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INJURY BIOMECHANICS RESEARCH
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Incidence of Head Injuries Attributable to Rotation

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This paper has not been screened for accuracy nor refereed by any body of scientific peers and should not be referenced in the open literature.

ABSTRACT

Head injuries continue to be one of the most frequent and debilitating consequences of automobile crashes. Each year in the United States, about 35,000 motorists suffer a head injury of AIS 3 or greater in a crash. About 12,000 of these victims die. The side impact crash mode appears to be the greatest source of head injuries, with an estimated 26% of the total. The incidence and nature of head injuries sustained in crashes is the subject herein. All possible brain injuries and skull fractures are denoted by 229 unique codes as described in the AIS Injury Coding Manual. It is assumed that these injuries may be placed into three broad categories: those manifested by rotation only (such as diffuse axonal injuries), those manifested by translation only (such as skull fractures), and those manifested by either rotation or translation. Upon categorizing each code into one of the three categories, NASS-CDS data may be interrogated to gain insights into the various types of head injuries. About 16% of motorists with head wounds have injuries deemed to be attributable to rotational effects only; another 16% have injuries attributable to translational effects only. About 29% incur both types of head injuries, and the rest (about 39%) have injuries that may be attributed to either translation or rotation. When one considers fatalities only, an estimated 842 deaths per year are attributable to rotationally-induced brain injuries. Such results highlight the need for a rotation-based anthropomorphic dummy metric to gauge head injury potential in crash tests.

INTRODUCTION

Each year in the United States, about 35,000 motorists suffer a moderate-to-critical head injury (AIS ≥ 2) in a crash. About 12,000 of these victims die. Notwithstanding a rapidly growing fleet of U.S. passenger cars equipped with air bags and increasing rates of seat belt use, a head injury remains the most common type of injury to all seriously injured motor vehicle occupants. The medical costs alone for head and brain injuries sustained in motor vehicle crashes account for over $2 billion in the United States every year (Miller et al, 1993).

The National Highway Traffic Safety Administration (NHTSA) is responsible for reducing deaths, injuries, and economic losses resulting from motor vehicle crashes. This is accomplished in part by setting and enforcing safety performance standards for motor vehicles. The performance of a vehicle in mitigating head injuries is assessed through the Federal Motor Vehicle Safety Standard (FMVSS) 200-series, notably FMVSS 201 (interior components), 208 (frontal crash protection), and 218 (helmets). Moreover, NHTSA has announced plans to revise FMVSS 214 (side impact crash protection) with a new head injury provision. These standards make use of a dummy exposed to collision forces. Within the 200-series of standards, the risk of head injury is judged by analyzing the resultant linear acceleration at the center of gravity of a dummy headform. The risk metric is referred to as the Head Injury Criterion (HIC). The HIC metric has its roots as a correlate to skull fractures in drop tests performed on cadavers (Versace, 1971).

Over the years, researchers at NHTSA and other institutions have contemplated the use of some other metric – such as angular acceleration – to be used along with or in lieu of HIC to assess head injury probability in a crash test (Mackay and Petrucelli, 1989). In searching for an appropriate metric, NHTSA takes a data driven approach to assure that its use in a federal regulation will lead to a significant reduction in injuries. Within NHTSA's biomechanics division, real-world data are used to answer three basic questions that guide the search for injury metrics:

1. What types of injuries should NHTSA strive to prevent?
2. What measurements are required of a crash dummy to ascertain whether such injuries are sustainable in a crash test?
3. How many lives may be saved under a given performance requirement to prevent such injuries?

Generally, there must be enough existing data to show that a proposed countermeasure (such as implementing an additional or new head injury metric) will reduce the risk of injuries significantly. To aid such assessments, NHTSA maintains epidemiological data on the nature, causes, and injury outcomes of crashes.

The National Automotive Sampling System - Crashworthiness Data System.

