Examining Concussion Rates and Return to Play in High School Football Players Wearing Newer Helmet Technology: A Three-Year Prospective Cohort Study

Micky Collins, Ph.D.
University of Pittsburgh Medical Center Sports Concussion Program, Department of Orthopaedic Surgery/University of Pittsburgh Medical Center for Sports Medicine, University of Pittsburgh Medical Center Pittsburgh, Pennsylvania

Mark R. Lovell, Ph.D.
University of Pittsburgh Medical Center Sports Concussion Program, Department of Orthopaedic Surgery/University of Pittsburgh Medical Center for Sports Medicine, University of Pittsburgh Medical Center Pittsburgh, Pennsylvania

Grant L. Iverson, Ph.D.
Department of Psychiatry University of British Columbia, Vancouver, British Columbia, Canada

Thad Ide, M.S.
Vice President, Research and Product Development, Riddell, Inc., Rosemont, Illinois

Joseph Maroon, M.D.
Department of Neurological Surgery, University of Pittsburgh Medical Center, Pittsburgh Steelers Football Club, Pittsburgh, Pennsylvania

Reprint requests:
Micky Collins, Ph.D., UPMC Sports Concussion Program, UPMC Center for Sports Medicine, 3200 South Water Street, Pittsburgh, PA 15206.
Email: collinsmw@upmc.edu

Received, June 2, 2005.
Accepted, December 5, 2005.

OBJECTIVE: The purpose of this study was to compare concussion rates and recovery times for athletes wearing newer helmet technology compared to traditional helmet design.

METHODS: This was a three-year, prospective, naturalistic, cohort study. Participants were 2,141 high school athletes from Western Pennsylvania. Approximately half of the sample wore the Revolution helmet manufactured by Riddell, Inc. (n = 1,173) and the remainder of the sample used standard helmets (n = 968). Athletes underwent computerized neurocognitive testing through the use of ImPACT at the beginning of the study. Following a concussion, players were reevaluated at various time intervals until recovery was complete.

RESULTS: In the total sample, the concussion rate in athletes wearing the Revolution was 5.3% and in athletes wearing standard helmets was 7.6% [χ^2 (1, 2, 141) = 4.96, $P < 0.027$]. The relative risk estimate was 0.69 (95% confidence interval = 0.499–0.958). Wearing the Revolution helmet was associated with approximately a 31% decreased relative risk and 2.3% decreased absolute risk for sustaining a concussion in this cohort study. The athletes wearing the Revolution did not differ from athletes wearing standard helmets on the mechanism of injury (e.g., head-to-head strike), on-field concussion markers (e.g., amnesia or loss of consciousness), or on-field presentation of symptoms (e.g., headaches, dizziness, or balance problems).

CONCLUSION: Recent sophisticated laboratory research has better elucidated injury biomechanics associated with concussion in professional football players. This data has led to changes in helmet design and new helmet technology, which appears to have beneficial effects in reducing the incidence of cerebral concussion in high school football players.

KEY WORDS: Cohort study, Concussion, Football, Helmet design, ImPACT, Return to play

Neurosurgery 58:275-286, 2006 DOI: 10.1227/01.NEU.0000200441.92742.46 www.neurosurgery-online.com

Changes in tackling rules and improvements in helmet designs reduced football-related head and brain injuries in the 20th century (24, 25). In general, there is considerable interest in the protective effects of headgear in a variety of sports, such as hockey, rugby, and soccer, both in the laboratory (36, 40, 41) and with athletes (4, 5, 31, 37, 47, 50). Recently, some of the most sophisticated laboratory research relating to helmets and concussions has been conducted with professional football players (45, 46). In these papers the authors describe techniques for laboratory reconstruction of on-field player impact events. The results of this study shed considerable light on the head impact dynamics that are associated with concussion and the tolerances of professional football players to these impacts (46). Further analysis of the impact vectors and initial points of head contact revealed that a large portion of the impacts that were analyzed and recreated in the laboratory were directed to the side of the head or face of the struck player (45).

Modern football helmet models used in youth, high school, college, and professional play meet the performance requirements of the National Operating Committee on Standards for Athletic Equipment (NOCSAE) (38, 39). The adoption of the NOCSAE standard by the National Collegiate Athletic Association (NCAA) in 1978 and the National Federation of State High School Associations (NFSHSA) in 1980, along with rules changes that modified allowable head contact during blocking and tackling, has been widely credited with reducing deaths and serious head and spinal injuries to football players throughout the 1980s and early 1990s (25, 52). While football helmets have been designed and manufactured explicitly to meet the requirements of NOCSAE for many years, manufacturers have been reluctant to claim that a particular helmet brand or model reduces the risk of concussion to the wearer. This is due largely to the absence of sound comparative data between helmet models and published information linking on-field impact dynamics with clinically diagnosed concussions.

In 1997, Riddell began a collaborative effort with Biokinetics and Associates, Ltd., an engineering group contracted to analyze and reconstruct game impacts as part of the National Football League MTBI Committee research project. The objective was to use information gathered from reconstructed game impacts to create a football helmet that would decrease the risk of concussion to the athlete. Knowledge of the impacts received by stuck and concussed players led to one of the principal objectives of the new helmet design project–reduction of impact forces imparted by blows to the side of the head and face. Football helmets tested using NOCSAE protocol are presented without faceguards attached and are not allowed initial points of impact distal to the Basic Plane (Frankfurt Horizontal Plane) of the head (the plane passing through the superior rims of the external auditory meatus and the inferior orbital notches). In laboratory recreations of head-to-head contact resulting in concussion to the struck player, Pellman (45) and colleagues reported 36% of the blows had initial points of contact distal to the Basic Plane. A new laboratory test method was developed to allow expedient replication of helmet-to-helmet impact events similar to those identified as leading to concussion on the playing field, with many of the blows directed at points on the head and face distal to the Basic Plane. Testing of materials, component, and padding structures was performed with a face-mask attached to the helmet. Statistical analysis suggesting nominal tolerance levels of 98 g peak translational acceleration or 300 Severity Index (45) was used as a performance guideline when evaluating design iterations in the laboratory.

In January of 2002, Riddell introduced the Revolution, a football helmet designed with the intent of reducing the risk of concussion to the athlete. A visual comparison of the Revolution and a traditional football helmet design is presented in *Figure 1*. Distinct design features include an exterior shell that extends anterior to and distal to traditional shell shapes along the wearer's mandible, increased offset from the interior surface of the shell to the wearer's head in this area, and a unique interior liner construction. Each of these features was incorporated to improve energy attenuation when blows are delivered to the side of the head or face. It was found during the testing phase that a new padding structure over the zygoma and lateral parts of the mandible of the wearer improved impact response of the helmeted head form. Traditional helmets tend to have limited energy attenuation capabilities in this area, using only a fitting device called a "jaw pad" below the wearer's ear. The new padding structure in the Revolution and the jaw pad fitting device used in traditional helmet designs are illustrated in *Figure 1*.

Riddell Inc. approached the University of Pittsburgh Medical Center (UPMC) Sports Concussion Program in the summer of 2002 and requested that a study be conducted examining whether the Revolution helmet was effective for reducing the incidence and severity of concussion in high school athletes. During the last three football seasons (2002-2004), the UPMC Sports Concussion Program has directed a concussion management program for 17 high schools in Western Pennsylvania. A large-scale observational naturalistic cohort study has been conducted over the course of three football seasons with these schools. Approximately half of the participating athletes were fitted with the Revolution Helmet and the other half wore standard helmet types. However, helmet assignment was not controlled or influenced, in any way, by the researchers. There were two main research questions. First, the incidence rate of diagnosed concussion was closely followed between these two groups, with the intent of measuring concussion rates in athletes using both helmet types. Second, recovery times were detailed using a clinical protocol and ImPACT, a computerized neurocognitive test battery developed by the UPMC Sports Concussion Program. Prior research has shown utility of this program in delineating outcome following sports related concussion (6,8,19,21,26,27). All participating schools in this study were utilizing this software program as a tool for the clinical management of sports concussion.

