Changes in baseline concussion assessment scores following a school bus crash

Kristin M. Poland, Mary Pat McKay, Mark R. Zonfrillo, Thomas H. Barth, and Ronald Kaminski

ABSTRACT

Objective: The objective of this article is to present concussion assessment data for 30 male athletes prior to and after being involved in a large school bus crash. The athletes on the bus, all male and aged 14–18 years, were participating in their school's concussion management program that included baseline and postinjury testing using Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT).

Methods: This case study described changes in concussion assessment scores for 30 male athletes following a primarily frontal school bus crash. Data from the school's concussion management program, including baseline test data and postinjury assessment data, were reviewed. Athletes who required multiple postinjury assessments by the program were identified as having had significant cognitive changes as a result of the bus crash.

Results: Twenty-nine of 30 athletes were injured. One had lumbar compression fractures; others had various lacerations, abrasions, contusions, sprains, and nasal fractures. ImPACT data (postcrash) were available for all 30 athletes and 28 had available precrash baseline data. A total of 16 athletes (53.3%) had significant cognitive changes indicated by changes in their concussion assessment scores, some of which took months to improve.

Conclusion: This case study highlights a unique opportunity to evaluate concussion assessment data from 30 male athletes involved in a high-speed school bus crash. Further, these data provide additional insight into assessing the effectiveness of current school bus occupant protection systems.

Introduction

Concussion is a form of mild traumatic brain injury that results from direct head trauma or impact to another body region, resulting in forces transmitted to the head (McCrary et al. 2013). Typically, a concussion is diagnosed when functional cognitive changes or symptoms are present but neuroimaging is negative. Most research has focused on concussions sustained during sporting activities, falls, and assaults. These instances typically involve a single individual sustaining an injury as a result of an isolated event, making it difficult to assess trends. The shared crash experience of this group was unique. In this case study, 30 male high school baseball athletes, who were participating in their school's concussion management program, were involved in a high-speed, primarily frontal collision between their school bus and a sport utility vehicle (SUV). Because the principal direction of force was in the frontal direction, the athletes experienced similar crash forces throughout the bus. (Occupants in the front may have experienced slightly higher crash forces because there was less structure to absorb energy.) This crash enables a case study of changes in concussion assessment scores from a single trauma experienced simultaneously by 30 adolescent occupants.

In this mid-day crash, a 2004 Kia Sorento SUV experienced a left rear tire failure on a divided highway with a posted speed limit of 113 km/h (70 m/h) near Centerville, Louisiana (National Transportation Safety Board [NTSB] 2015a). The SUV, traveling at an estimated 113 km/h (70 m/h), crossed the median and was struck by a 2005 IC 66-passenger school bus, which was reportedly traveling at 88 km/h (55 m/h) prior to the crash. Initially, the front of the school bus struck the left front of the SUV. As shown in Figure 1, the SUV continued to rotate clockwise and made several impacts along the right side of the bus. The bus then veered off the road and crossed a shallow ditch before coming to rest in a plowed field. Figure 2 and Figure 3 show damage to the SUV and the school bus, respectively. In this crash, likely because of the speeds involved, the front of the school bus sustained a large amount of damage and the bus body shifted on the chassis. The school bus was not equipped with passenger seat belts but was equipped with standard compartmentalization, a passive form of occupant protection, including closely spaced, high-backed, energy-absorbing seats designed to deform up to 356 mm in a frontal crash. In a frontal crash, occupants quickly contact the seat back in front and distribute the forces over a large surface area, including their head, chest, and lower legs. Research has shown that compartmentalization is an effective method for mitigating serious injuries and fatalities in frontal collisions but does not prevent all flailing-related injuries or injuries resulting from impacts with non-energy-absorbing sur-
Figure 1. Scene drawing showing crash sequence, from tire tread separation to final rest positions of all vehicles and occupants ejected from the SUV.

faces inside the bus (NTSB 1999, 2013). Further, minor injuries or injuries that may result in concussions have not been fully evaluated in school bus crashes.