The Crashworthiness Data System (CDS) is an epidemiological database maintained by NHTSA. The CDS is a nationally representative probability sample of police-reported automobile crashes in the United States. CDS cases are limited to crashes that involve at least one passenger car that was towed from the crash scene due to damage resulting from the crash. Each case is assigned a weighting factor that represents an estimate of the number of like-mannered cases that occurred during the sample year.

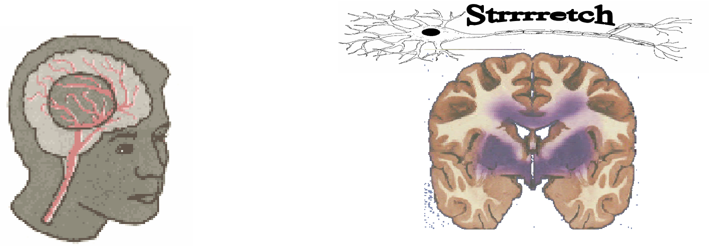
Injuries to motorists involved in CDS cases are also recorded in the database. Injuries are denoted with a seven-digit code in accordance with the Abbreviated Injury Scale (AIS). The AIS codes may be found in AAAM's AIS Injury Coding Manual (AAAM, 1998), which provides codes for over a thousand distinct injury types. The manual also gives synonyms and parenthetical descriptions of each code. In theory, the manual provides a code for every conceivable injury that one could sustain in a car accident. This includes 229 head injury codes.

OBJECTIVE

The objective of the study herein is to examine the CDS for evidence of brain injuries brought on by rotational head motion. In order to justify a new metric for head injuries, the data must show that there is a sound basis for reasoning that the current dummy (the Hybrid III) and injury metric (HIC) are insufficient to expose potentially injurious vehicles in federally mandated compliance tests. In other words, this study searches for real-world evidence in the CDS of brain injuries occurring in instances where HIC values (if it were possible to ascertain them) would probably have been low.

The first step in this process is to characterize brain injuries by type. Gennarelli (1993) describes two general types of brain injuries: focal injuries and diffuse injuries. Focal injuries are usually caused by head impacts and are characterized as contusions, lacerations, and hemorrhages that produce hematomas in the extradural, subdural, or intracerebral compartments of the head.

Diffuse brain injuries are usually caused by inertial loading of the head in which there is relative motion of the cranial contents. When the inertial accelerations are linear and deformations occur toward the surface of the brain, they give rise to vascular injuries such as contrecoup contusions and subdural hematomas that result from ruptures of bridging veins. On the other hand, inertial accelerations that are rotational produce strains that run deeper in the brain causing damage to the neurons, stretching of the axons, and white matter shearing. They give rise to diffuse axonal injuries (DAI) that are associated with unconsciousness, cerebral concussions, and posttraumatic coma.



Vessel Lesions
- Thrombosis (occlusion)
- Subdural hematoma
- Epidural hematoma
- Arterial laceration

Diffuse Axonal Injuries
- Loss of consciousness
- Lethargy (symptomatic)
- White matter shearing

Figure 1: a). Vessel lesions associated with high linear acceleration; b). DAI injuries associated with high angular acceleration.

Once the head injuries are properly characterized, data set as a whole may be interrogated for evidence of brain injuries brought on by rotational head motion.

DATA SOURCE

The findings herein are based on a data set extracted from nine years of CDS data, 1993-2001. The working data set only contains cases in which an occupant sustained a head injury of AIS ≥ 2. In all, there are 9881 cases in the dataset. The analysis described herein is based on five prominent variables within the dataset. They are described in the table below.

Table 1. Five Prominent Variables Within The Head Injury Dataset.