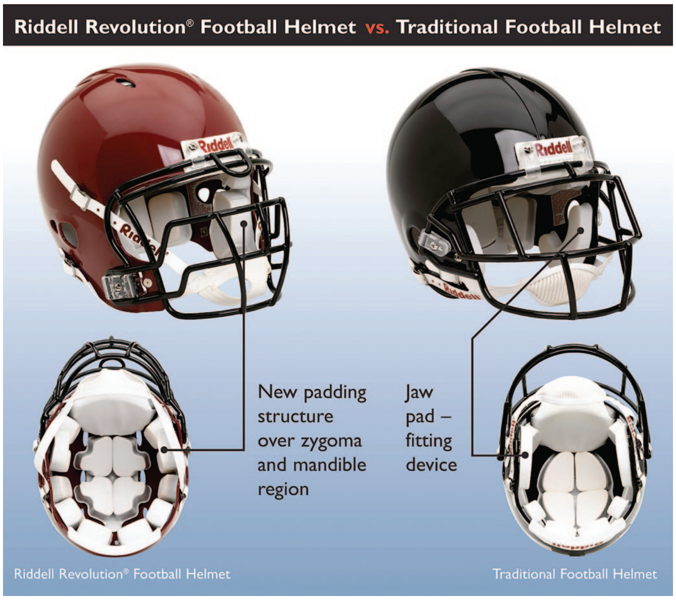

FIGURE 1. *Design features of the Revolution helmet.*

METHOD

Subjects

This three-year study consisted entirely of Pennsylvania high school football programs governed by the Pennsylvania Interscholastic Athletic Association (PIAA). The PIAA strictly enforces all of their rules regarding the number of preseason practices, scrimmages, and games each team may undertake every season. By rule, summer camp practices begin two weeks before regular season play commences, and each PIAA team is permitted one scrimmage at the end of both preseason weeks. All teams play a total of nine regular season games during a season. For this study, only preseason and regular season concussions were included in our database. No postseason play was included. Assuming three practices per day during the preseason (as is commonly accepted among high school programs) and three contact practices per week throughout the regular season, the database is comprised of concussions from 54 practices and 11 games per team per year, over a three-year period. The University of Pittsburgh Institutional Review Board approved this project, and all athletes and their parents signed approved consent forms prior to participating in the study.

In 2002, 11 schools participated. A total of 223 athletes from six schools consented for research and were fitted with the Revolution helmet. Five high schools served as a natural control group and were fitted and equipped with other standard NOCSAE-approved helmets. This group was comprised of 169 athletes. In 2003, 442 athletes from seven schools were fitted with the Revolution helmet. An additional 65 athletes were obtained from other high schools because some of their players opted to wear the Revolution helmets. Therefore, the total number of Revolution participants was 507. In 2003, 397 players from nine schools were fitted with standard helmets. For the 2004 season, the totals for these same schools yielded 508 participants wearing the Revolution helmet and 402 athletes wearing standard helmets. It should be noted that Schutt Sports Group placed into market in 2004 a newly manufactured helmet called the DNA. None of the participants in the current study utilized this product, thus the current analysis is a comparison between the new Riddell Revolution helmet and "standard" helmet types, helmet models of traditional design from Riddell and other manufacturers that were on the market prior to January 2002.

The athlete cohorts for each year were combined for analyses. The concussion rates are based on the total number of injuries sustained per athlete exposures. In summary, the total number of participants for the three-year study was 2141 high school football players. A total of 1173 of these athletes were fitted with the Revolution Helmet, whereas 968 athletes were equipped with standard helmet types. These should be considered athlete exposures, not unique athletes. The concussion rates are based on the cohort studied each season. These cohorts were added together for analyses. Some athletes were in more than one cohort if they played in consecutive seasons. The results also relate only to athletes who sustained a football-related concussion during the study period. Demographic, concussion history, and baseline ImPACT data pertaining to the larger group of non-concussed, uninjured athletes was not entered into the database and is not available for analysis.

All football players were male. The average age of the athletes in the Revolution group who experienced concussions (n = 62) was 16.3 years (SD = 1.1, range = 14-19) and in the standard helmet group (n = 74) was 15.9 years (SD = 1.3, range = 13-18). The average number of years of education completed for the athletes in the Revolution group was 9.9 (SD = 0.85, range = 8-11) and in the standard helmet group was 9.7 (SD = 1.0, range = 8-11). The athletes wearing the Revolution were significantly older than the athletes wearing standard helmets (t (134) = 2.0, $P < 0.044$). There was no difference in education between the groups. Past concussions were common in both groups. For example, 34% of athletes wearing the Revolution and 23% of athletes wearing standard helmets reported experiencing one or more previous concussions. The greater number of athletes wearing the Revolution helmet who had a previous concussion was not statistically significant.

Procedures

In-season concussion was diagnosed based upon the on-field presentation of one or more of the following symptoms after a blow to the head or body: 1) any observable alteration in mental status or consciousness; 2) the presence of loss of consciousness, disorientation, posttraumatic amnesia, or retrograde amnesia as identified by on-field examination; and/or 3) any self-reported symptoms at rest or exertion, such as posttraumatic headache, photosensitivity, nausea/vomiting, or dizziness. Following an on-field collision or general concern regarding the status of an athlete, initial diagnosis of concussion was made by certified athletic trainers and/or physicians who were present on the sideline at the time of injury. All practitioners involved in the study were trained to define concussion based upon these criteria. Participating schools had a devoted athletic trainer or physician who attended all practices and games.

A unique component of this study was an individualized clinical concussion management program. Athletes were assessed repeatedly with the ImPACT test battery to monitor recovery and to assist with decisions regarding return to play. ImPACT is a computerized neurocognitive test battery that assesses verbal memory, visual memory, information processing speed, and reaction time. ImPACT also contains a 21-item self-report symptom scale comprised of common symptoms associated with concussion (e.g., headaches, dizziness, and concentration problems).

Most of the athletes completed ImPACT during the preseason, which served as a baseline for comparison once a concussion was sustained (82.4% of the total sample; 88.7% of the Revolution group and 77.0% of the standard helmet group). Athletes were followed clinically, not according to a controlled research protocol, and no athlete was returned to play until they met standardized clinical recovery criteria. The general clinical pathway was to conduct the first evaluation within 72 hours, then at approximately one, two and three weeks postinjury, if necessary. Following their initial postinjury evaluation, athletes underwent another evaluation if they were not recovered (see standardized criteria below). Strict criteria in accordance with international return-to-play standards were utilized to determine return to play. All athletes needed to exhibit an asymptomatic presentation at rest and with physical exertion, as well as intact neurocognitive test performance. These criteria are consistent with prevailing International standards for safe and appropriate return-to-play following concussive injury (2, 13, 35). Given that a natural clinical protocol was utilized, this pathway resulted in differential attrition across the assessment intervals. The clinical pathway comparisons between groups are presented in *Table 1*. The postconcussion assessments took place, on average, at Day 2, 5, 10, and 18 for the Revolution group and at Day 2, 6, 14, and 24 for the standard helmet group.

Three specific criteria were applied to determine recovery from the sustained concussion. First, the athlete's total score on the Postconcussion Scale must have been less than 7. According to the normative data for high school males for this scale (n = 588), 40.5%

TABLE 1. Clinical pathway comparisons by group (number of days postinjury that athletes received ImPACT evaluation)[a]

	Revolution helmets				Standard helmets			
	n (%)	Median	M (SD)	Range	n (%)	Median	M (SD)	Range
Postinjury assessment 1	62 (100)	2.0	1.9 (1.1)	0-5	74 (100)	2.0	2.4 (2.1)	0-11
Postinjury assessment 2	58 (93.5)	5.0	6.7 (4.9)	1-31	57 (77.0)	6.0	8.5 (6.6)	2-36
Postinjury assessment 3	37 (59.7)	10.0	11.7 (6.1)	5-29	36 (48.6)	14.0	16.4 (8.0)	7-42
Postinjury assessment 4	18 (29.0)	18.0	19.0 (7.7)	10-37	14 (18.9)	24.0	24.9 (9.5)	12-46

[a]M, mean days post-injury; SD, standard deviation. Descriptive statistics for number of days postinjury for each assessment. The number of athletes returning for each follow-up also is presented.

