

Headform Impact Tests to Assess Energy Management of Seat Back Contact Points Associated with Head Injury for Pediatric Occupants

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ABSTRACT

Head injuries are the most common injuries sustained by children in motor vehicle crashes regardless of age, restraint and crash direction. Previous research identified the front seat back as relevant contact point associated with head injuries sustained by restrained rear seated child occupants. The objective of this study was to conduct a test series of headform impacts to seat backs to evaluate the energy management characteristics of relevant contact points for pediatric head injury.

A total of eight seats were tested: two each of 2007 Ford Focus, Toyota Corolla, 2006 Volvo S40, and 2008 Volkswagen Golf. Five to six contact points were chosen for each unique seat model guided by contact locations determined from real world crashes. Each vehicle seat was rigidly mounted in the center track position with the seatback angle adjusted to 70 degrees above the horizontal. A 3.5 kg child pedestrian headform was fired at a velocity of 24 km/h (6.67 m/s) in accordance to FMVSS 201 at 22 degrees above the horizontal starting from 10 cm from the center of the target. Resultant acceleration and HIC (15 ms and 36 ms) were calculated for each impact.

Within the class of small family vehicles, there was substantial variation in underlying seat structure across the locations of head impact identified in the case series resulting in a wide range of maximum resultant head acceleration - 27-165 g. Several impact locations, particularly those around the edge of seat back resulted in head acceleration greater than 80g used in regulatory tests. These data highlight the need to re-examine the current FMVSS 201, Occupant Protection in Interior Impact, to account for the typical impact locations of child occupants in crashes. In addition, further study is needed to understand the tolerance of the pediatric skull and brain to these types of impacts.

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INTRODUCTION

Head injuries account for about one third of all fatalities of children involved in motor vehicle crashes (MVC) [1] and are the most common serious injuries sustained by children in MVC regardless of crash direction. [2, 3, 4, 5] These injuries are of critical importance with regard to long-term disability. Such outcomes include persistent neuropsychological sequelae including altered behavior and diminished academic achievement, increased family strain and burden of care, and quality of life similar to pediatric oncology patients, all extending for years following the injury event. [6, 7, 8, 9, 10, 11, 12]

Although studies have been conducted to analyze crash-related brain injuries, the association of head contact with brain injury has only recently been investigated. These studies have identified head contact as necessary to the cause of head injuries in a majority (>95%) of adult occupants, suggesting that to produce the level of deceleration associated with head trauma, the head must be stopped by contact with a structure such as the vehicle interior. [13] Yoganandan *et al.* analyzed severe-to-fatal head injuries in motor vehicle crashes using the Crash Injury Research Engineering Network (CIREN) database. In the majority of the cases reviewed the instantaneous change in velocity (delta V) was below Federal Motor Vehicle Safety Standards (FMVSS)



Figure 1. Ford Focus, Toyota Corolla, Volvo S40, VW Golf

limits suggesting that in order to obtain the head deceleration needed to cause injury, head contact was necessary. In another study performed by Yoganandan *et al.*, CIREN data was used to analyze forty-one adult occupants of varying age with diffuse axonal injuries. Head contact was identified in all frontal, rear and far side crashes, and all but one of the nearside crashes (>95% of cases). [14] Our previous research has identified injury causation scenarios for rear seated, restrained child occupants. [15] Specifically, the role of contact to the seat back and to the vehicle side interior structure has been highlighted and a contact map developed that quantifies the locations of head contact. [16]

Once contact locations are identified, mitigation of head injuries generally involves a reduction of the head velocity as it approaches the vehicle interior or a reduction in the intensity of the loads the head is subjected to during an impact. The reduction of head velocity is generally achieved through improvements of the restraint of the torso, while loads applied to the head can be attenuated through the introduction of an interposing structure between the head and the interior, such as an airbag or energy-absorbing padding. For the front seat, a frontal impact crash test using a crash test dummy (FMVSS 208, NHTSA's New Car Assessment Program, Insurance Institute for Highway Safety frontal offset tests) evaluates the effectiveness of seat belts and frontal airbags in mitigating head injury by evaluating the head injury criteria. The headform impact test (FMVSS 201) allows assessment of energy management when a head-like structure contacts the vehicle interior. Together, these tests provide a comprehensive head injury mitigation approach to the front seat.

In the rear seat, however, a similar a comprehensive head injury mitigation approach is not provided, especially for child-sized occupants. Child restraint systems and booster seats are evaluated using a sled test program (FMVSS 213) where head excursion limits are imposed but many rear seats in actual vehicles do not provide the minimum excursion space in FMVSS 213 so head contact in some combinations of vehicle, front seat position and crush pulse is almost

guaranteed. [17] In addition, the headform impact test (FMVSS 201) does not test the full range of rear row interior points on which a child occupant's head might impact, and thus the ability of the rear seat interior to reduce impact loads to the head is unknown.