Variable Name	Description
1. InjCode	Seven digit AIS injury codes for each injury (head injuries and all others)
2. Mortality	Mortality outcome (fatal or non-fatal)
3. CrashMode	Type of collision (frontal, side, rear, other)
4. HeadInjType	Type of each head injury (induced by rotation, translation)
5. SurvivalRate	Survivability rate of each injury (see appendix head)

The first three variables, InjCode, Mortality, and CrashMode, are coded within the CDS and are taken directly from the database. The fourth variable, HeadInjType, denotes whether each head injury was likely induced by rotational or translational motion. Since this determination cannot be directly ascertained from the CDS record, the description of the injury itself is used to make this judgment.

Consistent with the aforementioned observations of Gennarelli (1993), injury codes that describe focal lesions are taken to be induced by translation or linear acceleration. For example, a head strike that results in a fractured skull obviously corresponds with high linear acceleration. Within the cranial contents, high linear accelerations are also associated with codes that describe injuries to the vascular network within the brain. These include vessel lacerations and lesions that lead to thrombosis and hematomas.

Rotationally-induced brain injuries include only those associated with diffuse axonal injuries (DAI) and deep inertial strains. The rest of the brain injuries are classified as “either”, meaning that they may be brought on by either translation or rotation. Most of the brain injury codes in the CDS are of this later variety: they are symptomatic and are described by a loss of consciousness or grogginess. Even though concussions are generally regarded as a mild form of DAI, they are conservatively treated herein as “either” because of the uncertainty often associated with such an injury. For example, a patient who has a severe thorax injury may lose consciousness. The state of consciousness would be coded on the CDS injury record, but certainly the patient ought not to be regarded as having a rotationally-induced brain injury. Figure 2 shows the breakdown of the 229 head injury codes by type. (This is only a distribution of the codes as they are presented in the coding manual given for illustrative purposes. The distribution within the CDS is presented later.)

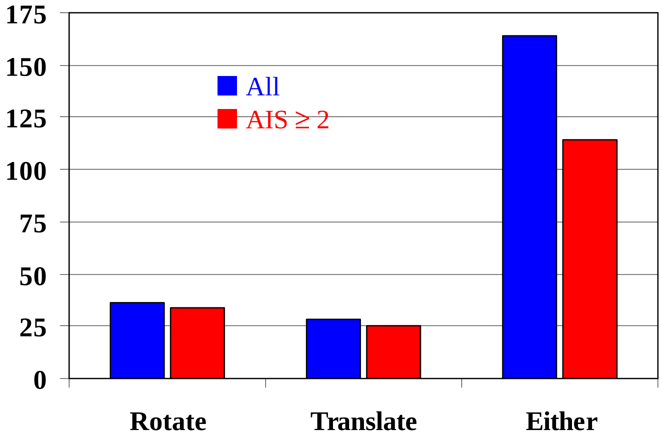


Figure 2: Distribution of the AAAM Coding Manual’s 229 head injury codes by causation.

The fifth variable, Survival Rate, corresponds with the survivability rate of each injury sustained (not just the head injuries). This variable is used to determine the number of fatalities attributable to a particular type of injury. Values of the Survival Rates for 171 of the 229 seven-digit head injury codes are given in the appendix. (Note: 58 head injury codes described in the coding manual do not appear in the CDS.)

The basis of the Survival Rate values is fully described by Martin and Eppinger (2003b). Survival Rate values are akin to the AIS severity scores of 1-6. But unlike AIS scores, unique Survival Rate values ranging from 0 to 1 are computed for each 7-digit code (although some codes describing very similar injuries share the same values). Moreover, the basis of each value is the

CDS data itself rather than the findings of an expert panel. The Survival Rate for a given code is the ratio of the number of times it was reported to be the cause of death over its overall incidence, as illustrated in Figure 3. The means to compute overall survivability is discussed later.

