

A CONTINUOUS VIDEO RECORDING SYSTEM ON A LAP-BELT EQUIPPED SCHOOL BUS: REAL-WORLD OCCUPANT KINEMATICS AND INJURIES DURING A SEVERE SIDE IMPACT CRASH

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ABSTRACT

A loaded truck-tractor semitrailer severely impacted the side of a lap-belt-equipped large school bus in which 30 students, age 5 to 11 years, were riding. The crash investigation obtained on-board video and audio from the school bus recording system, which had four active cameras that recorded at 15 frames per second. A total of 55 minutes 39 seconds of video and audio was obtained, including over 15 minutes after the bus came to final rest. Qualitative descriptions of occupant motion during the crash sequence were documented based on the time sequence of vehicle motion, including kinematics of lap-belted pediatric occupants, occupant-to-occupant interactions, and occupant-to-vehicle interactions. Further, quantitative measurements of occupant motion were performed by tracking visible body regions such as the head or center of the pelvis using commercially available motion analysis software. Occupant injuries were coded using hospital medical records and according to the Abbreviated Injury Scale 2008 manual.

Injury severity was higher in the rear of the bus near the region of impact, maximum intrusion, and maximum lateral accelerations. The injury severity scores (ISS) ranged from 1 to 6 in the front of the bus and from 1 to 57 at the rear, including the one student seated at the rear of the bus who was fatally injured. Head injuries included several mild to moderate traumatic brain injuries. Lateral head translations and velocities were evaluated. The lateral head displacements toward the impacted side in the front of the bus were similar to those in the rear during the initial impact, but the head displacements for occupants in the rear of the bus were greater during the secondary and tertiary rebound motions toward alternating sides of the bus. Lateral head velocities relative to the bus interior were generally almost twice as high in the rear of the bus as in the front. In addition, the magnitude of whole body pediatric occupant motion in the absence of injury was notable. Further, loss of consciousness negatively affected occupants' ability to self-evacuate, even when subjects regained consciousness.

The qualitative and quantitative descriptions represent the first time that lap-belted school bus pediatric occupant motion during a crash has been documented from continuous onboard video recordings. This unique data source allows the rare correlation of occupant kinematics with crash severity and injury outcomes in living humans.

INTRODUCTION

Pediatric biomechanics is a critical area of research to ensure the protection of these vulnerable occupants. Key data has been gathered from research through academic and industry partnerships. [1] Government programs, such as the National Highway Traffic Safety Administration (NHTSA) National Automotive Sampling System (NASS) and Crash Injury Research (CIREN), generate critical databases, crash reconstructions, and associated research. Although a significant amount of real-world information for a large number of crash types and scenarios has been

obtained in the past, there is still limited information available about real-world pediatric occupant kinematics and interactions with seats, restraints, and interior systems during the impact sequence.

Seat and restraint designs are developed using anthropomorphic test devices (ATD), which have biofidelity limitations, including seat positioning differences between the ATD and a human. [2] Further, pediatric ATDs are often scaled from adult ATDs and suffer from a lack of information establishing range of motion and injury thresholds. [3] Human volunteer research partially addresses the differences between ATDs and humans, but this research is conducted in sub-injurious settings. [4, 5] Naturalistic driving studies have the potential to provide information on a range of event severities as long as the appropriate data can be collected. [6] Accident reconstructions in conjunction with post mortem human subject (PMHS) testing address injurious crash levels, but pediatric PMHS testing is extremely rare [7] and does not include muscle response.

The objectives of this analysis were to document pediatric occupant injuries, qualitative observations from the continuous onboard video system, and quantitative measurements from the onboard video of occupant kinematics during the crash phase. The results present a unique data source to study the real-world movement and associated injuries of pediatric occupants.

METHODS

In this crash, a loaded truck-tractor semitrailer severely impacted the side of a lap-belt-equipped large school bus occupied by the driver and 30 students, age 5 to 11 years. (See *Figure 1.*) The school bus was equipped with a continuous audio and video recording system manufactured by Seon Design, Inc. The system had four active cameras, which recorded at 15 frames per second. The videos began prior to student loading of the bus and continued through the bus trip to the point of the collision and after. A total of 55 minutes 39 seconds of video and audio was obtained, including over 15 minutes after the bus came to final rest. The continuous video system captured useful data prior to, during, and after the crash.