The athletes on the bus were participants in an ongoing sports concussion assessment program, Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), which included baseline and postinjury testing (Iverson et al. 2003, 2005). The ImPACT program has 3 sections, which include demographic data, neurocognitive tests, and the Post-Concussion Symptom Scale. According to the developers of the ImPACT program, the program measures multiple aspects of cognitive function including attention, working memory, reaction time, nonverbal problem solving, response variability, and attention time (ImPACT 2016). These neurocognitive tests include 6 sections: word discrimination, design memory, Xs and Os, symbol matching, color match, and 3-letter memory. Five composite scores are calculated from these neurocognitive tests: verbal memory, visual memory, processing speed, reaction time, and impulse control. In addition, a total symptom score composite is calculated from the 22 symptom descriptors with a lower score indicating fewer symptoms reported by the test taker. The 22 symptoms are headache, nausea, vomiting, balance problems, dizziness, fatigue, trouble falling asleep, sleeping more than usual, sleeping less than usual, drowsiness, sensitivity to light, sensitivity to noise, irritability, sadness, nervousness, feeling more emotional, numbness or tingling, feeling slowed down, feeling mentally “foggy,” difficulty concentrating, difficulty remembering, and visual problems.

The ImPACT program was designed to provide clinical symptom and cognitive information regarding mild traumatic brain injury, such as a concussion (Iverson et al. 2003, 2005). The ImPACT technical manual states that the most effective manner to evaluate a potential concussion is to compare the athlete’s postinjury performance to the athlete’s baseline assessment, conducted preinjury. If a baseline test is not feasible (because of a previous concussion diagnosis, for example) the athlete’s performance can be compared to normative data provided by the ImPACT program. If a concussion is suspected, additional postinjury tests may be performed over a period of time to assist with return-to-play decisions.

Research has reported success using the ImPACT program for evaluating cognitive changes associated with concussion (Schatz et al. 2006). The main objective of this case study was to describe the changes in concussion assessment scores for 30 male athletes following a primarily frontal school bus crash.

Methods

The NTSB investigated this crash in support of its special investigation report on “Selected Issues in Passenger Vehicle Tire Safety” (NTSB 2014, 2015b). Data from the school’s concussion management program (ImPACT), including baseline test data
Table 1. Summary of the occupant positions, demographics, injury level, and concussion assessment-related information. The seating positions are identified by row number, left or right side (L or R), and aisle or window seat (A or W). Blank spaces for duration indicate that the athlete did not meet the criteria for cognitive changes suggestive of a concussion.