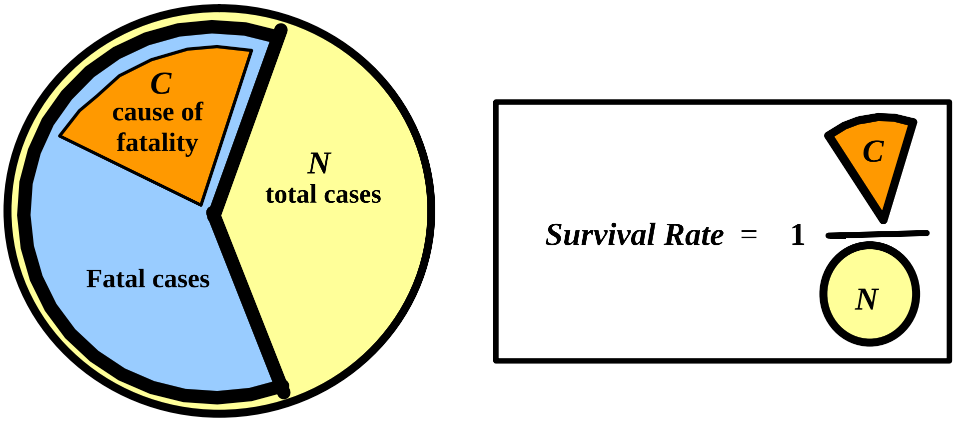


Figure 3: Computing the Survival Rate associated with a given injury code.

METHODS

Aside from simply revealing incidence levels, the Survival Rates may be applied to directly compute an estimate of the number of fatalities that are attributable to a particular type of injury, such as rotationally-induced brain injuries. Like the Survival Rates themselves, the basis of the analysis approach is presented by Martin and Eppinger (2003a). In short, only the two most serious injuries – the primary injury and secondary injury – are used to characterize a victim's entire injury record. For example, the injury profile of the victim shown in Figure 4 may be characterized by the two with the highest Survival Rates.

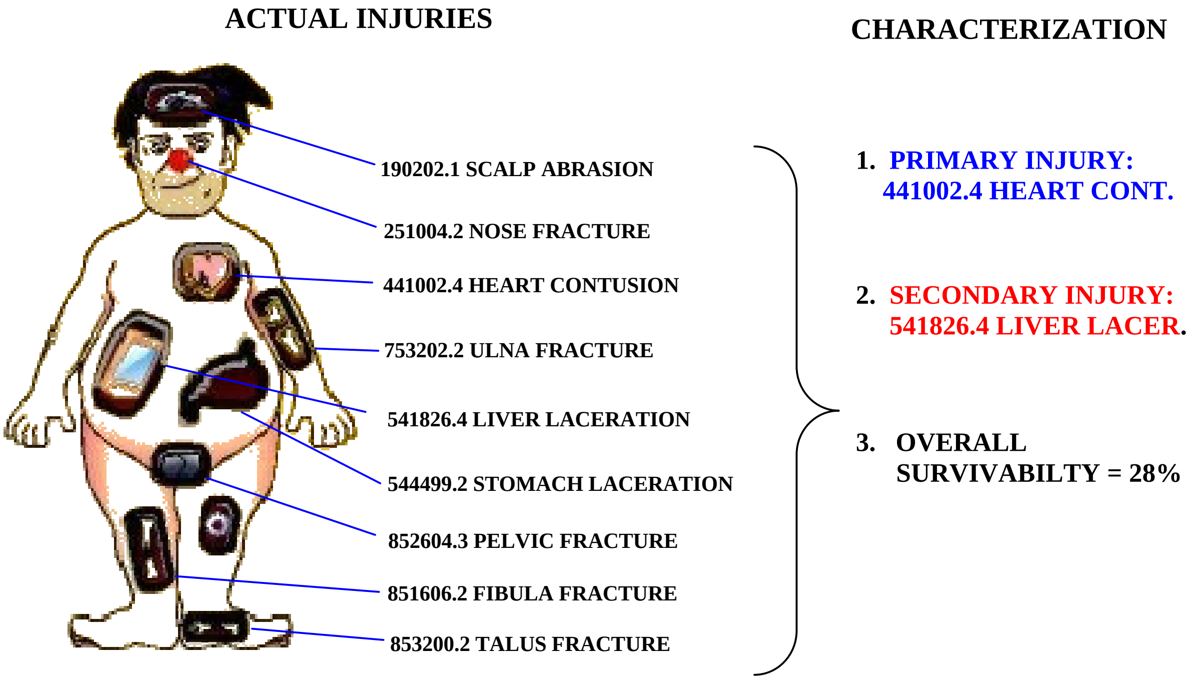


Figure 4: Two-injury characterization process.