Therefore the objective of this study was to conduct a test series of headform impacts to seat backs to evaluate the energy management characteristics of relevant contact points for pediatric head injury.

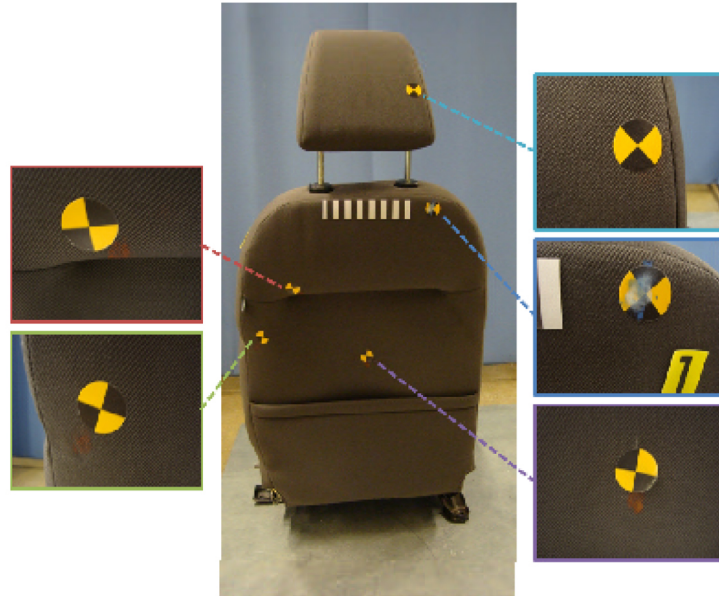
METHODS

In order to explore the energy management features of vehicle seat backs (a site of head contact as determined in a case review of head injuries sustained by child occupants (Arbogast et al, in review)), a small set of vehicles were chosen for a headform impact test series. Vehicles were chosen from a pool of small family sedans. The specific seat models to be tested were selected to ensure variability in the underlying seatback structure in order to demonstrate a wide variety of potential contacts. A total of eight seats were tested: two each of 2007 Ford Focus, Toyota Corolla (exact model year unknown but less than 5 years old), 2006 Volvo S40, and 2008 Volkswagen Golf. The seats were salvaged from full-vehicle crash tests or scrap yards, and thus were not new at the time of testing.

Five to six contacts were chosen for each unique seat model guided by the contact maps from the case review (Arbogast et al, in review). Generally, a target was placed on the top right corner of the seatback, the upper center and/or the left or right seatback, the left side structure, the mid-center of the seatback, and the right headrest. Chosen contact positions were marked with targets. [Figure 1](#) indicates the impact locations on each seat.

Each vehicle seat was rigidly mounted in the center track position with the seatback angle adjusted to 70 degrees above the horizontal. A 50th percentile male Hybrid III anthropomorphic test device (ATD) was positioned in the seat to represent a front seat occupant. The lower legs and of

Ford Focus:



Note: the impact on the right headrest did not involve a painted headform and therefore there is no paint mark

Figure 2. Impact locations for each seat used in the test series. The target location is indicated by the marker and the actual location is indicated by the paint mark.

the ATD were removed due to limited space, reducing the overall weight of the ATD from 78.3 to 66.9 kg.

A 3.5 kg child pedestrian headform (Humanetics Innovative Solutions, Plymouth, MI) represented the head of a pediatric occupant seated in the rear seat of a vehicle. The headform was fired at a velocity of 24 km/h (6.67 m/s) in compliance with headform impact testing in US FMVSS 201.

Prior to firing, the headform was positioned 22 degrees above horizontal and a distance of 10 cm from the center of each target. The distance was chosen to meet the velocity requirements and ensure that gravity did not significantly alter the trajectory of the headform during free-flight. Paint was applied to the headform so that exact contact location on the seatback could be determined. High speed cameras positioned to the rear and on either side of the seatback recorded the impacts.

Before each test, seatback angle, distance from the ATD head top to vehicle seat headrest seam, and distance from ATD forehead to front plate were measured. If the seatback or dummy experienced any change in position in response to headform impacts, it was repositioned to duplicate the measurements at the beginning of the test series. A time period of approximately 10 minutes occurred between consecutive impacts (to different locations) on each seat.