score zero at baseline and 76% score 6 or less. Therefore, the majority of athletes score 7 or less during baseline, preseason testing. The selection of this cutoff takes into consideration that reporting some symptoms is "normal" but medium to high level symptom reporting likely reflects the ongoing effects of concussion. Second, the athlete must not have more than one ImPACT neurocognitive composite score that was statistically reliably worse than his baseline performance. Statistically reliable change, at the 80% confidence interval, is 9 points for the Verbal Memory composite, 14 points for the Visual Memory composite, 0.06 seconds for the Reaction Time composite, and 3 points for the Processing Speed composite (21). Having two or more ImPACT composite scores change for the worse from baseline to first follow-up evaluation is extremely uncommon among uninjured athletes, occurring in only 3.6% of a non-injured sample (21). Third, the athlete must have had all of his neurocognitive composite scores in the normal range. Scores below the 10^{th} percentile, according to the ImPACT normative data, were considered unusually low. Based on the normative data for males between the ages of 13 and 15 ($n = 183$), 10^{th} percentile cutoff scores are as follows: Verbal Memory composite < 73.0, Visual Memory composite < 60.4, Reaction Time composite > 0.66 seconds, and Processing Speed composite < 25.36. Based on the normative data for males between the ages of 16 and 18 ($n = 158$), 10^{th} percentile cutoff scores are as follows: Verbal Memory composite < 75.0, Visual Memory composite < 60.0, Reaction Time composite > 0.64 seconds, and Processing Speed composite < 29.65. There were two athletes who were 19 years old; normative data for 16 to 18 years olds was used for them. The only exception to the third criteria was if an athlete had one or more baseline scores below the 10^{th} percentile. Clearly, if an uninjured athlete performs poorly at baseline, and this is an accurate representation of his true abilities, we would not expect him to perform much better after a concussion. Therefore, if an athlete had very low scores at baseline ($<10^{th}$ percentile compared to normative data) his postinjury performances were examined carefully to determine when he returned to his preinjury level of functioning (criteria #1 and #2 were emphasized).

Measure

Version 2.0 of ImPACT is a brief (20–25 min) computer-administered neuropsychological test battery that consists of six individual test modules that measure multiple aspects of cognitive functioning including attention, memory, working memory, visual scanning, reaction time, and processing speed. Four composite (i.e., summary) scores are tabulated based upon these individual test scores. The Verbal Memory composite score represents the average percent correct for a word recognition paradigm, a symbol number match task, and a letter memory task with an accompanying interference task. These tests are conceptually similar to traditional verbal learning (word list) tasks and the auditory consonant Trigrams Test (i.e., the Brown-Peterson short-term memory paradigm), although the information is presented visually on the computer, not auditorily by an examiner. The Visual Memory composite score is comprised of the average percent correct scores for two tasks; a recognition memory task that requires the discrimination of a series of abstract line drawings, and a memory task that requires the identification of a series of illuminated Xs or Os after an intervening task (mouse clicking a number sequence from 25-1). The first test taps immediate and delayed memory for visual designs and the second test measures short-term spatial memory (with an interference task). The Reaction Time composite score represents the average response time (in milliseconds) on a choice reaction time, a go/no-go task, and the previously mentioned symbol match task (which is similar to a traditional digit symbol task). The Processing Speed composite represents the weighted average of three tasks that are done as interference tasks for the memory paradigms. In addition to the cognitive measures, ImPACT also contains a Post-Concussion Symptom Scale that consists of 21 commonly reported symptoms (e.g., headache, dizziness, "fogginess"). The dependent measure is the total score derived from this 21-item scale. The reliability (21, 22) and concurrent validity (17, 20) of the ImPACT test battery and the ImPACT Post-Concussion Symptom Scale (18, 23, 28), as well as the construct validity and sensitivity/specificity of the ImPACT test battery (8, 19, 21, 26, 27, 49), has been examined in a number of recent studies.

RESULTS

Across the three years of study, the concussion rate in athletes wearing the Revolution was 5.3% and in athletes wearing standard helmets was 7.6%. This was a statistically significant difference [χ^2 (1, 2, 141) $= 4.96$, $P < 0.027$]. The relative risk estimate was 0.69 (95% confidence interval = 0.499 - 0.958). There was a 31% decreased relative risk for sustaining a concussion among athletes wearing the Revolution helmet.

According to the literature, athletes with a history of concussion are at increased risk for future concussions (14, 16, 53). Therefore, for exploratory purposes, analyses were conducted examining the likely concussion rates between helmet groups in those with a history of concussion. Two steps were taken. First, athletes from our injury sample with known previous concussions were removed. Second, given that the prior incidence of concussion was not known in the larger, uninjured sample of athletes, prior incidence of concussion was estimated using the epidemiological statistics of Powell and Barber-Foss (48) of 3.66 concussions per 100 player-season exposures (i.e., 3.66% concussion rate for a three-year study). We multiplied each sample by 0.0366 and removed 43 athletes from the Revolution group and 35 athletes from the standard helmet group. These are the number of athletes in each group who theoretically had previous concussions.

After subtracting the actual and estimated athletes with previous concussions, there were 1109 players in the Revolution group and 916 players in the standard helmet group. Athletes from the injury database with previous concussions were subtracted first, followed by 3.66% of each sample that were estimated to have previous concussions (based on the literature). The concussion rates in these groups were 3.7% for those wearing Revolution and 6.2% for those wearing standard helmets. This finding was statistically significant [χ^2 (1, 2025) = 6.9, $P < 0.009$]. The relative risk estimate was 0.594 (95% confidence interval = 0.402–0.879). This means that wearing the Revolution helmet was associated with approximately a 41% decreased relative risk for sustaining a concussion in athletes who have never been concussed. The 95% confidence interval for this relative risk reduction is 12.1% to 59.8%. The absolute risk reduction was 2.5% (95% confidence interval = 0.7% to 4.3%).

TABLE 2. Percentages represent number of athletes in each subgroup experiencing on-field marker, immediate symptom, method of contact, and region of helmet where blow caused concussion.

	Immediate symptoms	
	Revolution helmets	Standard helmets
On-field marker		
Loss of consciousness	16.1%	13.5%
Confusion/disorientation	64.5%	71.6%
Retrograde amnesia	28.8%	26.0%
Posttraumatic amnesia	27.4%	25.7%
Headache	90.3%	94.6%
Dizziness	77.4%	77.0%
Balance problems	46.8%	54.1%
Visual changes	38.7%	39.2%
Personality changes	22.6%	28.4%
Fatigue	50.0%	54.1%
Sensitivity to light or sound	43.5%	44.6%
Numbness or tingling	17.7%	17.6%
Method of contact		
Head-head	71.0%	71.6%
Head-ground	16.1%	20.3%
Head-body	9.7%	6.8%
No head contact	1.6%	1.4%
Missing data	1.6%	0.0%
Region of head hit		
Frontal	56.5%	62.2%
Right temporal	16.1%	14.9%
Left temporal	12.9%	9.5%
Occipital	12.9%	13.5%
Missing data	1.6%	0.0%

There were 62 athletes in the Revolution group and 74 in the standard helmet group. There were no statistically significant differences between groups on any variable presented in this table.

On-Field Concussion Markers, Symptoms, and Mechanisms of Injury

Prevalence of on-field markers of concussion, namely confusion/disorientation, loss of consciousness, retrograde amnesia, and posttraumatic amnesia, were also examined between groups. These results are presented in *Table 2*. There were no statistically significant differences on these markers between groups.

The vast majority of athletes in both groups reported headaches as an immediate symptom of concussion. Acute dizziness was reported by more than 75% of athletes. Balance problems, fatigue, sensitivity to light or sound, and visual changes were reported by one-third to one-half of players. There were no statistically significant differences in the reporting of individual symptoms between groups (*Table 2*). The average number of on-field symptoms reported by players wearing the Revolution was 4.1 (SD = 1.9) and the average number of symptoms reported by the standard helmet group was 4.3 (SD = 2.0). This was not a statistically significant difference.

Athletic trainers were also instructed to give full details as to the type and location of the blow to the head or body that resulted in concussion. These represent purely observational data and therefore should be considered exploratory. These results also are presented in *Table 2*. The most common mechanism for concussion was a head-to-head blow. The front part of the head was most frequently struck. There were no significant differences between groups in terms of method of contact or region of head hit.

Acute Effects on Cognition and Symptom Reporting

The acute effects of concussion on symptom reporting and neurocognitive test performance were examined by group.

The athletes wearing the Revolution helmet were seen sooner than the athletes wearing standard helmets (Mean = 1.9 versus 2.4 d; t (134) = −2.0, $P < 0.043$). This was because a small subset of the athletes wearing the standard helmets was seen more than five days postinjury. Therefore, athletes seen more than five days postinjury were dropped (n = 3). This resulted in no statistically significant differences in time postinjury for the first assessment. On average, athletes in both groups were seen at 48 hours postinjury.