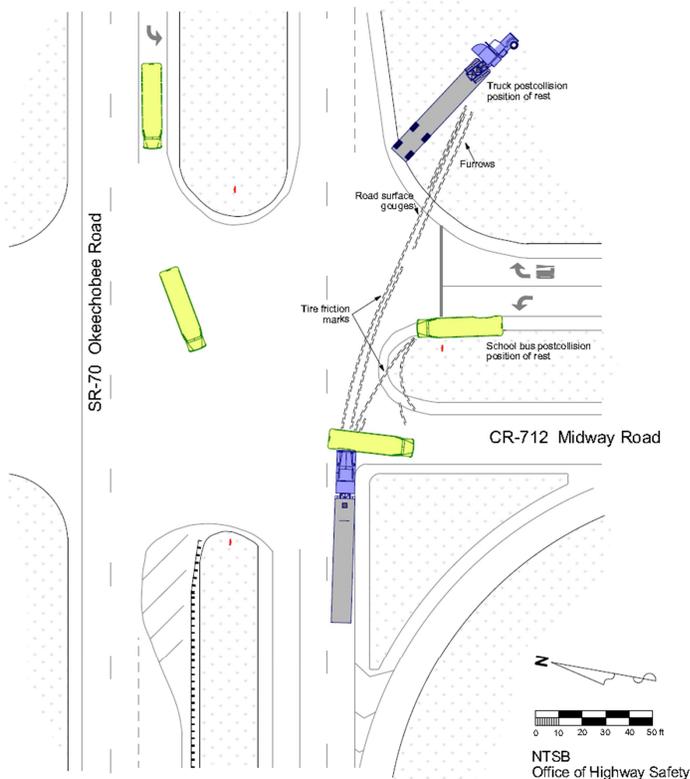


Figure 1. The crash scene diagram.

Vehicle and Occupant Descriptions

Each of the four camera positions was individually labeled, by the Seon Design, Inc. video system, as “Step”, “Front”, “Mid”, and “Rear” according to their location and orientation. **Figure 2** shows a still image with four frames from each of the four onboard video cameras prior to the loading of the school bus. (By statute, the NTSB is prohibited from releasing onboard video and audio recordings that show occupants.) All four camera views were evaluated for the entire recorded duration to describe the motion of the school bus and the occupants using both qualitative and quantitative methods. During the precrash phase, qualitative descriptions of the driver’s actions, communications, the vehicle motion, and any relevant video overlay information, such as “RT” indicating the right turn signal was illuminated or “BRK” indicating that the brake was applied, were documented based on the crash timeline. In addition, qualitative descriptions of each visible occupant’s belt use, seating position prior to impact, position at final rest, whether the occupant was ejected from the seat compartment, occupant-to-occupant interactions, occupant-to-vehicle interactions, and state of consciousness postcrash were documented based on the timeline developed for the vehicle motion.



Figure 2. Still images from the onboard video system showing the four camera views prior to the occupants loading onto the school bus. The four camera views, starting in the upper left corner and moving clockwise, are “Step”, “Front”, “Rear”, and “Mid”. Text detailing the row numbers is overlaid on the images for clarity.

Further, quantitative positions and velocities of the school bus and the visible occupants were calculated. The process to estimate the dynamic school bus motion history has been described previously. [8] Briefly, a model of the camera was developed and calibrated. In an iterative process, each video frame from the camera was matched to a synthesized video frame, including known landmarks outside the bus, generated by the camera model. When the frames matched, the bus position and orientation was established. For the quantitative occupant motion, the “Front” and “Mid” cameras provided the clearest view of the occupant motion and were the source of this documentation. The basic method to calculate the occupant motion required the calibration of the visible occupant space within the two-dimensional recorded video frame. ProAnalyst Professional Edition (Version 1.5.6.5) was used to calibrate the local occupant seating coordinate system, based on interior bus dimensions measured from the three-dimensional laser scans of the school bus, and to track the occupants’ (or interior surfaces’) motion.