Thus, instead of using just a single maximum AIS injury, the "Primary/Secondary" model uses two injuries. Whereas the primary injury sets the upper limit of the survival probability, the secondary injury can be thought of as a "survivability modulator". This two-injury approach uses the actual CDS outcomes to help select and sort injuries. These two survival rates are combined in a function that produces an estimate of survival. So, not only are the Survival Rates used to compute overall survivability, they are used to select which two injuries are chosen to represent the injured victim in the first place. Any other injuries have been found to have very little effect on overall survivability and are thus excluded from the survival function.

RESULTS

A review of the 9881-case dataset shows that the distribution of actual brain injury types in real-world accidents contained in the CDS is far different from the distribution in Figure 1 of the 229 brain injury codes within the AAAM manual. This distribution is given in Figure 5 for both fatalities and for injuries of AIS ≥ 2 (moderate to critical injuries). When examining CDS cases individually and collectively, some of the codes show up several times while others never appear at all. For cases where a single occupant sustains two or more types of head injuries, a "Combination" distinction is provided.

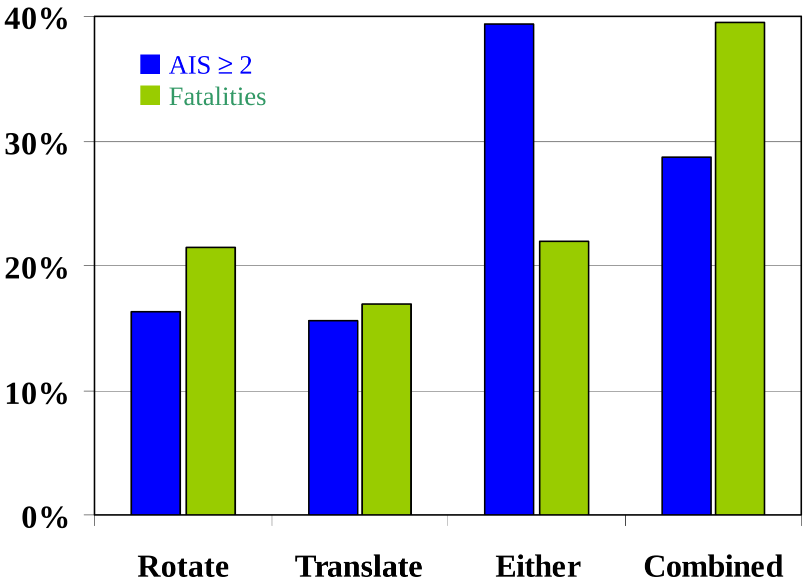


Figure 5: Distribution of the head injuries by injury causation.
Source: 1993-2001 CDS.

When only the rotationally-induced cases are considered, the frontal and side impact mode predominate, as shown in Figure 6. However, about 60% of all crashes are frontal, compared with about 25% for side impact (NHTSA, 2002). Given the lower exposure rate for the side impact mode, the propensity to incur a rotationally-induced brain injury is much higher in side impacts than in the frontal mode. (Note: although not presented herein, the working CDS dataset indicates that all head injuries are more likely to be sustained in side impacts, not just rotationally-induced ones.)