At baseline, athletes in the Revolution group obtained higher scores on the Verbal Memory composite [t (107) = 2.45, $P < 0.016$)]. There were no other significant differences between groups on the composites. Difference scores were created by subtracting the postconcussion score from the baseline score. The athletes in the Revolution group had a greater decrement (i.e., difference score) from baseline to postconcussion on the Verbal Memory composite [t (107) = 2.02, $P < 0.046$)]. There were no significant differences between groups on the other difference scores.

Descriptive statistics, paired t test results, and effect sizes for the baseline and first postconcussion assessment are presented in *Table 3*. For both groups, there were statistically significant worsenings on all four neurocognitive test composites and on total self-reported symptoms. As seen in *Figure 2*, there were large changes in test performance and dramatic increases in symptom reporting at the time of the first postinjury assessment. Because of the attrition rate, due to recovery, inferential statistical analysis of the composites across the serial assessments was not possible. However, recovery rates by group can be presented.

Recovery Rates

The mean number of days to recover and return to play for the Revolution group was 10.9 days (median = 7.5, SD = 8.4, IQR = 4 – 14.25, range = 1 – 37) and for the standard helmet group was 13.0 days (median = 10.0, SD = 10.5, IQR = 4 – 19.5, range = 1 – 42). This difference was not statistically significant. The cumulative frequency recovery curves, by group, are presented in *Figure 3*. The recovery and return to play rates are summarized in *Table 4* . There was a nonsignificant trend toward faster recovery at three weeks postinjury for the Revolution group [χ^2 (1, 136) = 3.2, $P < 0.076$]. As seen in *Figure 3*, there is a slightly larger gap between groups at 20 days postinjury. Exploratory unplanned analyses revealed an 88.7% recovery rate for the Revolution group and a 75.7% recovery rate for the standard helmet group [χ^2 (1, 136) = 3.8, $P < 0.051$].

The athletes with no previous concussions were analyzed separately. The mean number of days to recover and return to play for the Revolution group was 10.5 (median = 8, SD = 7.2, IQR = 6 – 13.5, range = 1 – 29) and for the standard helmet

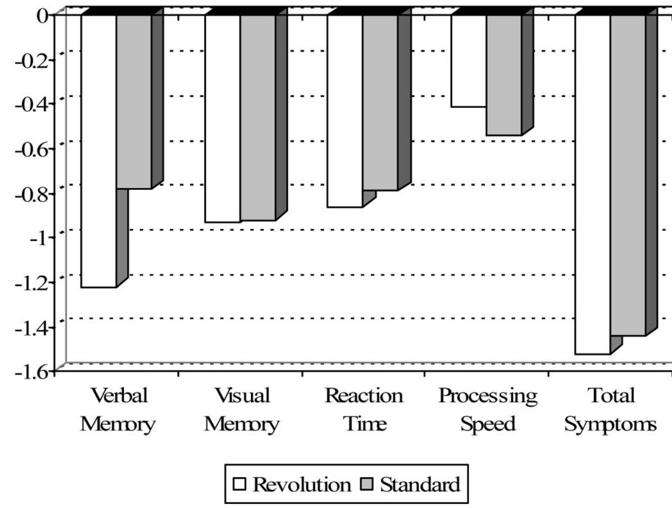

FIGURE 2. *Cohen's effect sizes for changes in test performance from baseline to first post-injury evaluation on impact computerized concussion test battery.*

TABLE 3. Descriptive statistics, paired t test results, and effect sizes for baseline and first postinjury ImPACT evaluation[a]

	Revolution helmets				Standard helmets			
	M	SD	*P*-value	d	M	SD	*P*-value	d
Baseline verbal memory	86.53	8.10	<0.001	1.22	82.63	8.48	<0.001	0.78
Postconcussion verbal memory	72.40	14.98			74.26	13.01		
Baseline visual memory	77.40	10.43	<0.001	0.93	74.44	11.07	<0.001	0.92
Postconcussion visual memory	66.40	13.28			62.56	14.73		
Baseline reaction time	0.564	0.056	<0.001	0.86	0.577	0.059	<0.001	0.79
Postconcussion reaction time	0.655	0.155			0.663	0.159		
Baseline processing speed	36.76	6.80	<0.006	0.41	35.12	5.25	<0.001	0.54
Postconcussion processing speed	33.67	8.40			31.35	8.83		
Baseline total symptoms	3.28	6.14	<0.001	1.52	4.22	8.21	<0.001	1.44
Postconcussion total symptoms	20.93	17.08			25.35	21.16		

[a]M, mean score; SD, standard deviation; d, Cohen's effect size. Cohen's effect sizes are represented in pooled standard deviation units. By convention, 0.2 = small, 0.5 = medium, and 0.8 = large effect sizes. This was the first postinjury evaluation for both Revolution and Standard helmet groups.

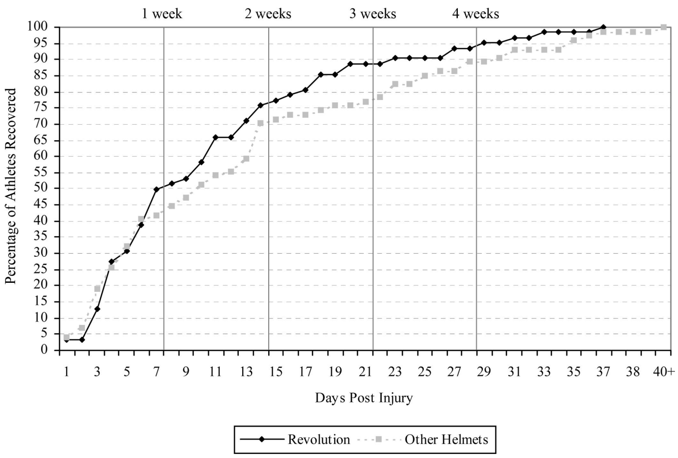

FIGURE 3. *Concussion recovery rates by helmet group.*

TABLE 4. Recovery and return to play rates in all athletes and athletes with no previous concussion

Interval	Revolution helmets	Standard helmets
All athletes		
One week	50.0%	41.9%
Two weeks	75.8%	70.3%
Three weeks	88.7%	77.0%
Four weeks	93.5%	89.2%
Athletes with no previous concussion		
One week	48.8%	45.6%
Two weeks	78.0%	71.9%
Three weeks	90.2%	78.9%
Four weeks	97.6%	91.2%

[a]There were 62 athletes in the Revolution group and 74 in the standard helmet group. Percentages represent what proportion of each subgroup recovered and returned to play by designated time interval. No significant differences were found between helmet groups.

group was 12.2 (median = 9, SD = 10.1, IQR = 4 – 17.5, range = 1 – 37). This difference was not statistically significant. Their recovery and return to play rates also are presented in *Table 4*. The apparent trend towards faster recovery at three weeks postinjury for the Revolution group was not statistically significant.

DISCUSSION

Advances in football helmet design and implementation have been, to date, primarily focused on changes in the interior of the helmet (e.g., padding placement and air bladders). Research funded through NFL Charities and conducted from 1996 to 2001 (46) calculated collision characteristics of NFL players on the field and allowed for the reconstruction of these collisions in the laboratory. This research led to the development of new laboratory testing methods for football helmets and to new helmet designs from Riddell, as well as another manufacturer. The current field study represents the first of its kind to investigate this newer helmet technology outside of the biomechanical laboratory environment. Although laboratory studies allow for more rigid experimental control, subsequent field testing also represents an important component of helmet evaluation.

This was a naturalistic, observational, prospective cohort study that examined concussion rates and return to play in high school athletes wearing traditional (i.e., standard) helmet design and the Revolution helmet, representing new helmet technology. The rate of concussion in athletes wearing the Revolution helmet (5.3%) was significantly lower than the rate in athletes wearing traditional helmets (7.6%). These concussion rates are fairly consistent with previously reported rates (1, 7, 9, 15, 16, 29, 33, 34, 48). The relative risk reduction associated with wearing the newer helmet was 31%, and the absolute risk reduction was 2.3%. In context, if 1.5 million high school students participate in football each year and the concussion rate is approximately 4 to 10%, then the relative risk reduction means that 18,600 to 46,500 fewer high school football players would sustain concussion. For exploratory purposes, we estimated the relative risk reduction for athletes presumed to have no history of concussion and it was 41%. Absolute risk reduction for this estimated sample was 2.5%.