Resultant headform accelerations-with time zero adjusted to 5% of the maximum resultant acceleration-and Head Injury Criteria (HIC) values (15 msec and 36 msec) were calculated for each test. Values were compared for identical seats and for similar contact locations across all seat models. After testing of each seat was complete, pictures were taken of the

contact locations, and one seat of each type was cut apart to allow for photo documentation of the underlying structure and examination for any damage.

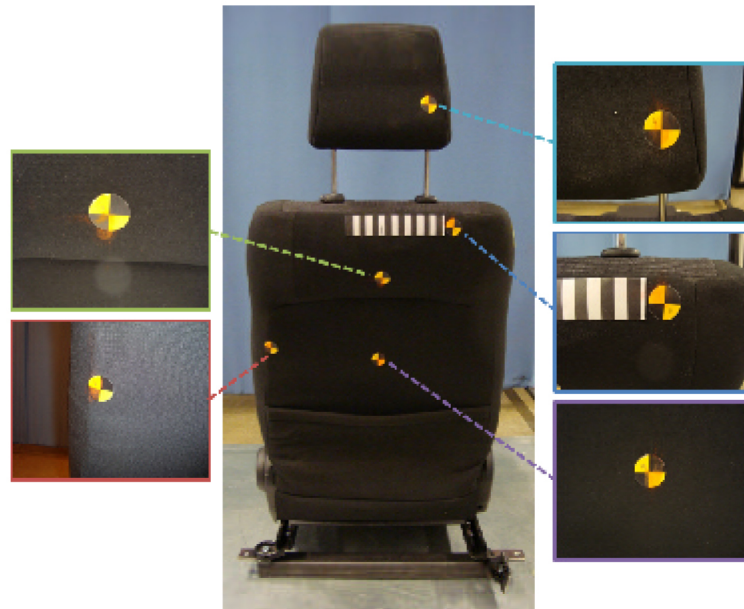
RESULTS

The headform impact test series resulted in consistent impacts to the desired locations. Figure 2 shows the contact locations for each impact indicated by the paint marks. All seats received an impact on the structural portion of the headrest, the center (non-structural) of the seat back, the lateral structure of the seatback, and the upper center structure of the seat back. The remaining 1 or 2 impact points for each seat were chosen in order to load other important structures on that particular seat design.

Each impact was repeated on another seat of the same make and model. The within make-model comparison is shown in Figure 3. The Toyota and Ford seats were very repeatable in their responses except for the contact location in the center of the seat back where there is little structure. The Volvo and Volkswagen were less repeatable when comparing repeated contacts to similar locations.

The resultant acceleration of similar contact locations across seat types were compared (Figure 4).

Toyota Corolla:



Volvo S40:

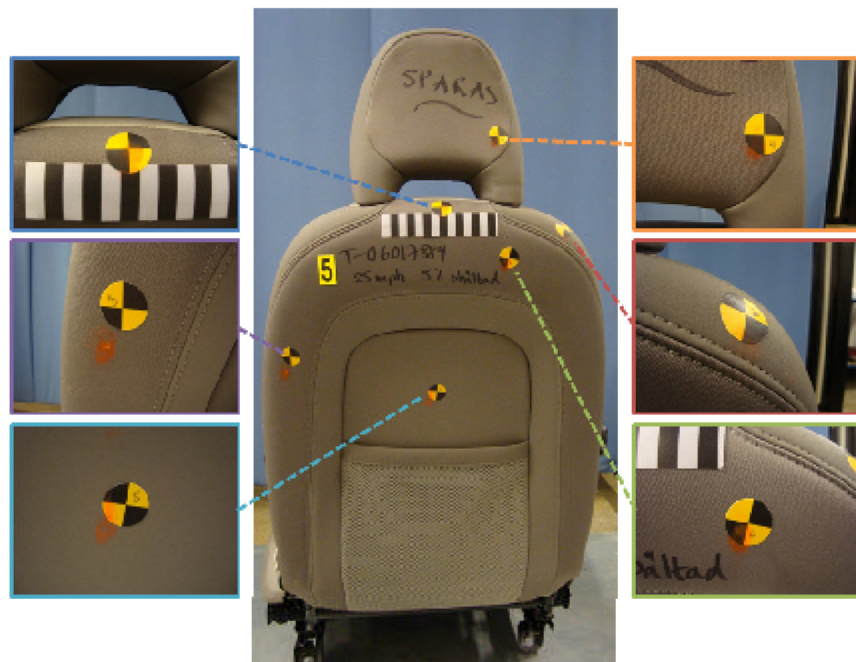


Figure 2 (cont'd). Impact locations for each seat used in the test series. The target location is indicated by the marker and the actual location is indicated by the paint mark.