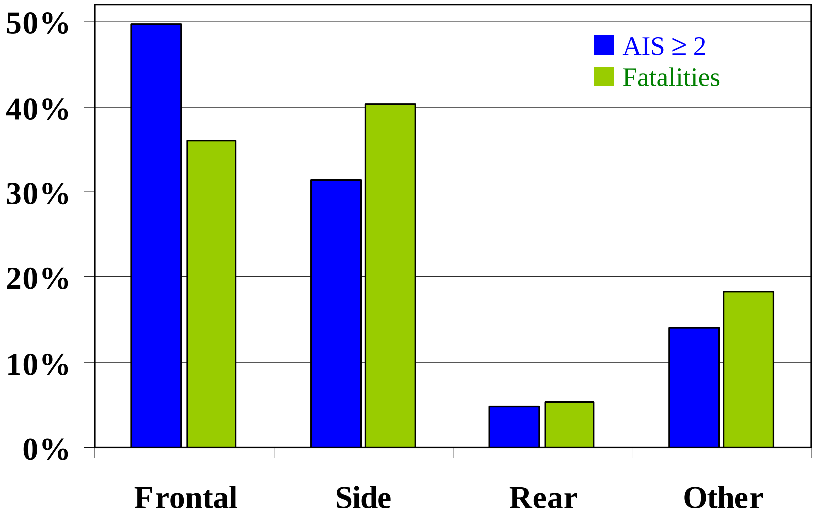


Figure 6: Distribution of the rotationally-induced head injuries by crash mode. Source: 1993-2001 CDS.

Figure 5 is merely a distribution of head injury *incidence*. It does not explicitly address question no. 3 described in the Introduction. That is, it does not explain how many lives may be saved if a given type of brain injury could be avoided. For example, Figure 5 only says that 21% of fatal crash victims who sustain a brain injury receive the type attributable to rotational head motion (and not any other type of head injury). While the brain injury probably contributed to the fatal outcome in most of the cases, there were injuries in other body regions, too. As such, Figure 5 does not provide a direct estimate of fatalities due to rotationally-induced brain injuries.

For a more exacting estimate, the two-injury characterization of each dataset case (described earlier in the "Methods" section) may be used to find the number of fatalities that are directly attributable to rotationally-induced brain injuries. This requires two "sweeps" through the dataset as described below and in Figure 7.

The upper table in Figure 7 shows a snapshot of an Excel sheet containing the 9881-case dataset, where each row represents an injured occupant. All injuries appear in the right-hand green columns from which the top two injuries (blue and red columns) are selected. Survival Rate values for these two injuries are obtained from a lookup table (similar to the one in the Appendix) and combined with the CDS national weighting factors to produce a survival probability estimate (black columns).

The number of fatalities attributable to rotationally-induced brain injuries is found by taking two sweeps through the dataset as illustrated in Figure 7. In the first sweep, only the n cases where $P1$ and/or $S1$ (the primary and secondary injuries) are rotationally-induced brain injuries (n = 1539 such cases) are retained. The Survival Rates of these two injury codes, $P1_{SR}$ and $S1_{SR}$, are found in the lookup table. In the second sweep, only the n cases are examined, but injury codes associated with rotationally-induced brain injuries are disregarded.

From the remaining injury codes, new primary and secondary injuries and their Survival Rates, $P2_{SR}$ and $S2_{SR}$ are found. Note that $P1 = P2$ if $P1$ is not a rotational brain injury, and likewise for $S1$ and $S2$. Finally, a total of 842 annual fatalities attributable to rotationally-induced brain injuries is found by subtracting the results of Sweep 2 from Sweep 1. This is expressed mathematically by Equation 1.

$$\text{Attributable Fatalities} = \sum_{\boldsymbol{i}=1}^{\boldsymbol{n}} \left\{ \boldsymbol{F}\left(\boldsymbol{P1_{SR}}, \boldsymbol{S1_{SR}}\right)_{\boldsymbol{i}} - \boldsymbol{F}\left(\boldsymbol{P2_{SR}}, \boldsymbol{S2_{SR}}\right)_{\boldsymbol{i}} \right\} \boldsymbol{ratwgt} \qquad [1]$$

