Technical challenges in replicating serious head injuries in a dynamic rollover test

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Abstract

The complexity of a dynamic rollover test poses many challenges in the evaluation of its outcome and the prediction of serious injuries. The choice of an anthropomorphic test device (ATD), its initial position, restraint method, and included instrumentation can all affect the measurements made during a test. Further, impacts sustained by an ATD may not necessarily be representative of real world scenarios due to inconsistencies in its biofidelity compared to a human. The results of dynamic rollover tests, performed using different devices including the Jordan Rollover System (JRS), were analysed to determine how different methods of test setup and vehicle performance affected the measured head response of an ATD. The head contact locations of the ATDs were compared to the head injury locations of occupants in rollover crashes collected from the National Automotive Sampling System's Crashworthiness Data System (NASS CDS). The results indicate that pre-test ATD positioning and in-test ATD movement are the most important factors with regard to head response. Overall the results indicate that the methods and instrumentation, including the ATD, previously used for conducting dynamic rollover tests on the JRS may not be adequate to produce and measure ATD head response that is both indicative of serious head injury and empirically sound.

Introduction

In Australia head injury is described as a contributing cause of death (COD) for approximately 45 % of all fatally injured contained and restrained occupants involved in single vehicle rollovers (Fréchède et al., 2011). In the United States serious head injuries are sustained by approximately 21 % of seriously injured occupants in pure trip-over rollover crashes (Mattos et al., 2013a). Distinct injury patterns, including location of head contact, concomitant injuries, and vehicle roof performance have been noted for occupants sustaining serious head injury in pure rollover crashes (Hu et al., 2005; Mattos et al., 2013a, 2013b, 2014; Ridella et al., 2009). Serious head injuries in rollover crashes appear to be almost exclusively the result of direct impacts between the head of the occupant and interior roof structure (Mattos et al., 2013a, 2013b, 2014; McLean, 1995; Ridella, 2008) which is consistent with other crash modes (Got et al., 1983; Yoganandan et al., 2010) and head injury criteria (Prasad et al., 1985).

Historically, rollover tests have been conducted with the primary goals of studying vehicle structural response, occupant kinematics, or the performance of restraints and countermeasures (Chou et al., 2005). Injury assessment has typically been a secondary concern in these tests which is partially due to a lack of an appropriate ATD and injury criteria for the rollover crash mode. The authors are currently unaware of any dynamic test protocol that has been specifically chosen to replicate the vehicle kinematics of a rollover crash that resulted in a serious injury. Existing dynamic rollover tests and protocols have been chosen either arbitrarily to facilitate comparative analysis by ensuring a rollover, to produce significant roof crush, or to replicate a portion of a previously performed dynamic test (Friedman et al., 2006; Kerrigan et al., 2013; Moffatt et al., 2003; SAE, 1967; Viano et al., 2009). Others have selected a protocol based on average trip conditions of real world rollovers (Asay et al., 2010; Croteau et al., 2010). The main goal of the Dynamic Rollover Occupant Protection (DROP) project is to define a test procedure(s), based on serious injuries, that can assess a vehicle's safety performance in a rollover crash (Grzebieta et al., 2013a).

This paper will present observations of head impact characteristics and the resulting measured response in relation to the test method used. The three aspects defined by the test method that will be investigated are the setup and impact conditions (including ATD positioning), measurement method, and method of assessing outcomes.

Methods

The results of dynamic rollover tests, obtained directly from the test facility or via published literature or online, in which the kinematics of the head were measured by a restrained ATD, were analysed for this study. The ATD and vehicle response measures that were collected included head centre of gravity (CG) tri-axial linear acceleration and angular velocity, upper neck axial force, and roof deformation measurements. The method of restraint, initial position, and headroom of the ATD were noted in each test. All significant head impacts, defined as direct contact to the head resulting in peak linear accelerations greater than 20 g, and confirmed by high speed interior video, or greater than 50 g, without video confirmation, were analysed. High speed interior video, where available, was used to determine the location of each significant impact.

Raw test data was available for dynamic rollover tests conducted using the Jordan Rollover System (JRS) (Bish et al., 2008), the JRS-II (Grzebieta et al., 2013b), the National Highway Traffic Safety Administration's (NHTSA) rollover test device (RTD) (Segal et al., 1983; Yaek et al., 2010), the SAE J2114 rollover dolly (SAE, 1999), and a selection of curb-, soil-, and ramp-trip tests. The curb-, soil-, and ramp-trip tests will be referred to collectively as 'Trip-tests.' The raw data and videos for the JRS tests were provided by the Center for Injury Research (CFIR). All other raw data and videos for the aforementioned tests were downloaded from NHTSAs vehicle crash test database (NHTSA, 2014). The remaining test data were obtained from results published by authors using the following test devices: the Controlled Rollover Impact System (CRIS) (Moffatt et al., 2003; Raddin et al., 2009), the SAE J2114 rollover dolly and drop tests (Bahling et al., 1990; NHTSA, 1999), and friction trip tests (Viano et al., 2009).

Test protocol, including ATD positioning, vehicle modifications, countermeasure deployment, and test conditions varied between and within test devices. Tests conducted with the CRIS and J2114 dolly used production and reinforced vehicles. Countermeasures such as side curtain airbags and seat-belt pretensioners were deployed in some JRS, J2114 dolly, and Trip-tests. Headliners were removed in most CRIS tests. In all tests, except for seven conducted with the JRS, the ATD was positioned according to the Federal Motor Vehicle Safety Standard (FMVSS) 208 (NHTSA, 1972). Slack was introduced to the lap belts of ATDs in some dolly and CRIS tests to replicate the amount of excursion experienced by live human volunteers. In the seven JRS tests with an out of position (OOP) far-side ATD the ATD was leaned toward the near-side door with a tether that released prior to impact. The far- and near-sides of a vehicle in a rollover are defined as those remote or adjacent to the direction of roll, respectively (i.e. the left side is the far side in a vehicle rolling to its right).