The “Front” camera was centered in the middle of the school bus interior. As a result, the perspective calibration was used in ProAnalyst, using four points representing the base and top of the windows on each side of the bus in a position closely matching the occupant’s initial seated position. Row 2 and row 3 were calibrated. Seat spacing and seat width were used to verify the calibrations. The “Mid” camera was offset toward the driver’s side of the bus looking toward the passenger side of the bus. The perspective calibration was implemented again for row 7, using four points representing the base and top of the windows on both sides of the bus in a position closely matching the tracked occupant’s initial seated position. For row 6, because the top of the windows were not visible in the camera view, the perspective calibration was used but the four points represented the base of the windows and the base of the seat pan on both the driver and passenger side of the bus. The perspective calibration was adjusted to most closely match the tracked occupant’s motion within a seat row. As a result, there were multiple calibrations defined for both row 6 and row 7. Seat spacing and seat width were used to verify the calibrations. The motion in the local occupant seating coordinate system was then transformed into the bus body coordinate system. Positions and velocities were calculated relative to the bus body coordinate system.

The videos documented student loading onto the bus, the use of seat belts for most students, and occupant positions throughout the bus trip. These continuous recordings helped establish an accurate seating chart, including occupant age and gender, preimpact position, and the level of restraint for most of the students.

Injury Coding

Abbreviated Injury Scale (AIS) scores were assigned and injury descriptions were summarized for all occupants who received medical attention. Copies of medical records and digital radiographic images were reviewed to confirm injuries. Standard AIS coding rules were used based on the most recent AIS manual. [9] Injuries were summarized using several metrics: the traditional International Civil Aviation Organization (ICAO) code with categories of uninjured, minor, serious, or fatal; the comprehensive AIS score; and the total Injury Severity Score (ISS) ranging from 0-75. Individual injuries by ISS body region, AIS code, and injury description were listed for each school bus occupant that received treatment and for the fatally injured occupant. [10]

Given the availability of the on-board video system, observation of loss of consciousness (LOC) was used to help determine the concussion diagnoses. Occupants were given the diagnosis of concussion if there was probable or certain LOC on the bus and no intracranial hemorrhage, or if a final concussion diagnosis was confirmed in the medical record (regardless of whether the passenger experienced LOC). Concussions were not coded if the patient had LOC with any intracranial hemorrhage.

RESULTS

Qualitative Observations from Continuous Video System

The continuous video system confirmed that the bus driver was not distracted by a cell phone or other portable electronic device and that he had both hands on the steering wheel during the left turn maneuver just prior to the collision. The driver consistently used the turn signals to indicate a transition from one lane to another and to indicate motion into the left turn lane prior to the collision. The driver also applied braking in preparation for this left turn. Further, it was apparent that the driver perceived the impact threat, though too late, because he turned his head toward the oncoming truck. The onboard videos and associated audio recordings showed that the driver encouraged seat belt use at the beginning of the trip and that he did not appear to be distracted by students just prior to the collision.

The continuous recordings also documented student loading onto the bus, the use of seat belts for most students (some views were partially obscured, including the seating position of the fatally injured occupant), and occupant positions throughout the bus trip. These data helped investigators establish an accurate seating chart, pre-crash occupant positions, and the level of restraint for most of the occupants. Pre-crash video and audio documentation showed that the driver’s attentiveness to passenger safety and seat belt rules was a factor in the number of students who properly wore and adjusted their seat belts.