In Equation 1, *ratwgt* is the CDS national expansion factor for each case, *i*. *F* is a function that provides the probability of survival. The form of the survivability function is given in Equation 2. The values of the two exponents in Equation 2 are determined by optimization process that when given the actual mortality produces the best estimates (lowest deviance) of the probability of survival.

$$F(P_{SR}, S_{SR}) = (P_{SR})^{0.382} \cdot (S_{SR})^{1.014} \qquad [2]$$

The same methodology may also be used to determine an estimated 5046 annual fatalities attributable to head injuries in general (rotationally-induced and otherwise). Table 2 provides the annual estimates for both instances when this process is carried out.

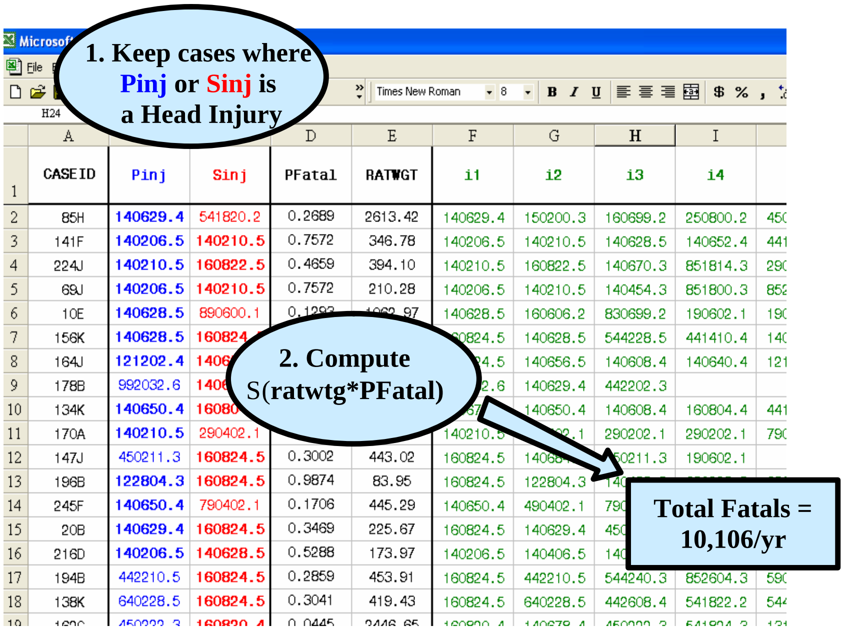
Given the conservative approach in assigning injury typecasts, the finding of 842 fatalities attributable to rotationally-induced head injuries is probably a moderately-to-low estimate. If brain injury codes describing a loss of consciousness (LOC) were re-classified as rotationally-induced, the estimate climbs to 1381 per year, or 27% of fatalities due to head injuries.

Even at that, 1381 is still conservative given the limitations of CDS injury coding. Crash victims who are “dead on arrival” (DOA) often have incomplete injury records because there has been no thorough medical examination. In other words, since rotationally-induced brain injuries are not normally observed by lay coroners, they often do not appear on the injury records of DOA cases even if they actually exist.

The head injury dataset may also be used to assess whether NHTSA’s longstanding HIC metric is sufficient to detect all head injuries. This is accomplished by observing whether rotationally-induced brain injuries occur in the absence of head contacts or presumed high linear head accelerations. In re-examining the n = 1539 cases (those where one of the top two injuries is a rotationally-induced brain injury), those where the victim suffered an injury that could possibly be attributed to head contact or high linear accelerations are omitted. For example, if a chin laceration – even a minor one – appears on the injury record, the case is discounted. Or, if the CDS “injury source” record indicates that the injury was caused by head contact, the case is omitted.