| Occupant number | Row | Side | Window or aisle | Number per seat | Age (years) | Height (cm) | Weight (kg) | BMI | Age-and sex-adjusted BMI (%) | NTSB injury level | Duration (days) | Number of postinjury assessment tests |
|-----------------|-----|------|-----------------|-----------------|-------------|-------------|-------------|-----|-----------------------------|-----------------|----------------|-------------------------------|
| 1a              | 3   | L    | A               | 2               | 15          | 175         | 73          | 31.0| 83                         | Minor           | 12             | 3                            |
| 2               | 3   | L    | W               | 2               | 16          | 183         | 95          | 28.5| 95                         | Minor           | 1              | 1                            |
| 3               | 3   | R    | A               | 2               | 15          | 178         | 77          | 24.4| 87                         | Minor           | 12             | 3                            |
| 4               | 4   | R    | W               | 2               | 15          | 178         | 92          | 29.0| 97                         | Minor           | 6              | 2                            |
| 5               | 4   | L    | W               | 1               | 17          | 188         | 95          | 27.0| 91                         | None            | 1              | 1                            |
| 6               | 4   | R    | W               | 2               | 16          | 168         | 68          | 24.2| 82                         | Minor           | 1              | 1                            |
| 7               | 4   | R    | A               | 2               | 14          | 183         | 79          | 23.7| 87                         | Minor           | 12             | 3                            |
| 8a              | 5   | L    | W               | 2               | 15          | 185         | 73          | 25.1| 65                         | Minor           | 1              | 1                            |
| 9               | 5   | L    | A               | 2               | 15          | 173         | 77          | 25.8| 92                         | Minor           | 1              | 1                            |
| 10              | 5   | R    | W               | 2               | 15          | 178         | 59          | 18.7| 30                         | Minor           | 1              | 1                            |
| 11              | 5   | R    | A               | 2               | 15          | 188         | 97          | 28.2| 95                         | Minor           | 1              | 1                            |
| 12              | 6   | L    | A               | 2               | 16          | 170         | 70          | 24.3| 83                         | Minor           | 25             | 4                            |
| 13              | 6   | L    | W               | 2               | 17          | 180         | 79          | 24.4| 79                         | Minor           | 12             | 3                            |
| 14              | 6   | R    | W               | 2               | 16          | 183         | 71          | 25.8| 59                         | Minor           | 25             | 4                            |
| 15              | 6   | R    | A               | 2               | 16          | 168         | 73          | 21.0| 90                         | Minor           | 1              | 1                            |
| 16              | 7   | L    | A               | 2               | 16          | 191         | 88          | 24.4| 83                         | Minor           | 24             | 3                            |
| 17              | 7   | L    | W               | 2               | 16          | 173         | 66          | 22.0| 64                         | Minor           | 12             | 3                            |
| 18              | 7   | R    | W               | 2               | 15          | 183         | 86          | 25.8| 91                         | Minor           | 60             | 3                            |
| 19              | 7   | R    | A               | 2               | 16          | 178         | 66          | 20.8| 49                         | Minor           | 9              | 2                            |
| 20              | 8   | L    | W               | 2               | 17          | 188         | 82          | 23.1| 66                         | Minor           | 1              | 1                            |
| 21              | 8   | L    | A               | 2               | 18          | 175         | 66          | 21.4| 42                         | Minor           | 1              | 1                            |
| 22              | 8   | R    | W               | 2               | 16          | 168         | 64          | 26.6| 69                         | Minor           | 101            | 5                            |
| 23              | 8   | R    | A               | 2               | 15          | 168         | 64          | 22.6| 76                         | Minor           | 12             | 3                            |
| 24              | 9   | L    | W               | 2               | 18          | 180         | 68          | 20.9| 32                         | Minor           | 1              | 1                            |
| 25              | 9   | L    | A               | 2               | 17          | 180         | 77          | 23.7| 75                         | Minor           | 1              | 1                            |
| 26b             | 9   | R    | W               | 2               | 16          | 168         | 64          | 24.5| 76                         | Serious          | 72             | 3                            |
| 27              | 9   | R    | A               | 2               | 18          | 178         | 68          | 21.5| 43                         | Minor           | 12             | 3                            |
| 28              | 10  | L    | W               | 1               | 18          | 175         | 75          | 24.4| 73                         | Minor           | 1              | 1                            |
| 29              | 10  | R    | W               | 1               | 18          | 178         | 84          | 26.5| 88                         | Minor           | 1              | 1                            |
| 30              | 11  | L    | W               | 1               | 17          | 185         | 68          | 19.8| 25                         | Minor           | 9              | 2                            |

aNo baseline data due to an early injury.
bPrevious concussion documented.

and postinjury assessment data, were collected and reviewed. The majority of the athletes involved in this accident had a baseline ImPACT clinical screening performed with details from the assessment documented in a 5-page report. Athletes with a previous concussion diagnosis were compared to normative data provided with the ImPACT program. Athletes had one or more follow-up ImPACT clinical assessments performed after the crash. In addition, the athletes were assessed using the balance error scoring system balance test (Bell et al. 2011). All testing was administered by the school’s athletic trainer and the results were interpreted by one of 2 physicians associated with the school, both of whom were trained to use ImPACT.

According to the athletic trainer responsible for administering ImPACT, athletes were assessed using scores from 3 portions of the program, including the (1) number of symptoms with a score above zero, (2) ImPACT neurocognitive results, and (3) balance test results. The physicians associated with the school and trained to use ImPACT considered an athlete to have significant postcrash cognitive changes suggestive of a concussion if there were more than 5 symptoms with a score above zero, if the physician assessed the ImPACT test to be abnormal, and if there were 3 or more errors on the balance test. If the athlete was considered to have sustained cognitive changes suggestive of a concussion by the physicians, additional postinjury ImPACT assessments were performed. If multiple postinjury assessments were performed, then the duration of concussion symptoms was calculated based on the time between the accident and the last assessment performed. The number of postinjury assessments was also documented.

Additional information gathered during the investigation and from ImPACT reports included athlete seating position, age, height, and weight; body mass index (BMI) and age-/sex-adjusted BMI percentile were calculated from this information. Injury data were gathered during the investigation, including data from available medical records and self-reported injury information collected during postcrash interviews. Analysis was performed using SPSS v.19 to calculate chi-squared statistics comparing characteristics of notable changes in cognitive performance postinjury.