As seen in *Table 2*, the two helmet groups did not differ in their rates of on-field markers of concussion (e.g., loss of consciousness), immediate symptoms (e.g., headaches), method of contact (e.g., head to head), or location of head struck (e.g., frontal). The incidence of loss of consciousness in this study (i.e., 13–16%) was very similar to a previous large-scale study (i.e., 15.6%; 34), but higher than most other studies (e.g., 4.8%–8.9%; 16, 29, 32, 33). Confusion and disorientation following concussion was common in this study, as in other studies (16, 29). Consistent with previous studies, the two most common symptoms following concussion were headaches and dizziness (16, 43).

On average, both helmet groups showed substantial decrements in cognitive functioning and major symptom reporting when seen within five days of injury (average interval was two days postinjury; see *Table 3* and *Fig. 2*). When compared to baseline, preseason testing, athletes wearing the Revolution helmet had a significantly greater decrement on the ImPACT Verbal Memory composite at two days postinjury. There were no significant differences on the other cognitive composites or on self-reported symptoms. Neuropsychological decrements and high levels of symptom reporting in the initial days postinjury is a well-documented finding in most studies involving amateur athletes (3, 7, 9, 10, 11, 15, 29, 30, 32–34, 51), but not NFL players (42).

The two helmet groups did not differ significantly on the average number of days to recover and return to play following concussion. There was a nonsignificant trend toward faster recovery at three weeks postinjury for the Revolution group ($P < 0.076$). Of interest is examining the recovery rates following concussion in our high school sample. For example, for both groups, approximately 50% of the sample had recovered by one week postinjury. At three weeks, approximately 12% of the Revolution sample and 23% of the standard helmet sample had yet to recovery from concussion. These finding are inconsistent with the much faster estimated recovery times for collegiate (33) and professional (42, 44) football players. These data are consistent with a small body of evidence suggesting that younger athletes might take longer to recover from concussive injury (12). Another factor that may contribute to these differential findings is that the current study utilized computerized testing procedures to document recovery, whereas the other referenced studies utilized traditional paper and pencil test approaches. Computerized testing may offer a more sensitive approach to track recovery over time, especially since this paradigm circumvents the ″practice effects″ commonly seen with paper and pencil approaches (21, 22). It is possible that a combination of age and measurement factors may be playing a role in the relative protracted nature of recovery seen in this current high school study. Based upon our recovery results, prudent postconcussion assessment and follow-up evaluations are indicated in the high school athlete.

There are a number of significant limitations to this study. Of necessity, this study was designed to be purely observational and naturalistic. For ethical reasons, no study subject was assigned to a particular helmet group by study personnel and the investigators in no way influenced the selection of athletes for use of the standard or Revolution helmet. As is the common practice in high school sports, teams procure NOCSAE certified athletic equipment based on a variety of factors including but not limited to the age of their current stock of helmets, individual student needs, and budgetary constraints. Without random assignment, there is no way of knowing whether there were meaningful differences between groups on some important variable(s) that might have influenced concussion rates or recovery times. For example, a player may have been assigned a helmet based on parental request or some other unknown factor. It should be noted that the Revolution sample of athletes were, on average, older than the traditional helmet sample (by approximately one-half year). It is possible this age differential may have played a role in the higher incidence of concussion seen in the traditional helmet group. Further study regarding this issue is warranted.

It should also be noted that there was a nonsignificant trend toward the Revolution group having a higher incidence of concussion prior to their inclusion in this study (i.e., 34% versus 23% reported experiencing one or more previous concussions). Therefore, it is possible that the Revolution helmet was assigned to some athletes who were believed to be at greater risk of injury (based on the perception by some school personnel that this helmet was a ″safer″ helmet). This in turn may actually have lead to the assignment of athletes to the Revolution group who were more concussion prone, thus resulting in the greater inclusion of ″higher risk″ athletes in the Revolution group.

Another limitation is the fact that the study took place in real time, with athletes returning to play based on a clinical pathway. Utilizing this type of methodology, it was necessary to give up experimental control of factors such as precise assessment intervals and requiring all athletes to complete a specific number of assessments. Athletes were returned to play when they met clinical criteria, not at a specific time period postinjury. This clinical pathway, although consistent with recent concussion management guidelines (e.g., 2, 13, 35), resulted in natural attrition rates and somewhat variable assessment intervals for the two groups.

The schools in western Pennsylvania that participated in this study had inventories of traditional football helmets and faceguards prior to the 2002 football season. Helmets that were not newly manufactured prior to the 2002 season were refurbished and recertified to the NOCSAE standard by a National Athletic Equipment Reconditioners Association (NAERA) member. This was done to ensure that the effects of prior wear on the older helmets did not affect the outcome of the study. Reports issued annually by NAERA to its membership indicate that properly reconditioned and recertified football helmets do not diminish in measured performance when compared to newly manufactured helmets. The Revolution helmets included in the study were, by necessity, newly manufactured prior to the 2002 playing season then recertified by a NAERA member prior to the subsequent playing seasons. Revolution helmets manufactured in 2003 and 2004 were added to the test pool in subsequent study years as needed.

The design features and engineering specifications of the Revolution football helmet were derived, in large part, from the NFL sponsored research (46, 47) and from the knowledge and experience of the manufacturer. As described in the introduction, protective features of the Revolution in the side of the head and face were added as a result of analysis of open field impact recreations performed by BioKinetics and Associates (47). Head to head impacts and impacts to the front portion of the helmet were often cited as concussion causing events in the current study, but event observations/reports were not limited to open field impacts and were not limited to impacts to the side of the head and face. A potential hypothesis is that other features of this new helmet technology, such as increased offset from the interior of the outer shell to the wearer's head and the liner design may be playing a potential role in decreasing the risk of concussion to the high school athlete. Further research exploring these issues is warranted and indicated.

This study provides preliminary evidence that new helmet technology might substantially reduce (though certainly not prevent) the occurrence and incidence of concussion in high school football players. In addition, there appeared to be a trend toward faster recovery in athletes who wore the new helmet technology. Of course, in this unblinded, uncontrolled, naturalistic study, it cannot be determined what factors might have influenced these recovery rates. Moreover, there are obvious ethical limitations that restrict the amount of experimental control (e.g., random assignment of helmets) that investigators can exert in this type of research. Future field research could be improved by gathering additional information regarding the years of experience, playing time, and skill level of athletes wearing different types of protective headgear. Based upon past research, history of previous concussions is an essential variable to study, given the increased risk for future concussions in athletes with past concussions. In addition, there might be a variety of socioeconomic and social psychological factors that influence the purchase and individual assignment of particular helmet types.

Future studies in this area are urged to replicate and advance field studies such as the current analysis, especially because research to date has relied almost exclusively on laboratory research. Our current understanding of the biomechanics, injury markers, acute presentation, symptom evolution, and recovery associated with sports-related concussion is advancing rapidly through research efforts around the world. Potential fruits of these efforts are advances in helmet technology and other equipment advances with the aim at reducing the incidence and severity of concussive injury. Well designed and controlled field studies will play a critical role in understanding the potential benefits of such advances in reducing the occurrence and morbidity of sports concussion. Clearly, at this point, no helmet or other technology is available to prevent concussion from occurring, though definite strides are being made from both an equipment and clinical management perspective.