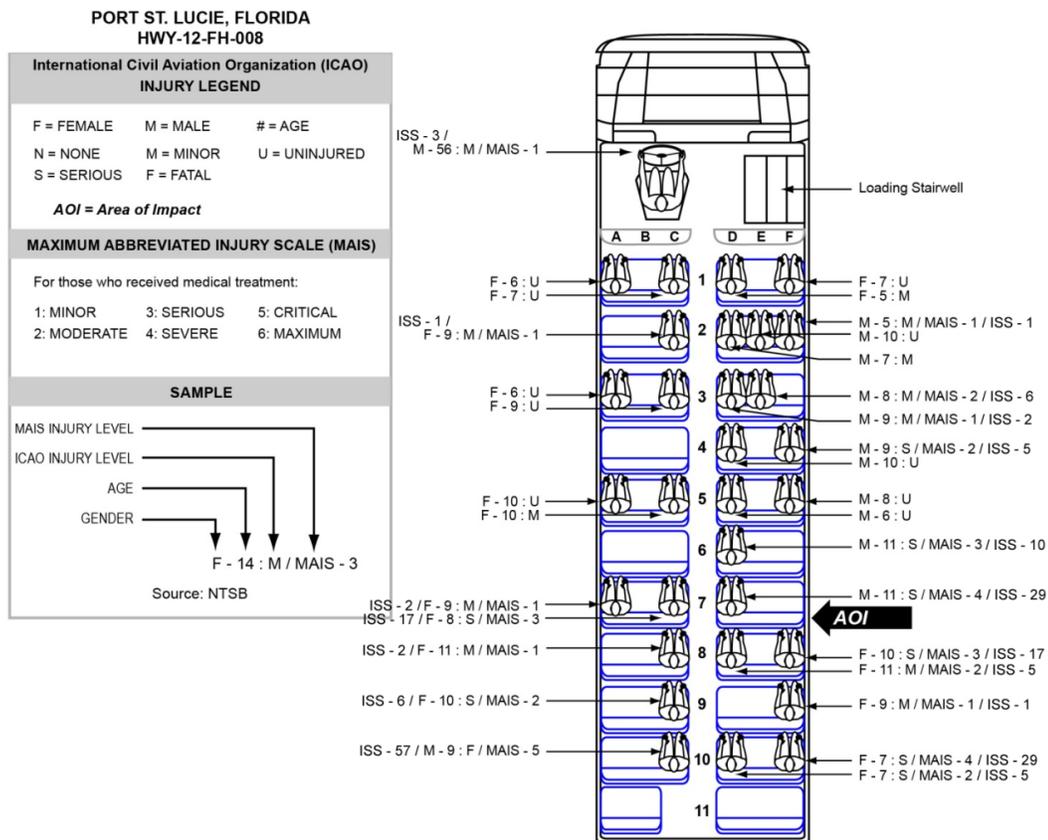
The most beneficial data obtained from the onboard video system were related to the crash sequence and the post-crash environment. The four interior cameras remained in place and functional throughout the crash event and continued recording for over 15 minutes after the initial impact.

Crash Sequence and Post-crash Events as Determined from Video Systems

Impact occurred at 15:55:03 and the bus came to final rest almost 10 seconds later. During the motion to final rest, the bus yawed approximately 180 degrees and experienced two large roll events. The first non-occupant to enter the school bus was an adult female who entered the bus at time 15:55:28 through the open rear emergency exit door and provided assistance to occupant 10D about 15 seconds after the bus came to final rest. She continued to provide assistance to the bus occupants until the end of the video recording, which stopped at 16:10:07. The first uniformed officer boarded the school bus about 3 minutes and 22 seconds after the bus came to final rest and emergency medical services arrived about 8 minutes and 22 seconds after the bus came to final rest.

Seating Chart and Injuries

The seating chart established based on the continuous onboard video system is shown in **Figure 3**. All occupants are marked with the ICAO code. For those occupants with medical records, the maximum AIS level and the ISS score are also documented. In addition, occupant gender and age are listed. Seating positions were labeled based on the seat row (1-11) and the seat position (A-F from left to right as viewed from the back). The area of impact (AOI) is shown on the chart. Additional details on the injury documentation are included in the NTSB’s Highway Safety Report – Commercial Vehicle Onboard Video Systems. [11]



Belt Use

Belt use was visible for twenty-two occupants and of those, seven appeared to wear the lap belt loosely or slightly loosely (1D, 2C, 4D, 5C, 7D, 8D, and 8F), as determined by the visible tension in the belt and the motion of the occupant during the crash sequence. There were no observations showing a lack of belt use, however, belt use was not visible for eight occupants (3D, 3E, 4F, 5A, 5F, 10C, 10D, and 10F) due to the obstructions of the seatbacks and the occupant's seating distance from the onboard cameras.

Occupant Position Relative to Seat Compartment Post-crash

Twelve occupants were ejected from their seat compartment during the crash sequence (1C, 1D, 2C, 2D, 3C, 3D, 4D, 5A, 5C, 9C, 10C, and 10D). All of these occupants, except occupant 5A, were initially seated along the aisle and most were ejected into the aisle post-crash despite wearing the lap belt. Occupant 5A was ejected into the aisle and then backward into seat row 6, on the driver side of the bus. Belt use was not visible for occupant 5A due to the camera positions and obstructions from the seatbacks. Other occupants (7C, 7D, 8C, and 8D) were not considered to be ejected from the seat compartment but it was noted that the occupants' heads and upper torsos flailed outside the seating compartment into the adjacent seating compartment across the aisle during the crash sequence.