Tests conducted using the CRIS also used a tethering system for the ATDs that maintained their standard forward and lateral position until just prior to roof-to-ground impact.

Injury measures

The measures (Table 1) used to assess head injury include accepted injury assessment reference values (IARVs) as well as other proposed injury criteria. Injury criteria accounting for both linear and rotational motion of the head are analysed in this study as they have been shown to be the mechanisms responsible for various types of brain injuries (Gennarelli et al., 1972; King et al., 2003). Head injury measures for all significant head impacts were either calculated directly from raw data, when available, or transcribed from reported results.

The peak resultant linear acceleration, measured at the head CG, is likely the most frequently measured kinematic response of an ATD in crash testing. The Head Injury Criterion (HIC), which is calculated from the resultant linear acceleration, is also widely reported. Although these criteria are likely appropriate for assessing skull fracture (Vorst et al., 2003) they may not be appropriate for assessing serious brain injury (Newman, 1980). The calculation of HIC (NHTSA, 1972) is expressed as:

$$HIC = max\left[(t_2 - t_1)\left(\frac{1}{t_2-t_1}\int_{t_1}^{t_2} a(t)dt\right)^{2.5}\right], \qquad (1)$$

where $a(t)$ is the resultant linear head acceleration and t_1 and t_2 represent times, separated by no more than 36 ms, for which the HIC is maximised. For this study the maximum time interval $(t_2 - t_1)$ was taken as 15 ms as suggested by Prasad et al. (Prasad et al., 1985).

A skull fracture criterion (SFC) has been developed to predict skull fracture in anterior (forehead) and lateral (temporoparietal) head impacts (Vorst et al., 2004). The SFC, which is closely related to the HIC, is calculated as the average resultant linear acceleration of the CG of the head over the period of time of max HIC:

$$SFC = \frac{\Delta V_{HIC}}{t_2-t_1}, \qquad (2)$$

where

$$\Delta V_{HIC} = \int_{t_1}^{t_2} a(t)dt, \qquad (3)$$

and all values are defined as in (1).
The only injury measure included in this study that is solely associated with brain injury and based on angular motion of the ATD head is the Brain Injury Criterion (BrIC) (Takhounts et al., 2013). This measure is calculated as:

$$BrIC = \sqrt{\left(\frac{\omega_x}{\omega_{xC}}\right)^2 + \left(\frac{\omega_y}{\omega_{yC}}\right)^2 + \left(\frac{\omega_z}{\omega_{zC}}\right)^2}, \qquad (3)$$

where ω_x, ω_y, and ω_z are maximum angular velocities about the X-, Y-, and Z-axes, respectively, that result from an impact to the head. The critical angular velocities for each direction, ω_{xC}, ω_{yC}, and ω_{zC}, are defined as 66.25, 56.45, and 42.87, respectively.

No accepted injury criteria exist for assessing the likelihood of basal skull fractures in superior-inferior head impacts. However, some experiments have produced fractures of the occipital condyles similar to those observed in real world rollover crashes (Mattos et al., 2013a) in which peak head-contact forces in the range of 7.5 – 17 kN were recorded (Alem et al., 1984; McElhaney et al., 1995). ATD peak upper neck compressive axial forces, which are approximately equal to the head contact force in superior-inferior head impacts (Fréchède et al., 2009), are presented when available. These values are presented for reference, keeping in mind that head contact forces in drop tests using ATDs (Fréchède et al., 2009; Sances et al., 2002) are typically 3-5 times greater than in similar tests using post mortem human subjects (PMHS) (Viano et al., 2008).

Table 1. Injury measures and associated thresholds

Criterion	Injury type	Threshold values
Peak resultant linear acceleration	Skull fracture, brain injury	200 g (260 g), 10% (50%) risk of skull fracture; 100 g (162 g), 10% (50%) risk of AIS 3+ head injury (Mertz et al., 2003; Peng et al., 2013)
HIC	Skull fracture, brain injury	875 (1500), 10% (50%) risk of skull fracture; 875 (1400), 10% (50%) risk of AIS 4+ brain injury (Mertz et al., 2003)
BRIC	Brain injury	0.45 (0.87), 10% (50%) risk of AIS 3+ brain injury (Takhounts et al., 2013)
SFC	Skull fracture	120 g (135 g), 15% (50%) probability of fracture (Peng et al., 2013; Vorst et al., 2004)
Upper neck force	Skull base fracture	Reference only (Alem et al., 1984; McElhaney et al., 1995)

Results

General results

There were 115 significant head impacts recorded by 109 ATDs in 80 tests from which one or more head injury criteria could be calculated. All tests were conducted with Hybrid-III 50th percentile male ATDs except for two JRS tests that utilized Hybrid-III 5th percentile female ATDs (Table 1A). The vehicles experienced between 1 and 16 quarter turns with an average of 6 quarter turns. The duration of each test ranged from about 3 to 7 seconds. Roof intrusion above the seated position of each ATD ranged from 0 to 546 mm with an average of 160 mm.

The significant head impacts were slightly more common for ATDs seated on the near-side, 34 impacts for 27 ATDs, than on the far-side, 81 impacts for 82 ATDs. Twenty-one ATDs, 10 near- and 11 far-side, recorded multiple significant head impacts in tests using the J2114 dolly (14), RTD (6), and the CRIS (1). The vehicles in 19 of these tests experienced multiple roof inversions. There were 17 ATDs, 3 near- and 14 far-side, that did not record any significant head impacts; 14 of these were in curb-trip (5), ramp (5), or soil-trip (4) tests with deployed side curtain airbags. Eight of the nine ATDs in Trip-tests with deployed side curtain airbags and pretensioners did not record a significant head impact.