REFERENCES

1. Albright JP, McAuley E, Martin RK, Crowley ET, Foster DT: Head and neck injuries in college football: An eight-year analysis. **Am J Sports Med** 13:147–152, 1985.
2. Aubry M, Cantu R, Dvorak J, Graf-Baumann T, Johnston K, Kelly J, Lovell M, McCrory P, Meeuwisse W, Schamasch P: Summary and agreement statement of the First International Conference on Concussion in Sport, Vienna 2001. Recommendations for the improvement of safety and health of athletes who may suffer concussive injuries. **Br J Sports Med** 36:6–10, 2002.
3. Barr WB, McCrea M: Sensitivity and specificity of standardized neurocognitive testing immediately following sports concussion. **J Int Neuropsychol Soc** 7:693–702, 2001.
4. Benson BW, Mohtadi NG, Rose MS, Meeuwisse WH: Head and neck injuries among ice hockey players wearing full face shields vs half face shields. **JAMA** 282:2328–2332, 1999.
5. Benson BW, Rose MS, Meeuwisse WH: The impact of face shield use on concussions in ice hockey: A multivariate analysis. **Br J Sports Med** 36:27–32, 2002.
6. Collins MW, Field M, Lovell MR, Iverson G, Johnston KM, Maroon J, Fu FH: Relationship between postconcussion headache and neuropsychological test performance in high school athletes. **Am J Sports Med** 31:168–173, 2003.
7. Collins MW, Grindel SH, Lovell MR, Dede DE, Moser DJ, Phalin BR, Nogle S, Wasik M, Cordry D, Daugherty KM, Sears SF, Nicolette G, Indelicato P, McKeag DB: Relationship between concussion and neuropsychological performance in college football players. **JAMA** 282:964–970, 1999.
8. Collins MW, Iverson GL, Lovell MR, McKeag DB, Norwig J, Maroon J: On-field predictors of neuropsychological and symptom deficit following sports-related concussion. **Clin J Sport Med** 13:222–229, 2003.
9. Delaney JS, Lacroix VJ, Gagne C, Antoniou J: Concussions among university football and soccer players: A pilot study. **Clin J Sport Med** 11:234–240, 2001.
10. Erlanger D, Feldman D, Kutner K, Kaushik T, Kroger H, Festa J, Barth J, Freeman J, Broshek D: Development and validation of a web-based neuropsychological test protocol for sports-related return-to-play decision-making. **Arch Clin Neuropsychol** 18:293–316, 2003.
11. Erlanger D, Saliba E, Barth J, Almquist J, Webright W, Freeman J: Monitoring resolution of postconcussion symptoms in athletes: Preliminary results of a web-based neuropsychological test protocol. **J Athl Train** 36:280–287, 2001.
12. Field M, Collins MW, Lovell MR, Maroon J: Does age play a role in recovery from sports-related concussion? A comparison of high school and collegiate athletes. **J Pediatr** 142:546–553, 2003.
13. Guskiewicz KM, Bruce SL, Cantu RC, Ferrara MS, Kelly JP, McCrea M, Putukian M, Valovich McLeod TC: National Athletic Trainers' Association Position Statement: Management of Sport-Related Concussion. **J Athl Train** 39:280–297, 2004.
14. Guskiewicz KM, McCrea M, Marshall SW, Cantu RC, Randolph C, Barr W, Onate JA, Kelly JP: Cumulative effects associated with recurrent concussion in collegiate football players: The NCAA Concussion Study. **JAMA** 290: 2549–2555, 2003.
15. Guskiewicz KM, Ross SE, Marshall SW: Postural stability and neuropsychological deficits after concussion in collegiate athletes. **J Athl Train** 36:263–273, 2001.
16. Guskiewicz KM, Weaver NL, Padua DA, Garrett WE Jr: Epidemiology of concussion in collegiate and high school football players. **Am J Sports Med** 28:643–650, 2000.
17. Iverson GL, Franzen MD, Lovell MR, Collins MW: Construct validity of ImPACT in athletes with concussions. **Arch Clin Neuropsychol** 19:961–962, 2004.
18. Iverson GL, Gaetz M: Practical considerations for interpreting change following concussion, in Lovell MR, Echemendia RJ, Barth J, Collins MW (eds): Traumatic brain injury in sports: An international neuropsychological perspective. Netherlands, Swets-Zeitlinger, pp 323-356, 2004.
19. Iverson GL, Gaetz M, Lovell MR, Collins MW: Relation between fogginess and outcome following concussion. **Arch Clin Neuropsychol** 17:2002, 769–770.
20. Iverson GL, Lovell MR, Collins MW: Validity of ImPACT for measuring processing speed following sports-related concussion. **J Clin Exp Neuropsychol** 27:683.–689, 2002
21. Iverson GL, Lovell MR, Collins MW: Interpreting change on ImPACT following sport concussion. **Clin Neuropsychol** 17:460–467, 2003.
22. Iverson GL, Lovell MR, Collins MW, Norwig J: Tracking recovery from concussion using ImPACT: Applying reliable change methodology. **Arch Clin Neuropsychol** 17:770,2002.
23. Janusz JA, Gioia GA, Gilstein K, Iverson GL: Construct validity of the ImPACT Post-Concussion scale in children. **Br J Sports Med** 38:659,2004.
24. Levy ML, Ozgur BM, Berry C, Aryan HE, Apuzzo MJ: Analysis and evolution of head injury in football. **Neurosurgery** 55:649–655, 2004.
25. Levy ML, Ozgur BM, Berry C, Aryan HE, Apuzzo MJ: Birth and evolution of the football helmet. **Neurosurgery** 55:656–662, 2004.
26. Lovell MR, Collins MW, Iverson GL, Field M, Maroon JC, Cantu R, Podell K, Powell JW, Belza M, Fu FH: Recovery from mild concussion in high school athletes. **J Neurosurg** 98:296–301, 2003.
27. Lovell MR, Collins MW, Iverson GL, Johnston KM, Bradley JP: Grade 1 or "ding" concussions in high school athletes. **Am J Sports Med** 32:47–54, 2004.
28. Lovell MR, Iverson GL, Collins MW, Podell K, Johnston KM, Pardini D, Stump J, Norwig J, Maroon JC: Measurement of symptoms following sports-related concussion: Reliability and normative data for the post-concussion scale. **Appl Neuropsychol** 21:91–99, 2005.
29. Macciocchi SN, Barth JT, Alves W, Rimel RW, Jane JA: Neuropsychological functioning and recovery after mild head injury in collegiate athletes. **Neurosurgery** 39:510–514, 1996.
30. Makdissi M, Collie A, Maruff P, Darby DG, Bush A, McCrory P, Bennell K: Computerised cognitive assessment of concussed Australian Rules footballers. **Br J Sports Med** 35:354–360, 2001.
31. Marshall SW, Loomis DP, Waller AE, Chalmers DJ, Bird YN, Quarrie KL, Feehan M: Evaluation of protective equipment for prevention of injuries in rugby union. **Int J Epidemiol** 34:113–118, 2005.
32. Matser JT, Kessels AG, Lezak MD, Troost J: A dose-response relation of headers and concussions with cognitive impairment in professional soccer players. **J Clin Exp Neuropsychol** 23:770–774, 2001.
33. McCrea M, Guskiewicz KM, Marshall SW, Barr W, Randolph C, Cantu RC, Onate JA, Yang J, Kelly JP: Acute effects and recovery time following concussion in collegiate football players: The NCAA Concussion Study. **JAMA** 290:2556–2563, 2003.