Results

As a result of the crash, the belted 37-year-old female SUV driver, two adolescent rear-seated males, and one 6-year-old rear-seated female died. Evidence indicated that the rear-seated SUV passengers were unbelted. A belted, front-seated, adolescent male SUV passenger was seriously injured. On the school bus, the 40-year-old female driver and the one adult coach were injured and 3 other adult coaches were uninjured. (The adult coaches were all seated in the first 2 rows of the school bus.) Twenty-nine of 30 male athletes on the bus were injured. One athlete had lumbar compression fractures; others had various lacerations, abrasions, contusions, sprains, and nasal fractures. Table 1 summarizes each athlete’s seating location,
demographics, BMI, age-/sex-adjusted BMI percentile, level of injury, duration of concussion symptoms if a concussion was suspected, and the number of postinjury assessments that were performed. Table A1 (see online supplement) documents the total symptom scores and the ImPACT neurocognitive composite scores for each athlete tested, including baseline tests when available, all postinjury assessments, and associated injury information. (Balance assessments score results were not available for review postcrash.) Athletes were between 14 and 18 years old (mean and median 16) with age-/sex-adjusted BMI percentiles ranging between 25 and 97%. Baseline ImPACT data were available for 28 of the 30 athletes. Those athletes without baseline data were assessed based on normative data. Postcrash ImPACT data were available for all 30 athletes. A total of 16 athletes (53.3%) had significant postcrash cognitive changes suggestive of a concussion; among these, cognitive changes and/or symptoms lasted an average of 26 days (range 6–101 days). A seating chart showing the seating locations for all 30 athletes is shown in Figure 4. Although the athletes are all depicted seated upright and facing forward, their actual orientations at the time of the crash are unknown. Athletes identified as having significant postcrash cognitive changes suggestive of a concussion are marked with grey hatching. The athletes were evenly distributed between the left and right sides of the bus, yet 10 of the 16 with significant postcrash cognitive changes (62.5%) were sustained by occupants on the right side of the bus. When examining the distribution throughout the length of the bus, 11 athletes (68.8%) with significant postcrash cognitive changes were seated near the center of the bus in rows 6–9. This region is also near the rear wheel wells on the bus, which are marked with the dashed lines in Figure 4. Despite these general observations, no significant statistical effects were identified for row, side of the bus, number of occupants per seat, age, aisle vs. window seating, height, weight, or BMI.

Discussion

This case study is the first known report of concussion assessment data on multiple high school athletes involved in a school bus crash. Overall, the results show observations with more athletes near areas of impact (front and right side) sustaining significant postcrash cognitive changes suggestive of a concussion but no statistically significant results were found based on seating position or occupancy per seat or for any of the age or anthropometric measures. Although the athletes all experienced the same crash environment and deceleration, the crash pulse experienced at a given seat location likely varied along the length of the bus and from one side to the other. For example, athletes seated toward the front of the bus may have experienced higher longitudinal forces than those seated in the back because the bus body absorbed some of the impact energy as the forces were transmitted along the length of the bus. In addition, although the SUV impacted the right side of the bus below the passenger compartment, these impact forces may have caused some of the athletes to experience occupant-to-occupant impacts or occupant-to-interior impacts along the right sidewall. Further, compartmentalization is designed to function for the occupant seated upright and facing forward, thus providing the greatest distribution of force across the head, chest, and legs as the occupant travels forward, and then contacts and deforms the energy-absorbing seat back in front. If the athlete was out of position relative to the seat back in front, the effectiveness of the compartmentalization system may have been reduced. In addition, the position of the athlete (and his seatmate, if present) as the bus bounced off the road and through the shallow ditch may have influenced the risk of concussion. The installation and proper use of passenger lap/shoulder belts may reduce the risk of occupant-to-occupant and occupant-to-interior impacts (NTSB 2013) and thereby decrease the risk of these significant postcrash cognitive changes suggestive of a concussion.

There are some limitations to this case study. It is limited to the results of a single crash; no comparisons to school bus collisions involving smaller children or similar-sized, belted adolescents can be made. There is very limited information regarding the crash pulse and crash forces, limiting any conclusions regarding those important factors. The bus lacked an inward-facing onboard video recording system, so the exact position of the occupants immediately prior to or during the crash is
unknown (Poland et al. 2015). It is possible that position was one of the key determinants of concussion risk in this group. Although we attempted to describe the cognitive effects, it is likely that there were other social, psychological, and educational effects of the concussions (or other injuries) not captured by this investigation. Finally, this was an ecologic study and the number of athletes on the bus may have limited the power of our analysis.