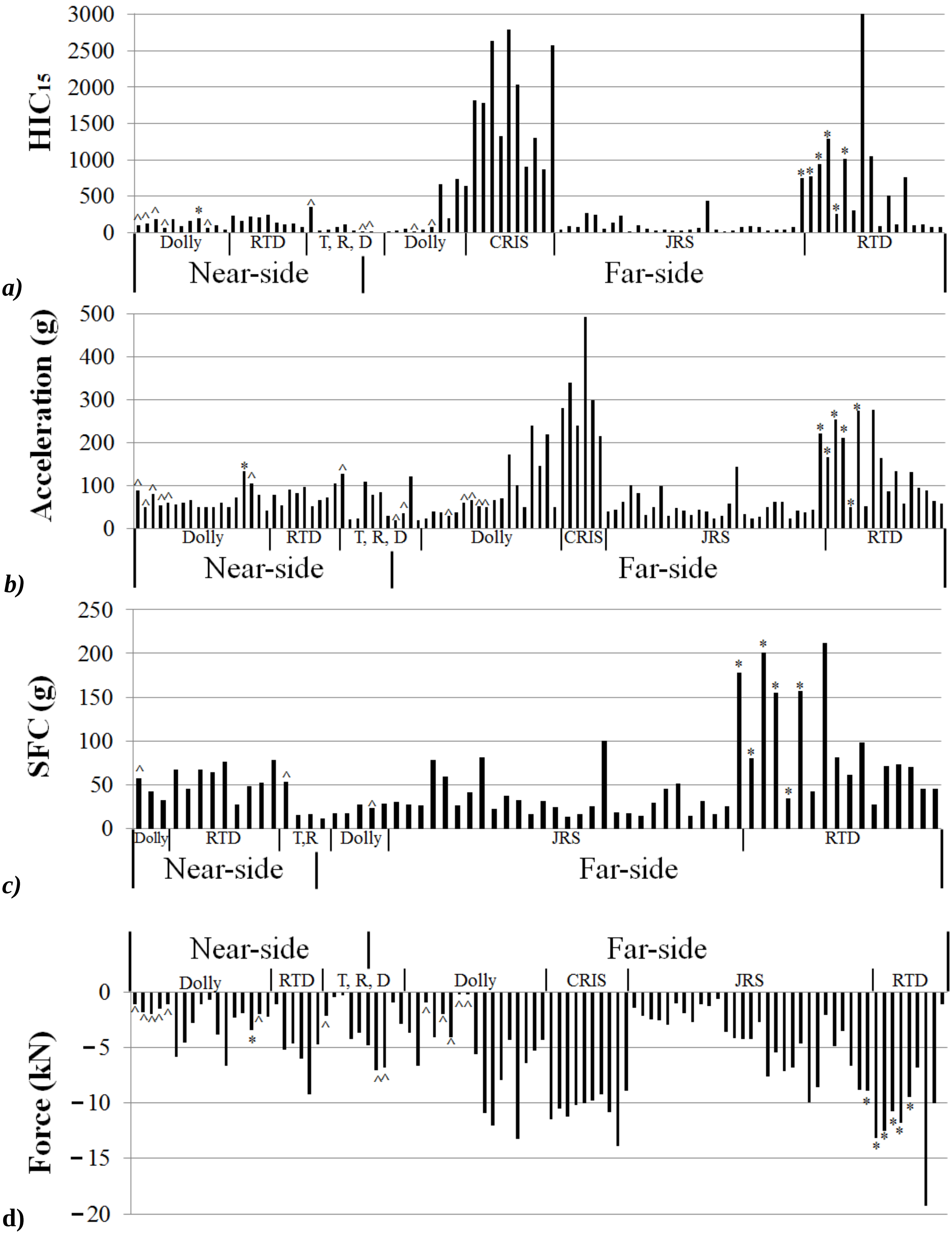

Figure 1. a) HIC; b) Peak resultant linear acceleration; c) SFC; and d) Peak upper neck axial compressive force (F_z) disaggregated by test device and ATD seat position

T, R, D denotes trip, ramp, and drop tests

^ denotes impact without a concurrent roof-to-ground impact

* denotes partial ejection

Injury measures

The HIC threshold value, 875, for a 10% risk of skull fracture or AIS 4+ brain injury was exceeded in 14 head impacts for 13 far-side ATDs in tests using the CRIS (9) and the RTD (5) (Figure 1a). Three of the five head impacts in the RTD tests were due to direct impact with the ground after a partial ejection. The average amount of roof intrusion for the CRIS and RTD tests for these impacts was 167 mm and 440 mm, respectively.

Twenty-six head impacts, for 23 ATDs (5 near, 18 far), measuring a peak resultant linear acceleration over 100 g were recorded (Figure 1b). Two of the five near-side head impacts were due to head impact with the adjacent window during either the initial curb trip or near-side tyre impact with the ground at the conclusion of the roll. Six of the impacts (5 far-side) were due to partial ejection.

Five head impacts were recorded that exceeded the SFC 15 % threshold for skull fracture for four ATDs (Figure 1c). All of these impacts also exceeded the HIC and peak resultant acceleration thresholds as mentioned above except for one: a partial ejection in a JRS test with HIC_{15} of 754.

The peak upper neck axial forces that occurred during significant head impacts are given in Figure 1d. The average peak force experienced by far-side occupants was twice (6.2 kN) that recorded by near-side occupants (3.1 kN). Average peak forces were greatest in tests conducted with the CRIS (10.6 kN) and RTD (8.4 kN) while tests performed with the JRS (4.3 kN) and dolly (4.0 kN) were similar. Tests performed with a tripping or dropping mechanism had the lowest average peak forces (3.3 kN).