34. McCrea M, Kelly JP, Randolph C, Cisler R, Berger L: Immediate neurocognitive effects of concussion. **Neurosurgery** 50:1032–1040, 2002.
35. McCrory P, Johnston K, Meeuwisse W, Aubry M, Cantu R, Dvorak J, Graf-Baumann T, Kelly J, Lovell M, Schamasch P: Summary and agreement statement of the 2nd International Conference on Concussion in Sport, Prague 2004. **Br J Sports Med** 39:196–204, 2005.
36. McIntosh AS, McCrory P: Impact energy attenuation performance of football headgear. **Br J Sports Med** 34:337–341, 2000.
37. McIntosh AS, McCrory P: Effectiveness of headgear in a pilot study of under 15 rugby union football. **Br J Sports Med** 35:167–169, 2001.
38. National Operating Committee on Standards for Athletic Equipment: Standard Drop Test Method and Equipment Used in Evaluating the Performance Characteristics of Protective Headgear, in ND001.
39. National Operating Committee on Standards for Athletic Equipment: Standard Performance Specification for Newly Manufactured Football Helmets, in ND002.
40. Naunheim RS, Standeven J, Richter C, Lewis LM: Comparison of impact data in hockey, football, and soccer. **J Trauma** 48:938–941, 2000.
41. Norman RW, Bishop PJ, Pierrynowski MR: Puck impact response of ice hockey face masks. **Can J Appl Sport Sci** 5:208–214, 1980.
42. Pellman EJ, Lovell MR, Viano DC, Casson IR, Tucker AM: Concussion in professional football: Neuropsychological testing—Part 6. **Neurosurgery** 55:1290–1305, 2004.
43. Pellman EJ, Powell JW, Viano DC, Casson IR, Tucker AM, Feuer H, Lovell M, Waeckerle JF, Robertson DW: Concussion in professional football: Epidemiological features of game injuries and review of the literature–Part 3. **Neurosurgery** 54:81–96, 2004.
44. Pellman EJ, Viano DC, Casson IR, Arfken C, Powell J: Concussion in Professional Football: Injuries Involving 7 or More Days Out—Part 5. **Neurosurgery** 55:1100–1119, 2004.
45. Pellman EJ, Viano DC, Tucker AM, Casson IR: Concussion in professional football: Location and direction of helmet impacts—Part 2. **Neurosurgery** 53:1328–1341, 2003.
46. Pellman EJ, Viano DC, Tucker AM, Casson IR, Waeckerle JF: Concussion in professional football: Reconstruction of game impacts and injuries. **Neurosurgery** 53:799–814, 2003.
47. Pettersen JA: Does rugby headgear prevent concussion? Attitudes of Canadian players and coaches. **Br J Sports Med** 36:19–22, 2002.
48. Powell JW, Barber-Foss KD: Traumatic brain injury in high school athletes. **JAMA** 282:958–963, 1999.
49. Shatz P, Stump J, Collins MW, Lovell MR: Sensitivity and specificity of the ImPACT test battery for concussion in athletes. **Arch Clin Neuropsychol** (in press).
50. Torg JS, Harris SM, Rogers K, Stilwell GJ: Retrospective report on the effectiveness of a polyurethane football helmet cover on the repeated occurrence of cerebral concussions. **Am J Orthop** 28:128–132, 1999.
51. Warden DL, Bleiberg J, Cameron KL, Ecklund J, Walter J, Sparling MB, Reeves D, Reynolds KY, Arciero R: Persistent prolongation of simple reaction time in sports concussion. **Neurology** 57:524–526, 2001.
52. Zemper ED: Analysis of cerebral concussion frequency with the most commonly used models of football helmets. **J Athl Train** 29:44–50, 1994.
53. Zemper ED: Two-year prospective study of relative risk of a second cerebral concussion. **Am J Phys Med Rehabil** 82:653–659, 2003.

Acknowledgments

Mr. Ide is an employee of Riddell, Inc. and a member of Riddell Holdings, LLC, parent company to Riddell, Inc. Riddell provided a grant to the University of Pittsburgh Medical Center, where Drs. Collins, Lovell, and Maroon are faculty. Riddell also provided the Revolution helmets, at a reduced cost, to study participants. Riddell was not involved in other aspects of the study. Regarding ImPACT, this program was utilized solely as the dependent measure in assessing neurocognitive change evidenced in the concussed sample of high school athletes. Drs. Collins, Lovell, and Maroon are co-developers and shareholders of ImPACT Applications. Grant Iverson has no affiliation, financial or otherwise, with Riddell, Inc or ImPACT Applications. Special thanks to the players, athletic trainers, coaches, and administrators from the high school football programs in the Pennsylvania Interscholastic Athletic Association for their participation in this study. The authors thank Jennifer Bernardo and Molly Spore for their assistance with manuscript preparation. Dr. Collins is a co-developer of ImPACT and co-owner of ImPACT Applications, the company which distributes the ImPACT concussion management software. Dr. Lovell is a co-developer of ImPACT and co-owner of ImPACT Applications, the company which distributes the ImPACT concussion management software. Grant Iverson was the primary statistician on the project. Dr. Maroon is a co-developer of ImPACT and co-owner of ImPACT Applications, the company which distributes the ImPACT concussion management software.

COMMENTS

I have great respect for the Riddell Helmet and think it is as good as any helmet being made today. This article, however, does not convince me that it is superior.

First, as anyone who reads this journal knows, reviewers do not verify the authenticity of data and, occasionally, papers may be published over certain reviewers' objections. What a reviewer can do is to try to see if the methodology is sound, if the conclusions fit the results, if the article passes a more subjective, perhaps for better word "sniff test," and then offer constructive suggestions in terms of how to make the article better.

This article, in my opinion, suffers from a serious, if not fatal, methodological flaw that precludes my not doubting the data, but doubting the significance of the data. That flaw is that we do not know the age of the helmets that comprised the non-Riddell group. We assume the Riddell helmets were either new or nearly new because the product is new. However, the helmets that the Riddell helmets were being compared against are of indeterminate age and were very likely significantly older than the Riddell group. As Vice President of the National Operating Committee on Standards for Athletic Equipment (NOCSAE), the organization that makes the certification standards for football helmets and other athletic equipment, I am aware, as is the author of this article employed by Riddell, that new helmets test to a higher severity index level than older helmets. New helmets out of the box before receiving the thousands of hits that they will incur on ensuing seasons often test significantly below the 1200 severity index that they must pass. Then, with each year's passage of time, their abilities to attenuate acceleration forces decline. That is the reason for the requirement of helmet reconditioning and recertification after a period of years in use. Whereas the process of actually reconditioning and recertification is fairly tightly scrutinized, the periodic recall of those helmets already in the field is less tightly controlled. It would be expected that if the newer Riddell helmets, therefore, are being compared against helmets that are significantly older, that the older helmet would not perform to as high a degree as the newer helmet. That is why today when parents or athletes ask me which is the best helmet to wear, I tell them I don't know which brand is best, but I know that a new helmet will be better than an old helmet and if recurring concussions are a concern that they should equip themselves with a new helmet.

In the conclusion of the abstract, the authors state that "recent sophisticated laboratory research has better elucidated injury biomechanics associated with concussion in professional football players. This data has led to new helmet design and new helmet technology." Although that statement is accurate, I think it is important to understand that the study they are referring to involves 25 concussions out of 787 total National Football League (NFL) concussions that were studied over a 6-year period in the multiple studies published in this journal by Pellman et al. The reason why only 25 concussions could be studied is that only in those 25 cases were there the necessary camera angles and on-field yard markers in view on the video tape, so that the theoretical calculations of forces sustained could be made. These 25 concussions were all somewhat unique in that they involved wide receivers or quarterbacks in the open field sustaining a hit to the side of the helmet that they did not see coming from an individual who essentially made a helmet to helmet collision. Thus, based on 3% of the total concussions in this NFL study and concussions involving a somewhat unique set of circumstances, new helmet design ensued. Although this new helmet design may be an improvement for those 3% of concussions, I have no way of knowing whether it is an improvement for the other 97% of concussions that could not be studied. Therefore, I believe it is still an open question as to whether the new helmet design is truly superior to other Riddell helmets or competitive helmets in reducing concussion.

I think it is also relevant to understand that the severity index that helmets must pass to be on the market is 1200. Although the calculated severity index that must be gotten under to prevent concussion based on the theoretical calculations of Pellman et al. as well as some more recent data coming from the Symbex Instrumented Helmet System, is a severity index of 300. We currently know that no helmet tests to a severity index even double what would be needed to prevent concussion. Therefore, I would not expect any of the current helmets to have a dramatic impact on concussion prevention.

Other less serious concerns were that, although the sample size of athletes studied (2141), was ample, the true sample size of the injury group (136) was small, and this is really the only group that is being studied. Also, the age of the Riddell group was slightly older than the age of the non-Riddell group, and research exists suggesting that the younger developing brain might be more easily concussed and recover more slowly than an older brain.

For the above reasons, I do not think this article convincingly makes the case that the Riddell helmet is significantly better than other new helmets on the market. I strongly support the author's suggestion for additional study by them and corroboration of their findings by others who are not tied to or funded by Riddell, is appropriate.

Finally, I would like to commend Riddell for having the courage to come forward with a new football helmet after manufacturers, for many years, were unwilling to do so because of liability issues. This has forced competitors to attempt to make a better product as well. The current football helmets do a marvelous job of what they were designed to do, namely eliminate cranial fractures and minimize subdural hematomas. Helmets are not currently asked to be made to a severity index to prevent concussion as that severity index is the current severity index requirement. It is probable that if a severity index under 300 is going to be achieved, significantly innovative new materials and designs would be required.

Robert C. Cantu
Concord, Massachusetts

This observational study compared concussion rates and recovery patterns in high school football players wearing standard helmets with those of players wearing a newly developed helmet. The major modifications of the newer helmet consist of additional padding over the zygoma and mandible and extension of the exterior shell further anteriorly and inferiorly than in standard helmets. Postconcussive neurocognitive testing was performed through the ImPACT program at regular intervals, and the results were compared with those of preseason testing. The new helmets were found to decrease the relative risk of concussion by 31% (from 7.6 to 5.3%), an amount which was significant.