Occupant-to-Occupant and Occupant-to-Interior Impacts

There were nineteen documented instances of occupant-to-occupant impacts, 16 of which involved an impact of an occupant's head with either another occupant's head or other part of their body. All of the documented occupant-to-occupant contacts occurred for occupants in rows 2, 3, 5, 6, 7, 8, and 9. Generally, the occupants impacted other occupants within the same seating row, but in rows 5/6 and 8/9, impacts occurred between occupants originally seated in different rows. For example, occupant 5A's right torso was impacted by occupant 6D's head as occupant 5A traveled into the seat row behind and occupant 6D flailed in that direction. In rows 8/9, occupant 8F's body was pushed upward and rotated backward over the seatback such that occupant 8F's head impacted the chest and pelvis of the occupant seated directly behind (9F). (Occupant 8F's head also continued back and contacted the seat pan near occupant 9F's seating position.) Occupant 8F was lap belted and observations from the video showed the belt visible on the occupant's thighs. Occupants in row 1 interacted with each other but specific impacts between occupants were not noted. Occupants in row 10 were generally not visible due to the camera positions and the obstruction from the high seatbacks.

There were also nineteen documented instances of occupant-to-interior impacts. Nine of these involved an impact of the occupant's head onto a passenger side window or sidewall structure (2F, 3E, 4F, 5F, 6D, 7D, 8D, 8F, and 9F) and one other involved an impact of the occupant's head with a driver side window and sidewall structure (3A). All of these occupant-to-interior impacts were sustained by occupants seated against the sidewall or in a position without other occupants between them and the sidewall, except in row 8 where both occupants on the right side of the bus impacted the sidewall. The other occupant-to-interior impacts involved impacts onto the seat pans and the aisle-side edges of the seatbacks.

Loss of Consciousness and Head Injuries

Loss of consciousness (LOC) was observed in seven occupants (3E, 6D, 7C, 7D, 8D, 8F, and 10C). The state of consciousness was unknown for three other occupants (8F, 10D, and 10F) who were not visible post-crash. The other twenty occupants were conscious post-crash. Of those occupants with an observed LOC, only occupant 6D remained unconscious at the end of the video recording. (Occupant 10C was documented with a LOC but was the fatally injured occupant.) In addition, recorded audio discussions between the adult female and emergency medical responders indicate that occupant 10F was conscious at the end of the recording.

Head injuries were documented on the medical records for twelve occupants (2F, 3E, 6D, 7A, 7C, 7D, 8D, 8F, 9C, 10C, 10D, and 10F) including six who were diagnosed with only a concussion (3E, 7A, 8D, 8F, 9C, and 10D). All seven occupants with an observed LOC had a documented head injury. As expected from the dynamics of the bus, the majority of the head injuries were seen in occupants seated in the back half of the bus. For the two front seated occupants with head injuries, the sustained injuries were less severe. For example, occupant 2F was diagnosed with a head injury that was not further specified and occupant 3E was diagnosed

with a concussion with LOC. In the back half of the bus, the head injuries were more severe, especially for occupants in rows 6, 7, and 10. Occupant 6D's head injuries included cerebral contusions, a cerebral hematoma, a subdural hemorrhage, a mastoid fracture, and a skull fracture. Head injuries to occupant 7C included a cerebral subarachnoid hemorrhage and left and right intraventricular hemorrhages. For occupant 7D, head injuries included comminuted basilar skull fractures on the left and right sides, a temporal bone fracture, and left and right cranial nerve VII palsy. Interestingly, the head injuries to occupants in rows 8 and 9 were limited to only concussions and minor lacerations. Yet occupants in row 10 again experienced severe head injuries. Occupant 10C, who was fatally injured in the crash, sustained bilateral cerebral edemas, multiple cerebral subarachnoid hemorrhages, and a skull fracture. Occupant 10F sustained a cerebral subdural hematoma.

Evacuation

Nineteen occupants self-evacuated out the front loading door (1A, 1C, 1D, 1F, 2C, 2D, 2E, 2F, 3A, 3C, 3D, 4D, 4F, 5A, 5C, 5D, 5F, 7A, and 9F). Eighteen of those self-evacuated in 60 seconds or less, from the time the bus came to final rest. Another four occupants were assisted out the rear emergency exit door (8C, 8D, 9C, and 10D). Occupants 3E, 6D, 7C, 7D, 8F, 10C, and 10F remained on the bus at the end of the video recording. Occupant 10D was the first occupant removed from the school bus with assistance by the adult female at 15:55:33, which was about 20 seconds after the bus came to final rest. Occupant 1D was the first to self-evacuate out the front loading door at 15:55:43, 30 seconds after final rest. Occupant 7A was the last to self-evacuate out the front loading door at 15:58:12, almost 3 minutes after final rest. Occupant 8C was the last occupant removed with assistance before the video recording ended, at 15:58:39, about 3.5 minutes after final rest.