The BrIC was calculated for the significant head impacts of the eight ATDs that recorded the tri-axial angular velocity of the head. A comparison of the three brain injury measures for impacts in which a BrIC was able to be calculated is presented in Table 2. Five impacts exceeded the 10% injury threshold for AIS 3+ brain injury predicted by the BrIC, three of which also exceeded the peak resultant acceleration threshold. The impact producing the lowest BrIC was associated with injurious levels of HIC and peak resultant linear acceleration.

Table 2. Comparison of select brain injury measures.

Test type	BrIC	HIC	Peak resultant linear acceleration (g)
Soil-trip	0.42	14	20
Dolly	0.46	52	38
RTD	0.21	1293	210
RTD	0.46	513	133
RTD	0.67	109	57
RTD	0.76	765	131
JRS-II	0.51	78	37
JRS-II	0.34	19	25.5

Those exceeding 10% injury threshold are highlighted

In 17 tests two ATDs were seated in the front seats. Injury thresholds were exceeded for 10 of these ATDs, four of which occurred in the same test but were during different rolls.

Impact location

Although this study is focussed on head impacts caused by direct contact it is worth noting that peak resultant linear accelerations up to 23 g were recorded for non-contact events. The majority, 90 %, of the recorded significant head impacts were associated with a simultaneous roof-to-ground impact above the seated position of the ATD. Those impacts for near-side ATDs that were not associated with a roof-to-ground impact resulted from the head impacting the adjacent window when the vehicle was decelerated by a severe near-side tyre impact with the ground at the conclusion of the roll (6) or during the tripping event in a curb trip test (1). The significant head impacts recorded by far-side ATDs that were unrelated to an adjacent roof-to-ground contact occurred when the relative motion between the ATD head and upper interior roof, resulting from the linear and angular acceleration of the vehicle during near-side vehicle body-to-ground impacts, caused the two to contact each other. The average peak resultant linear acceleration measured for impacts without a concurrent roof-to-ground impact was 62 g with a maximum of 126 g.

The heads of ATDs in dolly and Trip-tests were most often in contact with the interior roof prior to the roof-to-ground contact that resulted in a significant head impact. Exceptions occurred when pretensioners were fired prior to roll initiation. In JRS tests it was more common for the head to contact the roof after that portion of the roof impacted the road surface; this occurred in 15 of 26 impacts. Vehicles tested on the dolly experienced angular velocities and accelerations 3 to 4 times greater than those tested on the JRS.

The tri-axial components of head linear acceleration at the time of peak resultant acceleration are displayed in Figure 2. All significant head impacts recorded by near-side ATDs resulted from impacts to the outboard temporoparietal region that accelerated the head toward the centre of the vehicle. Other than two impacts, N1 and N2, into the side window, which resulted in relatively large forward or rearward acceleration, the near-side ATD head was accelerated primarily in a lateral direction. Far-side ATD head motion was much more variable and appeared to be related to the amount of headroom available. The majority of impacts were aligned in a generally superior-inferior direction. One impact, F1, caused an upward acceleration occurred during a partial ejection. Contact to the upper outboard parietal resulting in acceleration downward and toward to the centre of the vehicle was the most common type. The impacts to the inboard parietal region occurred either due to partial ejection, F2-3, or during severe deformation of the roof, F4-8. High speed video for impact F8 showed, Figure 3, that the ATD head was positioned under the far-side roof rail at the time of roof-to-ground contact. All other non-vertical impacts to the head of a far-side ATD, for which interior video was available, occurred between the outboard region of the head and the inboard surface of the far-side roof rail or pillar.