Volkswagen Golf:

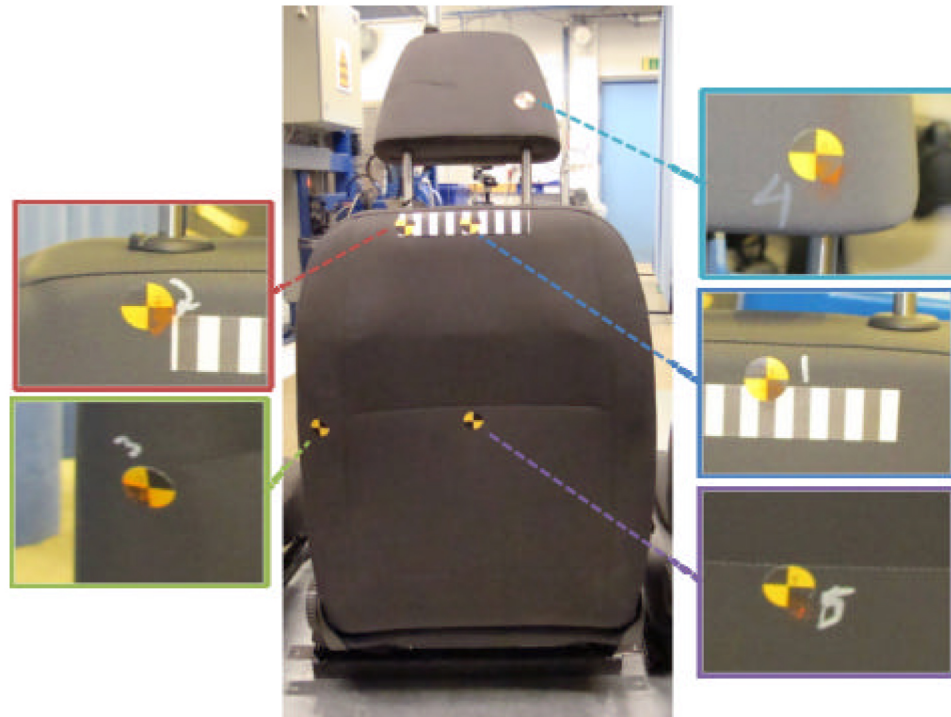


Figure 2 (cont'd). Impact locations for each seat used in the test series. The target location is indicated by the marker and the actual location is indicated by the paint mark.

The resultant head acceleration, 3-ms clip head acceleration, HIC 36, and HIC 15 for all vehicle seats and all impact locations is presented in [Table 1](#), [2](#), [3](#), and [4](#) respectively. Resultant acceleration values ranged from 27.0 g for the mid-center seat back for the Volvo to 164.8 g for the top right corner seat back for the Toyota. 3 ms clip head acceleration values ranged from 26.5 g for the mid-center seat back for the Volvo to 72.2 g for the upper center seatback of the VW Golf. The location of maximum head acceleration for the Ford Focus and Toyota Corolla was either the impact to the top right corner or that to the mid-center. The Volvo demonstrated general consistency across all impact locations. For the Volkswagen, both impacts to the upper structure of the seat back resulted in high accelerations. Due in part to the short time duration of the impacts, the resultant HIC from these accelerations were relatively benign. HIC36 ranged from 44-123 and HIC 15 ranged from 42-254.

There was substantial variation in underlying seat structure across the locations of head impact identified in the case series. No damage was observed in any impact location for any of the seats tested. ([Figure 5](#))

DISCUSSION

Previous research identified the front seat back as relevant contact point associated with head injuries sustained by restrained rear seated child occupants. In this study, a test series of headform impacts to seat backs was conducted to

evaluate the energy management characteristics of relevant contact points for pediatric head injury. The headform impact tests series demonstrated that the response varied with the underlying structure. The resultant head acceleration for all vehicle seats and all impact locations ranged from 27-165 g.

The current federal motor vehicle safety regulation governing interior occupant protection - FMVSS 201 - prescribes an impact to area of the seatback within the head impact area by a 6.8 kilogram, 165 mm diameter head form at a relative velocity of 24 kilometers per hour. The deceleration of the head form shall not exceed 80g continuously for more than 3 milliseconds. The head impact area is defined differently for seats with and without head restraints. For seats without head restraints, impacts are conducted at points within 100mm on either side of the seat centerline. For seats with head restraints, impacts are conducted with the head restraint at its lowest position at a point on the head restraint centerline. Impact direction can either be along a plane parallel to the vehicle longitudinal axis or normal to the surface at the point of contact. [[18](#)]