Injury Factors in Self-Evacuation: None of the occupants with an observed LOC were able to self-evacuate. Most occupants with a LOC regained consciousness during the period of the video recording but only occupant 8D was evacuated off the bus with assistance. The remaining occupants with an observed LOC were on the bus at the end of the recording, which was almost 15 minutes after the bus came to final rest.

Five occupants sustained pelvis and/or lower extremity fractures as a result of the crash (4F, 7C, 7D, 8F, and 9C). The sustained pelvic/lower extremity fractures were a closed left ankle fracture for occupant 4F, a right pubic fracture for occupant 7C, a pelvic ring fracture at the anterior iliac spine for occupant 7D, a right talus fracture for occupant 8F, and pelvic fractures at the sacral spine and at the right ramus through the pubic symphysis for occupant 9F. Of the occupants that sustained a pelvic/lower extremity fracture, three also experienced a LOC and a documented head injury (7C, 7D, and 8F). In addition, occupant 9C sustained a concussion without LOC, as discussed above. Only occupant 4F sustained a lower extremity fracture without a head injury or LOC and this occupant was able to self-evacuate 48 seconds after the bus came to final rest.

Spinal injuries were rare. (The driver, although not a focus of this paper, sustained a cervical spine sprain, or whiplash, and a lumbo-sacral spine strain.) Occupant 3D sustained a cervical spine sprain (whiplash) and occupant 10D, the fatally injured occupant, sustained a cord laceration with fracture and dislocation at C7-T1. Except for the fatally injured occupant, the minor spinal injuries did not affect evacuation.

Occupant Kinematics

Using the "Front" camera, the head positions of occupants 2C, 3C, and 3E and the pelvis position of occupant 3C were tracked in the bus based coordinate system. The lateral position versus time history can be seen in *Figure 4*, where the lateral centerline of the bus is zero and motion toward the driver side is in the positive direction. The lateral distance from the bus centerline to the sidewall was 1.17m and is labeled on the graph.

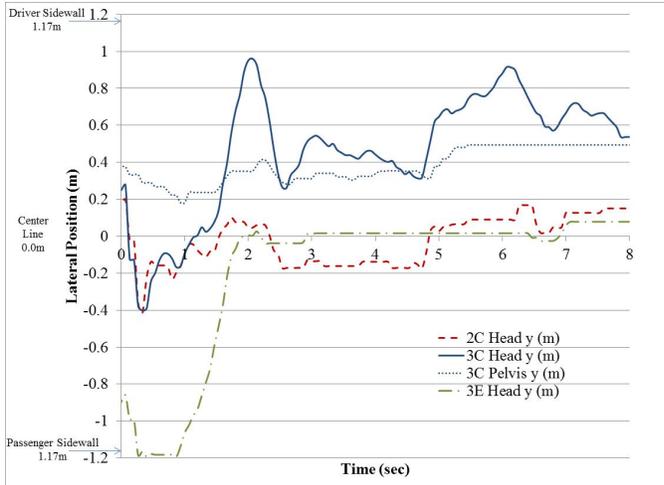


Figure 4. The lateral (y axis) head position of occupant 2C, 3C, and 3E and the lateral pelvis position of occupant 3C.

Using the “Mid” camera, the head positions of occupants 6D, 7A, 7C, and 7D and the pelvis position of occupant 6D and 7D were tracked. The lateral position versus time history can be seen in *Figure 5*.