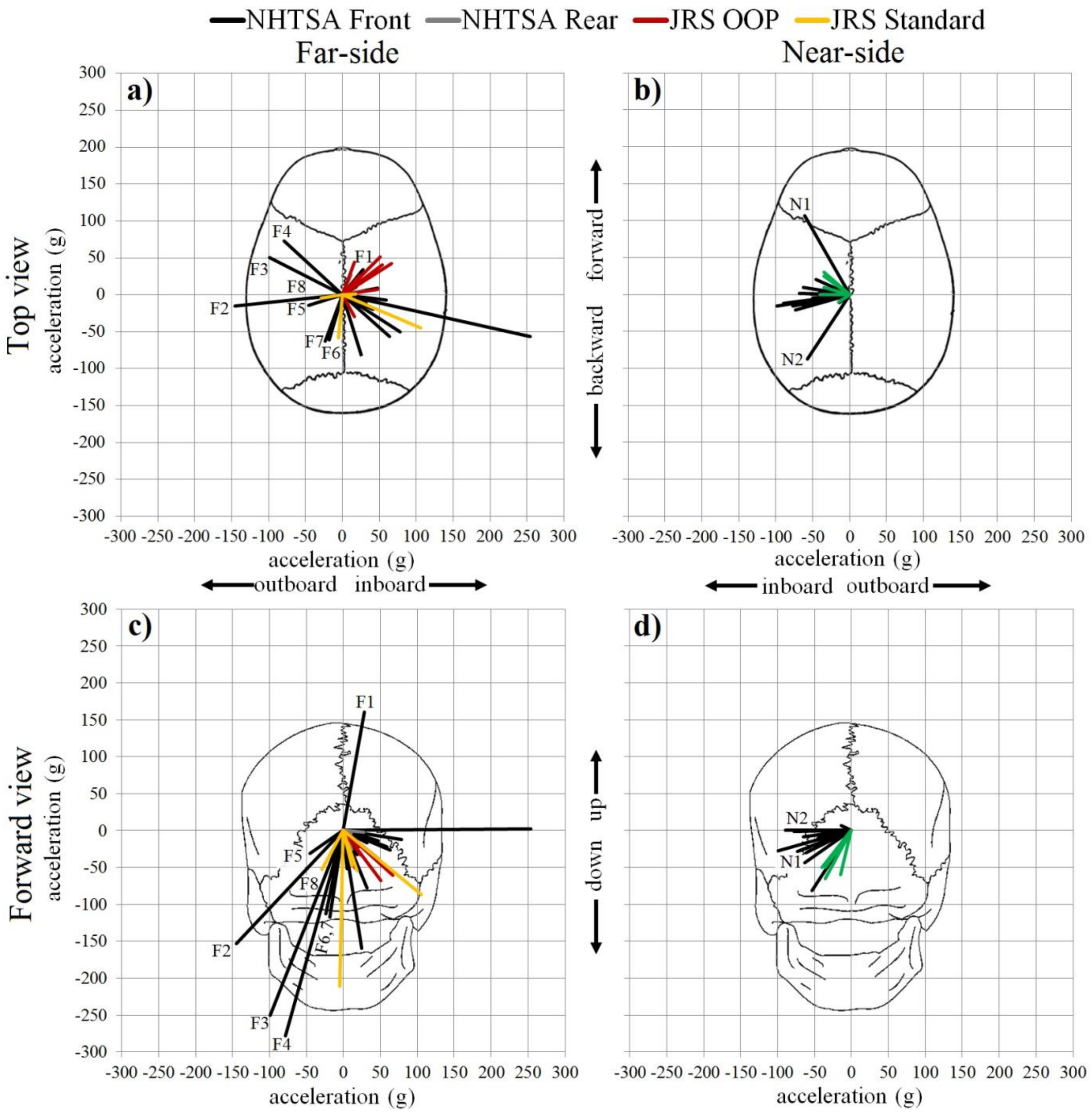

Figure 2.Components of ATD head CG acceleration at time of peak resultant acceleration for far-side (a, c) and near-side (b, d) ATDs as viewed from the top (a, b) and rear (c, d).

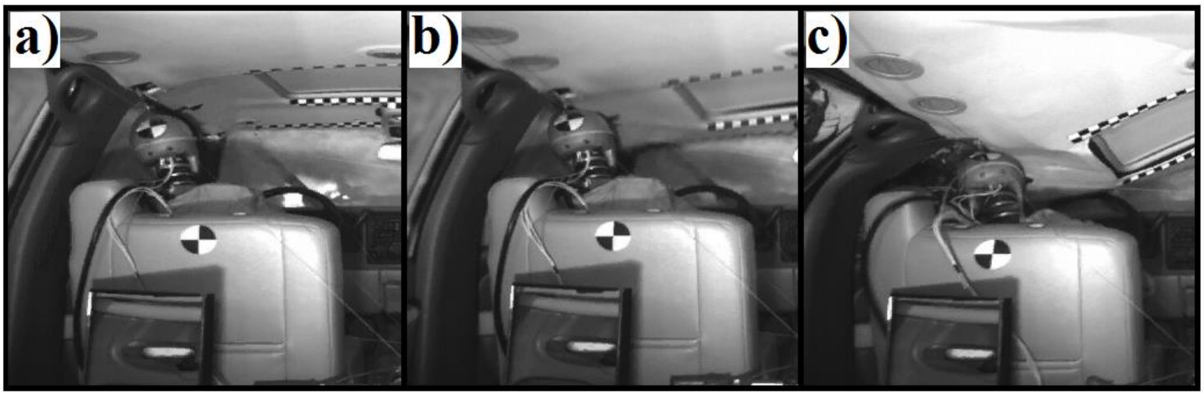

Figure 3. Video frames depicting inboard head contact for a far-side ATD in a JRS test: a) roof-to-ground impact; b) roof-to-head contact; c) peak roof deformation

Discussion

The wide range of methods used and results produced from the selection of tests in this study provide useful information regarding the production of potentially serious head injuries in dynamic rollover tests. Injury measures exceeding predicted thresholds for skull fracture and brain injury were recorded for ATDs in nearly every test method. The importance of using multiple injury criteria to account for both linear and angular motion was highlighted by the angular velocity measurements that exceeded brain injury thresholds while linear acceleration measures for the same impacts predicted no injury. Currently a single injury metric does not exist for predicting the wide range of injuries that can be sustained by the head and efforts to minimise particular measures, such as HIC, will not necessarily reduce other metrics (Sanchez-Molina et al., 2012). Furthermore, the wide range of impact locations on the ATD head is evidence that injury measures that account for the direction of impact, such as the BrIC or SFC, are necessary for rollover tests.

The characteristics of head contact for near-side ATDs were very consistent throughout all test methods and represented the attributes of real world head impacts (Mattos et al., 2013a). Near-side ATDs experienced significant head impacts when the adjacent roof impacted the ground or when the vehicle was decelerated as the near-side tyres impacted the ground and terminated the roll. The latter event was mitigated in tests with deployed side curtain airbags. Such countermeasures are already assessed in side impact tests and the ejection mitigation standard, FMVSS 226 (NHTSA, 2011b). It appears that side air curtains that remain inflated throughout the duration of the rollover event can affect head interaction with the vehicle interior. The only concern regarding the performance of these countermeasures in a rollover is that neither the deployment of the countermeasures nor their effectiveness on a vehicle with a deformed roof is assessed.