The NTSB primarily investigated this crash in order to evaluate the loss of control associated with the SUV’s tire failure. Because a school bus has a relatively rigid, heavy body structure compared to an SUV, and because the passenger compartment is high, school bus occupants often sustain few injuries in frontal crashes with passenger cars. Despite the large amount of front end damage to the school bus, its chassis shift, and the catastrophic damage to the SUV, only one athlete on the school bus sustained a serious injury. Another 28 athletes had minor injuries, and one was uninjured in the crash. The compartmentalized school bus successfully protected these high school athletes from life-threatening injuries. However, many non-life-threatening injuries have the potential for long-term sequelae. In this accident, the sports team’s concussion management program provided data not generally available that revealed more than half the athletes had significant postcrash cognitive changes suggestive of a concussion; these students were kept off the playing field for days to weeks to months. This study highlights the value of a comprehensive injury assessment, including neurocognitive evaluations, when addressing the longer term effects of school bus crashes. A better understanding of the risks and effects of “minor” injuries would allow a more complete and science-based approach to the question of requiring passenger lap/shoulder belt systems on large school buses.

Concussion results in significant health care utilization (Zonfrillo et al. 2015) and short-term disability (Barlow 2016) in children, adolescents, and young adults. Understanding the mechanisms involved in sustaining a concussion and the differences between individuals exposed to similar impact forces is important for accurate diagnosis, treatment, and return-to-play decisions for individuals. A comprehensive injury assessment program may enhance understanding of non-life-threatening injuries, especially in motor vehicle crashes. Similarly, motor vehicle crashes may provide a wealth of injury data to aid in the diagnosis, treatment, and return-to-school and return-to-play decisions for pediatric and adolescent patients. Future efforts should focus on collecting and analyzing data when occupants of motor vehicle crashes have concussion management program data available and, as part of comprehensive injury assessment, include neurocognitive testing to identify minor injuries that may have major effects.

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References

Barlow KM. Postconcussion syndrome: a review. J Child Neurol. 2016;31:57–67.
Bell DR, Guskiewicz KM, Clark MA, Padua DA. Systematic review of the balance and error scoring system. Sports Health. 2011;3:287–295.
ImPACT. The ImPACT Test. 2016. Available at: https://www.impacttest.com/products/The-ImPACT-Test-2. Accessed February 13, 2016.
Iverson GL, Lovell MR, Collins MW. Interpreting change on ImPACT following sport concussion. Clin Neuropsychol. 2003;17:460–467.
Iverson GL, Lovell MR, Collins MW. Validity of ImPACT for measuring processing speed following sports-related concussion. J Clin Exp Neuropsychol. 2005;27:683–689.
McCrorry P, Meeuwisse WH, Aubry M, et al. Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport held in Zurich, November 2012. Phys Ther Sport. 2013;14(2):e1–e13.
National Transportation Safety Board. Special Investigation Report: Bus Crashworthiness Issues. Alexandria, VA: National Technical Information Service; 1999. SIR99004.
National Transportation Safety Board. School Bus and Truck Collision at Intersection Near Chesterfield. Alexandria, VA: National Technical Information Service; 2013. HAR-13-01.
National Transportation Safety Board. Centerville, LA Docket Management System, HWY14MH006. 2014. Available at: http://dms.ntsb.gov/pv/pubdms/. Accessed February 25, 2016.
National Transportation Safety Board. Highway Accident Brief: Tire Deflation and Tread Separation, Cross-median Crash. Alexandria, VA: National Technical Information Service; 2015a. HAB-15-01.
National Transportation Safety Board. Special Investigation Report: Selected Issues in Passenger Vehicle Tire Safety. Alexandria, VA: National Technical Information Service; 2015b. SIR-1 5/02, PB2016-100009.
Poland KM, Barth TH, Zonfrillo MR, Kent RW, Arbogast KB. A continuous video recording system on a lap-belt equipped school bus: real-world occupant kinematics and injuries during a severe side impact crash. Paper presented at: 24th International Conference on the Enhanced Safety of Vehicles (ESV); June 2015; Gothenburg, Sweden.
Schatz P, Pardini JE, Lovell MR, Collins MW, Podell K. Sensitivity and specificity of the ImPACT Test Battery for concussion in athletes. Arch Clin Neuropsychol. 2006;21:91–99.
Zonfrillo MR, Kim KH, Arbogast KB. Emergency department visits and head computed tomography utilization for concussion patients from 2006 to 2011. Acad Emerg Med. 2015;22:872–877.