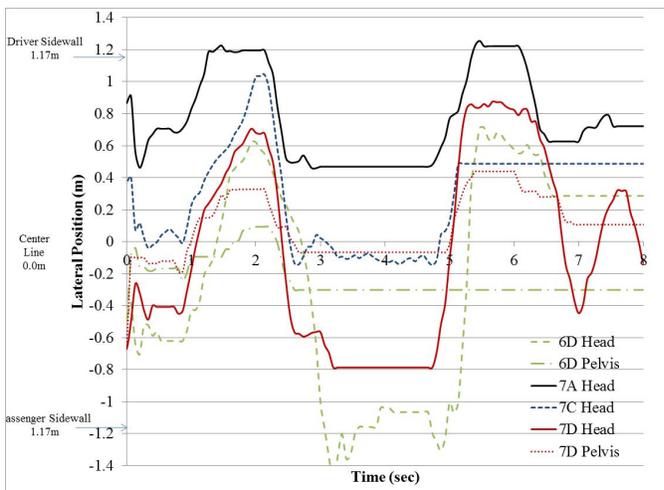


Figure 5. The lateral (y axis) head position of occupant 6D, 7A, 7C, and 7D and the lateral pelvis position of occupant 6D and 7D.

The position of the “Mid” camera did not remain stationary relative to the bus interior during the impact sequence. This relative motion between the camera and bus interior may have resulted from deformation at the floor and sidewall, camera orientation changes, or a combination of the two during the impact sequence. In an effort to document this relative velocity, four points fixed on the bus interior were tracked. The left sidewall experienced the least deformation and would, ideally, provide the best estimate of the camera velocity but since this sidewall moved out of the camera view for a portion of the impact sequence, points on the left sidewall were not tracked. Instead, the aisle-side position of seat 6C was used as a surrogate for the camera velocity since that seat was attached to the left sidewall and the floor underneath and experienced the least deformation of the interior points visible in the “Mid” camera.

Using this correction for the “Mid” camera, the maximum intrusion into row 7 was approximately 0.48m during the first 0.13 seconds with a recovery of 0.12m during the next 0.13 seconds. Similarly, the maximum velocity of the right sidewall in row 7 was 2.41 m/s and the maximum velocity of the aisle-side point on seat 7D was 3.50 m/s at 0.13 seconds. Note that these velocities are lower bounds on possible velocities because the calculation is limited by the video frame rate. Maximum displacement could have occurred between frames and not captured until the subsequent frame, 67 milliseconds later, which would reduce the calculated velocity.

Although the bus motion involved both translation and rotation, the initial occupant motion was predominantly lateral with some longitudinal components. Since the camera orientations were perpendicular to the lateral plane, motion in the lateral direction was well quantified. Table 1 summarizes the lateral head velocity at impact or immediately prior to impact along with a snap shot of the qualitative description of the occupant motion [12] at that time, during the initial motion toward the passenger sidewall. Note that all the velocities are negative indicating motion toward the passenger side of the bus.

Table 1.
Lateral head velocity immediately prior to or at the estimated time of the head contact from the video observations.

Occupant	Time (sec)	Lateral Head Velocity (m/s)	Qualitative Description of Occupant Motion
2C	0.267	-2.96	Torso reaches maximum articulation onto seat 2D with back nearly horizontal across aisle, shoulders are completely obscured behind the seatback of row 1
3C	0.133	-3.04	Upper body is fully articulated across aisle, occupant 3C’s head on seat 3D (behind row 2 seatback)
3E	0.133	-0.98	Head shifts towards window and sidewall moves towards head due to the impact, face is either making contact or about to make contact with lower portion of window
6D	0.133	-4.21	Occupant 6D flails completely to the passenger side, head impacting sidewall below window (sidewall was deforming toward occupant 6D)
7A	0.133	-5.43	Head of occupant 7A impacts the posterior hips of occupant 7C
7C	0.133	-5.34	Occupant 7C’s head near or in contact with left postero-lateral aspect of 7D’s torso
7D	0.133	-0.13	Occupant 7D’s head remains in essentially the same position relative to the camera as before the impact but due to the sidewall intrusion, the head and right shoulder are now in contact with the passenger side sidewall

DISCUSSION

This onboard video recording analysis utilized first of its kind data to describe the qualitative and quantitative kinematics of pediatric school bus occupants during a crash and related their movement to crash dynamics and injury outcomes. Being able to visualize living human movement in a crash setting provided insight into the magnitude of excursion capable from a restrained occupant, the flexibility without injury that children demonstrate, and the temporal nature of concussion.

Injury severity was highest for occupants in rows 6-8 and also in row 10. Likely, injuries were greatest in rows 6-8 because that was the region of impact and the area of maximum intrusion along the right passenger sidewall. In row 10, accelerations were the greatest in this region due to the dynamics of the bus as it pivoted about the front axle as a result of the side impact near the passenger side rear axle. These high accelerations likely resulted in the severe injuries for occupants in row 10.