The restraint method and initial positioning of the ATD as well as the angular acceleration of the vehicle were important factors in head-to-roof interaction for far-side ATDs. In tests performed with the J2114 dolly the heads of the near- and far-side ATDs were almost continually in contact with the interior roof (Gloeckner et al., 2007) while the heads of far-side ATDs in JRS tests were most frequently moving toward the roof at the time of roof-to-ground impact. Far-side ATDs also commonly experienced impacts to the outboard region of the head while the few inboard impacts typically occurred under severe roof deformation which may not be representative of modern vehicles that are subject to current roof strength and upper interior head protection requirements (NHTSA, 2009, 2010, 2011a). These impact locations do not align with what is observed from field data; the anterior region and inboard temporoparietal region of the head are the most common sites of head impact for far-side rollover occupants (Mattos et al., 2013a, 2013b). Studies of occupant kinematics during steer-induced trip-up and rollover spit tests concluded that live occupants will tilt their head laterally by 20 to 30 deg inboard and attempt to maintain a separation between their head and the interior roof surface (Lai et al., 2005; Yamaguchi et al., 2005). This head-neck angle change is not replicated by current ATDs and may limit their ability to replicate impacts to the inboard parietal region of a far-side ATD head. Also, the constraint provided by the JRS in the vehicle's X- and yaw-directions may prevent the occurrence of anterior head impacts since it precludes longitudinal motion of the vehicle.

In the primarily lateral rollovers included in this study, for which the JRS was designed to replicate, near- and far-side ATDs did not sustain head impacts exceeding injury thresholds during consecutive near- to far-side roof impacts. That is, for any given 180 deg of rotation, at most only one ATD, near- or far-side, recorded an injurious measure. This indicates that different test protocols would be required to replicate serious head injuries for near- and far-side ATDs.

Conclusion

The head response of 109 restrained ATDs used in 80 dynamic rollover tests were reviewed and presented. Injury measures were calculated from available kinematic data. The characteristics of the head response of far-side ATDs were much more varied than that of near-side ATDs. Near-side ATD head contact characteristics in dynamic rollover tests consistently replicate the patterns observed in field data. For far-side ATDs these characteristics appear to be related to the stature, initial position, and restraint method of the ATD. Multiple injury measures are likely needed to assess the multiple types of head injury that can result from rollover crashes including vault and basilar skull fracture and local and diffuse brain injuries. There is also a definite need for injury measures to be able to account for the direction and location of impact as the ATD heads were subjected to impacts in nearly every direction.

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Appendix A: Summary of test protocol

