (rushing, passing, kicking) for players with and without a history of concussion, based on national data on the distribution of plays during NCAA football games.

Table 4.—Cerebral Concussion in Players With and Without Previous History of Concussion*

Total number of players	6192	491
Number of players sustaining concussion	127	60
Percent	2.05	12.22
Relative risk = 5.95		

*These data cover only the 1988–1990 seasons, during which data on previous history of concussion were reported.

Discussion

These analyses provide the basis for addressing two important issues related to sports safety that previously have not received enough attention. The first is when to allow athletes to return to activity after sustaining a concussive injury, particularly those involving no loss of consciousness. The second issue is the need for continuous monitoring of field performance data, in addition to current laboratory testing procedures, for critical pieces of sports safety equipment, such as football helmets. I hope this report will serve as the impetus for further research and discussion on these important issues.

Previous reports on AIMS college football data have indicated that cerebral concussions constitute about 5% of the total injuries and are the fifth most frequent injury in college football.[20,22] At the high school level concussions have been reported as 5.4% of all football injuries,[3] 1 to 9% of all injuries,[9] and 24% of all reported football injuries.[5] It is interesting to note that in the Gerberich[5] study only about 9% of the injuries were initially reported as concussions when respondents were asked if a "concussion" had occurred. However, the additional incidents were revealed when respondents were asked if there had been an incident of "not knowing the time or place, or not remembering a play or an assignment on the field" following a blow to the head. These symptoms indicated a loss of consciousness and/or awareness and therefore a concussive event. This implies that, because of a lack of complete understanding of the medical term "concussion" on the part of players and coaches, many such incidents may go unreported, particularly in retrospective studies and those that do not use trained medical personnel as data sources.

Undoubtedly, helmets do reduce the number and severity of head injuries in football players. But the question remains, are all helmets doing an equivalent job of protecting the head? Could they do a better job? These questions become even more important when you consider research showing that closed head injuries, even when they do not involve loss of consciousness, produce measurable cognitive deficits (eg, memory, information processing) for up to 30 days following injury.[6] These effects are cumulative, with succeeding head injuries creating greater deficits for longer periods.[7] This should raise serious concerns about even mild, non-loss-of-consciousness head injuries (eg, the "bell ringer") to school age participants in football and other sports, and the resulting implications for classroom performance.

The problems presented by recurrent head injuries recently has become more apparent through the observations of clinicians who have reported instances of "second impact" fatalities in football players.[13,17] They believe that an initial concussive event in some individuals may cause swelling and loss of compliance in brain tissue, and a subsequent head injury before complete recovery leads to further swelling and death. The implication is that an athlete should not be allowed to return to participation, even after a minor head injury, until all symptoms have completely cleared. Kelly et al[13] present guidelines for management of concussion in sport that recommend that all symptoms be clear for 1 to 2 weeks before return to play is allowed.

Our results that players with any history of cerebral concussion during the previous 5 years were six times as likely to incur a concussion as those with no previous history of concussion is higher than the 4.1 times as likely rate among high school athletes reported earlier.[5] Our data include all concussions, however, while the previous study included only loss of consciousness injuries.

Current common practices regarding return to play following even minor head injuries must be reconsidered. Athletes, coaches, and parents often pressure medical personnel to return injured athletes to play as quickly as possible. Even at the high school level, it is common for players to be returned to play within a few minutes after a "bell ringer" or a loss of awareness incident.[5] It is difficult to implement relatively conservative guidelines, such as those suggested by Kelly et al.[13] This is especially true during games, where the risk of head injury is much higher than during practices, as implied by the concussion rates/1,000 A-E listed in Table 2 for games and practices combined, and the rates noted earlier for games only. With this recently developed information on the occurrence of second impact fatalities and the increased risks following an initial concussion, it is time for the sports medicine community to reconsider the current practice of sending a player back in as soon as he can see straight (and the athletic trainer may have to bear the brunt of that burden).

The occasional previous attempts to analyze field performance data for football helmets generally showed that all were performing at about the same level.[4,16,21] However, the constant changes in design and materials in the manufacture of helmets in continuing attempts to improve safety make such information obsolete within a very few years. For the first time the data presented in Table 2 clearly indicate that the distribution of the observed numbers of cerebral concussions among the different models of football helmets is significantly different from the expected distribution based on the number of exposures each model received in practices and games.

These descriptive analyses from a large national data set show very strong evidence that not all helmet models did an equivalent job of protecting against cerebral concussions. The degree of statistical significance of the chi-square tests is well beyond being close or questionable, and additional analyses of these data have shown no influence on this type of injury from such factors as player position or type of play. The question as to whether or not football helmets could do a better job of protecting the head from cerebral concussion can not be answered by this set of data until field performance data become available from any new models with which these data can be compared. With the growing awareness of the impact of even minor head trauma, as shown by the studies of Gronwall and Wrightson,[6,7] one must presume helmet manufacturers will be continuing their efforts to develop better designs and materials for their products.

All helmets used by American high school and collegiate football players must meet minimal impact attenuation standards at the time of manufacture, as established by the National Operating Committee on Standards for Athletic Equipment (NOCSAE), and undergo testing against these standards by the manufacturers and by independent NOCSAE investigators. A sampling of reconditioned helmets also are tested against the NOCSAE standard by the reconditioners to ensure that reconditioned helmets still meet the standard. The implementation of the NOCSAE football helmet standard about 20 years ago, along with subsequent rule changes against the use of the head as an initial contact point, has had a definite effect in improving the safety of the game.[12,14] However, it should be evident from the results presented here that these laboratory testing standards do not tell the whole story. Although NOCSAE and the helmet manufacturers have a continuous program of laboratory testing of football helmets, there is a definite need for field data to monitor performance of helmets under actual conditions outside the laboratory.

In a recent review of the validity and relevance of tests used for sport surfaces, Nigg[15] stated that the ideal procedure for assessing a sports surface with respect to its cushioning and frictional qualities (in relation to injuries) is an epidemiological study. Nigg's comments apply equally well to the testing of football helmets. Field performance data are needed to supplement laboratory data, since no amount of laboratory testing can duplicate the complex interactions of player, equipment, and environment that are the ultimate test of a football helmet in actual use. Timely field performance data can be used to spot equipment that may not be performing up to expectations, so that design changes can be made to improve performance.

Epidemiological studies of field performance data in the future should become an integral part of the process of monitoring the performance of critical sports safety equipment. This monitoring of on-the-field performance must be done on a continuing basis, since there are constant changes in design and materials that can make the results of such monitoring out-of-date in a relatively few years. The implementation of a continuing study of field performance data for football helmets and other critical pieces of sports safety equipment would be a major step in ensuring the future safety of participants at all levels in football and other sports.

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