The injury severity score (ISS) varied from 1 to 6 in the front of the bus. In the rear of the bus, the ISS ranged from 1 to 57 and included several mild to moderate traumatic brain injuries. Lateral head translations toward the point of impact in the front of the bus were similar to those in the rear during the initial impact, but the head translation for occupants in the rear of the bus was greater during the secondary and tertiary rebound motions toward each side of the bus. Lateral head velocities were generally higher in the rear of the bus except for occupant 7D who essentially did not move relative to the “Mid” camera. Instead, the sidewall intruded directly into his seating compartment and impacted his head and right shoulder before he began to flail toward the impact point. In the front of the bus, the lateral velocities of occupants’ heads ranged between -0.98 and -3.04 m/s, but in the rear of the bus the maximum lateral velocities of occupants’ heads were almost twice as high, ranging from -0.13 to -5.43 m/s.

Further, the magnitude of whole body pediatric occupant motion in the absence of injury was notable. For example, occupant 8F bent backward over the top of her seatback such that her head impacted the chest and pelvis of the occupant (9F) seated directly behind her. Her head continued downward, impacting the seat pan of seat 9F, as well. Her thighs were still restrained by the lap belt, which had slid down during her vertical translation and backward rotation. Despite this extreme hyper-extension, occupant 8F did not sustain any spinal injuries and her torso injuries consisted of only a lung contusion to the right middle and lower lobes and a right 7th rib fracture.

LOC had a noticeable effect on the ability for occupants to self-evacuate. Occupants with an observed LOC were not able to self-evacuate, even if they regained consciousness post-crash. Obviously, maintaining occupants’ consciousness during the crash is critical to a timely evacuation, especially for post-crash environments that may involve water immersion or fire. Impact onto intruding sidewall and window surfaces, along with upper body flailing enabling occupant-to-occupant impacts, was likely the main cause for the occupants’ LOC. Reducing the upper body flailing could be accomplished with greater upper body restraint, such as with a properly adjusted lap/shoulder belt. [13] Reducing the severity of impacts onto sidewall and window structures could be accomplished with school bus performance standards that address passenger protection for sidewalls, sidewall components, and seat frames, as first recommended by the NTSB in 2001. [14]

Other injuries, such as pelvic or lower extremity fractures, did not appear to negatively impact evacuation, if the injury was sustained by an occupant without a head injury or LOC. Spinal injuries, which may also reduce the ability to self-evacuate, were rare in this crash.

The study was limited by the resolution of the camera system and the frame rate, which was relatively low given the dynamics of the crash. The calculation of the vehicle dynamics was also limited due to the lack of a forward-facing camera. In addition, due to the high seatbacks on the school bus, occupants were not visible at all times during the crash sequence. Further, because concussions were not coded if the patient had LOC with any intracranial hemorrhage, the estimated number of concussions may be conservative. (For example, there may have been other occupants who had concussion and did not experience a visible LOC, but there was insufficient medical record documentation of symptoms or diagnosis). Additionally, there was variability in the available medical records for injured patients (for example, detail of radiographic imaging and reports and medical record documentation). As a result, some injuries may have not been captured. Similarly, there may have been occupants who did not seek medical attention, but who may have had minor injuries (for example, contusions, lacerations, and/or mild sprains).

The qualitative and quantitative descriptions represent the first time that lap-belted school bus pediatric occupant motion has been documented from onboard video recordings. The correlation of occupant kinematics with crash severity and injury outcomes was also unique. Ultimately, research using onboard video data from school buses can be a basis for a multidisciplinary approach to improving occupant safety.

CONCLUSIONS

The documentation of real-world lap-belted pediatric occupant kinematics in a severe side impact crash based upon video and audio recordings combined with medical records provides unique information to evaluate realistic pediatric occupant kinematics and provide data unable to be found elsewhere to evaluate ATD biofidelity. This information also provides unique insight into injury mechanisms and outcomes.

The continuous video system offered the first such documentation of lap-belted children involved in a severe side impact collision. The videos further highlight differences in occupant kinematics across a range of collision severities, which were evident when contrasting occupant motion in the front of the bus with occupant motion in the rear of the bus. Because of the length of the school bus and the center of rotation at the front axle, the crash was much more severe for rear-seated occupants than for those seated in the front of the bus.

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