Table 1A. Test parameters

Test parameters				Protocol						ATD		
Test vehicle	**Test device**	**Test**	**Test ID**	**Initial roll rate (deg/s)**	**Impact roll angle (deg)**	**Initial velocity (m/s)**	**Pitch (deg)**	**Drop height (mm)**	**Initial Yaw angle (deg)**	**Seat position**	**Seat**	**Type**
2010 Toyota Prius	JRS	1		190	145	6.7	5	101.6	80	11	Far	H-III 50th %ile Male
2010 Toyota Prius	JRS	2		190	145	6.7	10	101.6	80	11	Far	H-III 50th %ile Male
2009 Chevrolet Malibu	JRS	1		190	151	6.7	5	101.6	80	11	Far	H-III 50th %ile Male
2009 Chevrolet Malibu	JRS	2		190	143	6.7	10	101.6	80	11	Far	H-III 50th %ile Male
2009 Nissan Versa	JRS	1		190	144	6.7	5	101.6	80	11	Far	H-III 50th %ile Male
2009 Nissan Versa	JRS	2		190	145	6.7	10	101.6	80	11	Far	H-III 50th %ile Male
2008 Scion xB	JRS	1		190	150	6.7	5	101.6	80	11	Far	H-III 50th %ile Male
2008 Scion xB	JRS	2		190	155	6.7	10	101.6	80	11	Far	H-III 50th %ile Male
2007 Toyota Camry Hybrid	JRS	1		190	143	6.7	5	101.6	80	11	Far	H-III 50th %ile Male
2007 Toyota Camry Hybrid	JRS	2		190	135	6.7	10	101.6	80	11	Far	H-III 50th %ile Male
1999 Toyota Camry	JRS	1		300	132	6.7	5	101.6	80	11	Far	H-III 50th %ile Male
1999 Toyota Camry	JRS	2		190	133	6.7	10	101.6	80	11	Far	H-III 50th %ile Male
2006 Hyundai Sonata	JRS	1		190	143	6.7	5	101.6	80	11	Far	H-III 50th %ile Male
2006 Hyundai Sonata	JRS	2		190	145	6.7	10	101.6	80	11	Far	H-III 50th %ile Male
2007 Toyota Camry	JRS	1		190	145	6.7	5	101.6	80	11	Far	H-III 50th %ile Male
2007 Toyota Camry	JRS	2		190	145	6.7	10	101.6	80	11	Far	H-III 50th %ile Male
2000 GMC Jimmy	JRS	1		190	145	6.7	10	101.6	80	11	Far	H-III 5th %ile Female
1996 Isuzu Rodeo	JRS	1		240	153	8.1	10	101.6	80	11	Far	H-III 50th %ile Male
1997 Chevrolet Cavalier	JRS	1		240	142	8.6	10	101.6	80	11	Far	H-III 50th %ile Male
2003 Subaru Forester	JRS	2		170	151	5.6	10	101.6	80	11	Far	H-III 50th %ile Male
2003 Subaru Forester	JRS	2		170	151	5.6	10	101.6	80	11	Far	H-III 50th %ile Male
2004 Subaru Forester	JRS	2		170	151	5.6	10	101.6	80	11	Far	H-III 50th %ile Male
1997 Chevrolet Cavalier	JRS	1		170	142	6.7	5	101.6	80	11	Far	H-III 50th %ile Male
1997 Acura CL	JRS	1		205	144	8.0	10	101.6	80	11	Far	H-III 50th %ile Male
1996 Isuzu Rodeo	JRS	1		240	148	8.0	10	101.6	80	11	Far	H-III 5th %ile Female
1998 Mercedes Benz ML 320	JRS	1		231	144	8.0	10	101.6	80	11	Far	H-III 50th %ile Male
1993 Jeep Grand Cherokee	JRS	1		244	148	8.0	10	101.6	80	11	Far	H-III 50th %ile Male
2001 Chevrolet Suburban	JRS	1		214	140	6.7	10	101.6	80	11	Far	H-III 50th %ile Male
1999 Jeep Grand Cherokee	JRS	1		260	147	8.0	10	101.6	80	11	Far	H-III 50th %ile Male
2002 Ford Explorer	JRS-II	1		180	145	6.7	5	101.6	80	13	Far	H-III 50th %ile Male
2002 Ford Explorer	JRS-II	2		180	145	6.7	10	101.6	80	13	Far	H-III 50th %ile Male
1988 Dodge Caravan Mini Van	NHTSA RTD	1	1266			13.4	0	1219	45	13	Far	H-III 50th %ile Male
1989 Nissan Standard pickup	NHTSA RTD	1	1274			13.4	0	1219	45	11	Near	H-III 50th %ile Male
1989 Nissan Standard pickup	NHTSA RTD	1	1289			13.4	0	1219	45	11	Near	H-III 50th %ile Male
1989 Dodge Caravan	NHTSA RTD	1	1391			13.4	0	1219	45	13	Near	H-III 50th %ile Male
1989 Nissan Pickup	NHTSA RTD	1	1393			13.4	0	1219	90	11	Far	H-III 50th %ile Male
1989 Nissan Pickup	NHTSA RTD	1	1394			13.4	0	1219	90	11	Far	H-III 50th %ile Male
1989 Pontiac Grand Am	NHTSA RTD	1	1395			13.4	0	1219	90	11	Far	H-III 50th %ile Male
1988 Ford Ranger	NHTSA RTD	1	1520			13.4	0	1219	90	11	Far	H-III 50th %ile Male
1988 Dodge Ram	NHTSA RTD	1	1521			13.4	0	1219	90	11	Far	H-III 50th %ile Male
1981 Plymouth Reliant k	NHTSA RTD	1	1546			9.4	0	1219	45	11	Near	H-III 50th %ile Male
1991 Volvo 240	NHTSA RTD	1	1851			13.4	0	1219	90	11	Near	H-III 50th %ile Male
1991 Volvo 740	NHTSA RTD	1	1852			13.4	0	1219	90	11	Near	H-III 50th %ile Male
1990 Nissan Pickup	NHTSA RTD	1	1925			13.4	0	1219	90	11	Far	H-III 50th %ile Male
1990 Nissan Pickup	NHTSA RTD	1	1929			13.4	0	1219	90	11	Far	H-III 50th %ile Male
1990 Nissan Pickup	NHTSA RTD	1	2141			13.4	0	1219	90	11	Far	H-III 50th %ile Male
1989 Nissan Pickup	NHTSA RTD	1	2270			13.4	0	1219	90	11	Far	H-III 50th %ile Male
1993 Ford Explorer	J2114 rollover dolly	1	3012			13.4	0	228.6	90	11	Near	H-III 50th %ile Male
1994 Ford Explorer	J2114 rollover dolly	1				13.4	0	228.6	90	13	Far	H-III 50th %ile Male
2007 Ford Expedition	J2114 rollover dolly	1	6955			13.4	0	228.6	90	11	Far	H-III 50th %ile Male
2007 Ford Expedition	J2114 rollover dolly	1				13.4	0	228.6	90	13	Near	H-III 50th %ile Male
2007 Ford Expedition	J2114 rollover dolly	1				13.4	0	228.6	90	21	Far	H-III 50th %ile Male
2007 Ford Expedition	J2114 rollover dolly	1	6956			13.4	0	228.6	90	11	Far	H-III 50th %ile Male
2007 Ford Expedition	J2114 rollover dolly	1				13.4	0	228.6	90	13	Near	H-III 50th %ile Male
2007 Ford Expedition	J2114 rollover dolly	1				13.4	0	228.6	90	21	Far	H-III 50th %ile Male
2007 Ford Expedition	J2114 rollover dolly	1	6957			13.4	0	228.6	90	11	Far	H-III 50th %ile Male
2007 Ford Expedition	J2114 rollover dolly	1				13.4	0	228.6	90	21	Far	H-III 50th %ile Male
2007 Ford Expedition	Soil trip	1	6959			13.4	0	0	90	11	Far	H-III 50th %ile Male
2007 Ford Expedition	Soil trip	1				13.4	0	0	90	13	Near	H-III 50th %ile Male
2007 Ford Expedition	Soil trip	1				13.4	0	0	90	21	Far	H-III 50th %ile Male
2007 Ford Expedition	Soil trip	1	6960			13.4	0	0	90	11	Far	H-III 50th %ile Male
2007 Ford Expedition	Soil trip	1				13.4	0	0	90	13	Near	H-III 50th %ile Male
2007 Ford Expedition	Soil trip	1				13.4	0	0	90	21	Far	H-III 50th %ile Male
2007 Ford Expedition	Curb trip	1	6958			9.2	0	0	90	11	Far	H-III 50th %ile Male
2007 Ford Expedition	Curb trip	1				9.2	0	0	90	13	Near	H-III 50th %ile Male
2007 Ford Expedition	Curb trip	1				9.2	0	0	90	21	Far	H-III 50th %ile Male