One of the most gratifying messages of this article is that the results of sophisticated laboratory studies and injury modeling experiments can be directly applied to improving helmet design, which, in turn, seems to have a significant effect on the rate of concussion. These results are certainly encouraging. But, at the same time, let us hope that they represent only the first step in data-driven modifications in equipment, rules, and playing technique that make sports safer, while also keeping them fun and enjoyable.

Alex B. Valadka
Houston, Texas

Collins et. al. attempted to determine whether concussion rates and recovery times differed between high school football players who wore newer helmet technology and those who wore traditional helmet designs. The authors clearly state that there is no helmet that prevents concussion. I am in complete agreement. There is an inference that the Riddell Revolution helmet, with newer helmet technology, may minimize the risk of concussion when compared with traditionally designed helmets. Although helmets with newer technology may minimize the risk of concussion in football, there are some fundamental questions with the helmet comparison in this study. The Riddell Revolution was a brand new helmet introduced in 2002. New helmets obtain National Operating Committee on Standards for Athletic Equipment approval differently than reconditioned helmets. We do not have much information regarding the traditional helmets. The traditional helmets that are being compared with the Revolution may have gone through a reconditioning process many times before this study. It would not be surprising for high schools to reuse helmets for many years because of budgetary constraints. Certification of used helmets usually is recommended every 2 years. The reconditioning process involves a visual inspection, and only 4% of the batch actually undergoes laboratory testing. The decrease in concussion rates may be owing to newer materials instead of newer technology. Also, the mean age for those players who wore the Revolution helmet was statistically higher than those in traditional helmets. The authors in this study admit that age may explain a decrease in concussion rate.

I was surprised that the Schutt DNA helmet, introduced in 2004, was not worn by a single high school football player in the year of this study. Another interesting observation is that, despite the research and development that went into the Revolution regarding the zygoma and mandible pad and face mask, there were no differences in method of contact and region of head hit with regard to concussion. I expected a possible decrease in concussion rate in the Revolution for a hit to the side of the helmet. At the University of Southern California, we have used the Riddell Revolution. We have noticed problems with lacerations to other players who came in contact with the high chin strap metal buckles on top of the helmet, but that was corrected by replacing them with beveled buckles. We have also experienced helmets that have cracked on the shell near a ventilation hole. Some of the facemasks have deformed sooner than those of traditional helmets. Overall, our experience has been good with the Revolution helmet. We look forward to more studies like this one to learn more about improving helmet design and minimizing risk of concussion.

Russ Romano
Athletic Trainer
Los Angeles, California

In this prospective cohort study, Collins et al. suggest that a new helmet design lessened the incidence of absolute risks concussions by 2.3% each season of use when compared with standard helmets. The time to return to play after concussion was also reduced, but not to a statistically significant degree, between the two groups.

The study has several limitations in its design which may influence the results. Helmet selection was neither randomized nor controlled, and it is not entirely clear what factors led an athlete to be included in the new helmet design group or the standard group. Younger patients tended to use the older helmet type, and that group may be more susceptible to concussions. Those athletes using the new helmet type were "smarter" and "quicker" in their baseline responses compared to the old helmet user group, at least as measured by neuropsychological testing.

Most importantly, each of the authors has a business relationship with either the computerized neurocognitive testing equipment company (ImPACT) or the helmet manufacturer (Riddell) that were being evaluated. This fact represents a substantial conflict of interest, and the results should be interpreted accordingly.

Nonetheless, the aim and the outcomes of this study are exciting. Quantification of the various clinical features of concussion have improved the safety of contact sports, by providing health care professionals and athletic trainers with something tangible they can measure. Finally, some science seems to be appearing in the judgment of return to play decisions, and as described herein, may lead to improved technology of the equipment.

Arthur L. Day
Boston, Massachusetts

Despite modifications in equipment and rules in football, concussive injury remains a serious consideration with regard to the well-being of the athletes. This is likely even more true in athletes playing football at the high school level. This in conjunction with poor appreciation on the part of those individuals on the sideline of the diagnosis and initial treatment considerations of concussion fuels this continuing dilemma. In a 3-year, prospective, naturalistic, cohort study, the authors compared concussion rates and recovery times for athletes wearing newer helmet technology compared with traditional helmet design. Of 2141 high school athletes, 1173 wore the Revolution helmet manufactured by Riddell, Inc. Athletes underwent neurocognitive testing using ImPACT at the initiation of the study and were reevaluated after a concussion.

They report that the concussion rate in athletes wearing the Revolution was 5.3% compared with 7.6% in those wearing standard helmets ($P < 0$ .027]. The relative risk estimate was 0.69. Wearing the Revolution helmet was associated with approximately a 31% decreased relative risk and 2.3% decreased absolute risk for sustaining a concussion in this cohort study. Despite the large sample size of 2141 athletes, only 136 concussed athletes were identified at the end of the third year of study. The rate of loss of consciousness was relatively high, though consistent with the existing literature (3). Given the injury sample size of 136 athletes, there was not enough power to conduct meaningful comparisons by player position. This may be the result of enhanced education and observation by the sideline personnel as part of the study. Additionally, although there was a statistical difference in age, I do not think that it would contribute to a difference based upon the tenet that younger athletes tend to be more vulnerable to the effects of concussion.

The current study is the first "field study" of its kind and will certainly lead to both future studies and continued improvement in technology. By report, the study was not controlled or influenced in any way by the researchers. Riddell facilitated the current study with a grant and provision of Revolution helmets, but was not involved in any other aspects of the study.

Technological advancement in helmet design is of the utmost importance (1, 2). A related variable is the facility of distribution to athletes independent of cost. It is problematic that the National Athletic Equipment Reconditioners Association suggests that reconditioned and recertified helmets are the equivalent of newly manufactured helmets over a reasonable lifetime. Riddell suggests that its helmets be retired after 10 years of use. The authors comment that the effects of previous wear on older helmets did not influence the study and that all helmets were certified to the National Operating Committee on Standards for Athletic Equipment standard.

Michael L. Levy
San Diego, California

1. Levy ML, Ozgur BM, Berry C, Aryan HE, Apuzzo ML: Analysis and evolution of head injury in football. **Neurosurgery** 55:649–655, 2004.
2. Levy ML, Ozgur BM, Berry C, Aryan HE, Apuzzo ML: Birth and evolution of the football helmet. **Neurosurgery** 55:656–661, 2004.
3. McCrea M, Kelly JP, Randolph C, Cisler R, Berger L: Immediate neurocognitive effects of concussion. **Neurosurgery** 50:1032–1040, 2002.

Collins et al. present an elegant observational study with 2141 athletes participating from high schools in western Pennsylvania, of whom 136 experienced football-related concussion during a 3-year period. Their aim was, for the first time, to assess whether recent structural changes in the Revolution helmet led to a reduction in the incidence of football-related concussion when compared with players wearing traditional helmet types marketed before 2002. On field assessment, follow-up examination, and computerized neuropsychological testing were used for evaluations of the athletes. The authors describe the rationale behind the design modifications compared with the traditional football helmet, which primarily aims to attenuate force vectors to the temporal and mandibular areas.

Their results showed a statistically significant reduced rate of concussion in the players wearing the Revolution helmet compared with traditional helmet types (5.3 versus 7.6%). The newer design features are reported to have led to a concussive relative risk reduction of 31% and an absolute risk reduction of 2.3%. There were not significant differences in the characteristics, mechanisms, and manifestations of concussions in these athletes, other than the Revolution helmet sample athletes being an average of 6 months older.

This is a provocative and interesting study, which, by field testing this new equipment, completes the process which began by observation and video analysis of concussions in the NFL, reconstruction of game impacts in laboratory test dummies, and helmet design modifications based on trends and the biomechanics of head injury in football. The authors acknowledge the natural limitations in such a study and point out that further research with a larger number of subjects is necessary in order to duplicate these results and more fully appreciate the positive influence which new technology may offer in traditional contact sports. It will be of further interest to see what role NOCSAE will play in assessing and adopting these and other design modifications. Hopefully, this study will encourage others in industry and those involved in evaluation of the injured athlete to investigate the comparative performance of protective equipment in contact sports.

Julian E. Bailes
Morgantown, West Virginia