continued…

Test parameters				Protocol						ATD		
Test vehicle	**Test device**	**Test**	**Test ID**	**Initial roll rate (deg/s)**	**Impact roll angle (deg)**	**Initial velocity (m/s)**	**Pitch (deg)**	**Drop height (mm)**	**Initial Yaw angle (deg)**	**Seat position**	**Seat**	**Type**
2007 Ford Expedition	Ramp	1	6961			13.4	0		90	11	Near	H-III 50th %ile Male
2007 Ford Expedition	Ramp	1				13.4	0		90	13	Far	H-III 50th %ile Male
2007 Ford Expedition	Ramp	1				13.4	0		90	23	Far	H-III 50th %ile Male
2007 Ford Expedition	Ramp	1	6962			13.4	0		90	11	Near	H-III 50th %ile Male
2007 Ford Expedition	Ramp	1				13.4	0		90	13	Far	H-III 50th %ile Male
2007 Ford Expedition	Ramp	1				13.4	0		90	23	Far	H-III 50th %ile Male
2007 Ford Expedition	Curb trip	1	6963			9.2	0	0	90	11	Far	H-III 50th %ile Male
2007 Ford Expedition	Curb trip	1				9.2	0	0	90	13	Near	H-III 50th %ile Male
2007 Ford Expedition	Curb trip	1				9.2	0	0	90	21	Far	H-III 50th %ile Male
1983 Chevy Malibu	Drop test	1	88028A		160	0.0		304.8		11	Near	H-III 50th %ile Male
1983 Chevy Malibu	Drop test	1			160	0.0		304.8		13	Far	H-III 50th %ile Male
1983 Chevy Malibu	Drop test	2	88028B		160	0.0		304.8		11	Near	H-III 50th %ile Male
1983 Chevy Malibu	Drop test	2			160	0.0		304.8		13	Far	H-III 50th %ile Male
1983 Chevy Malibu	Drop test	1	890118		160	0.0		304.8		11	Near	H-III 50th %ile Male
1983 Chevy Malibu	Drop test	1			160	0.0		304.8		13	Far	H-III 50th %ile Male
2000 Ford Crown Victoria	CRIS	1	50302	227	184	3.6	0	269	90	11	Far	H-III 50th %ile Male
2000 Ford Crown Victoria	CRIS	1	50902	226	182	3.5	0	269	90	11	Far	H-III 50th %ile Male
2000 Ford Crown Victoria	CRIS	1	51502	223	184	3.6	0	281	90	11	Far	H-III 50th %ile Male
2000 Ford Crown Victoria	CRIS	1	61102	227	185	3.6	0	297	90	11	Far	H-III 50th %ile Male
2000 Ford Crown Victoria	CRIS	1	61802	363	190	8.9	0	325	90	11	Far	H-III 50th %ile Male
2000 Ford Crown Victoria	CRIS	1	62102	361	188	8.9	0	322	90	11	Far	H-III 50th %ile Male
1996 Chevrolet Blazer	CRIS	1	41103	226	185	3.6	0	246	90	11	Far	H-III 50th %ile Male
1996 Chevrolet Blazer	CRIS	1	41703	226	185	3.6	0	246	90	11	Far	H-III 50th %ile Male
1996 Isuzu Rodeo	CRIS	1	11908	317	184	16.7	0	480	90	11	Far	H-III 50th %ile Male
1995 Landrover Discovery	CRIS	1	703366	573	201	13.6	11	546	99	11	Far	H-III 50th %ile Male
2005 Volvo XC90	CRIS	1	60605	224	182	3.4	5	274	90	11	Far	H-III 50th %ile Male
1983 Chevrolet Malibu	J2114 rollover dolly	1	870707			14.3	0	228.6	90	13	Near	H-III 50th %ile Male
1984 Chevrolet Malibu	J2114 rollover dolly	1	870708			14.3	0	228.6	90	11	Far	H-III 50th %ile Male
1985 Chevrolet Malibu	J2114 rollover dolly	1				14.3	0	228.6	90	13	Near	H-III 50th %ile Male
1986 Chevrolet Malibu	J2114 rollover dolly	1	870804			14.3	0	228.6	90	11	Far	H-III 50th %ile Male
1987 Chevrolet Malibu	J2114 rollover dolly	1				14.3	0	228.6	90	13	Near	H-III 50th %ile Male
1988 Chevrolet Malibu	J2114 rollover dolly	1	870805			14.3	0	228.6	90	11	Far	H-III 50th %ile Male
1989 Chevrolet Malibu	J2114 rollover dolly	1				14.3	0	228.6	90	13	Near	H-III 50th %ile Male
1990 Chevrolet Malibu	J2114 rollover dolly	1	871028			14.3	0	228.6	90	11	Far	H-III 50th %ile Male
1991 Chevrolet Malibu	J2114 rollover dolly	1				14.3	0	228.6	90	13	Near	H-III 50th %ile Male
1992 Chevrolet Malibu	J2114 rollover dolly	1	871030			14.3	0	228.6	90	11	Far	H-III 50th %ile Male
1993 Chevrolet Malibu	J2114 rollover dolly	1				14.3	0	228.6	90	13	Near	H-III 50th %ile Male
1994 Chevrolet Malibu	J2114 rollover dolly	1	890309			14.3	0	228.6	90	11	Far	H-III 50th %ile Male
1995 Chevrolet Malibu	J2114 rollover dolly	1				14.3	0	228.6	90	13	Near	H-III 50th %ile Male
1996 Chevrolet Malibu	J2114 rollover dolly	1	890425			14.3	0	228.6	90	11	Far	H-III 50th %ile Male
1997 Chevrolet Malibu	J2114 rollover dolly	1				14.3	0	228.6	90	13	Near	H-III 50th %ile Male
Saab 9-3	Friction trip	1	K2511			11.7	0	178	90	11	Far	H-III 50th %ile Male
Saab 9-3	Friction trip	1				11.7	0	178	90	13	Near	H-III 50th %ile Male

Seat position as defined in NASS-CDS:
driver (11); front passenger (13); rear left, middle, right passenger (21, 22, 23)