When all such cases are discounted, there are still 85 fatalities per year that are estimated to be attributable to rotationally-induced brain injuries. These cases provide the best evidence that brain injuries are being sustained in the absence of a mechanism that produces high linear acceleration (and high HIC values). Again, this figure is a conservative estimate since most of the non-rotationally-induced head injuries are of the LOC variety, which are classified as “Either”. However, many of these LOC injuries are undoubtedly symptomatic of a mild form of a diffuse axonal injury (which is typically rotationally-induced). When LOC injuries are regarded as “rotationally-induced”, the estimate climbs to 529. Estimates under the less conservative approach are given in Table 2 along with the more conservative estimates.

Sweep 1: Find head injuries



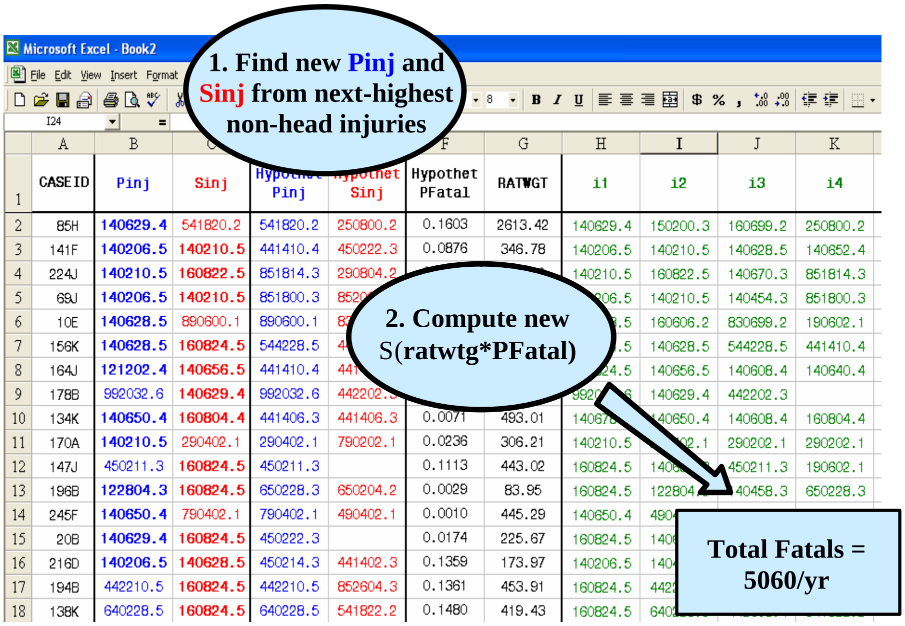
1. Keep cases where Pinj or Sinj is a Head Injury

2. Compute S(ratwtg*PFatal)

Total Fatals = 10,106/yr

	CASEID	Pinj	Sinj	PFatal	RATWGT	i1	i2	i3	i4
2	85H	140629.4	541820.2	0.2689	2613.42	140629.4	150200.3	160699.2	250800.2
3	141F	140206.5	140210.5	0.7572	346.78	140206.5	140210.5	140628.5	140652.4
4	224J	140210.5	160822.5	0.4659	394.10	140210.5	160822.5	140670.3	851814.3
5	69J	140206.5	140210.5	0.7572	210.28	140206.5	140210.5	140454.3	851800.3
6	10E	140628.5	890600.1	0.1293	1062.97	140628.5	160606.2	830699.2	190602.1
7	156K	140628.5	160824	[illegible]	[illegible]	0824.5	140628.5	544228.5	441410.4
8	164J	121202.4	1406	[illegible]	[illegible]	4.5	140656.5	140608.4	140640.4
9	178B	992032.6	1406	[illegible]	[illegible]	2.6	140629.4	442202.3	
10	134K	140650.4	16080	[illegible]	[illegible]	67	140650.4	140608.4	160804.4
11	170A	140210.5	290402.1	[illegible]	[illegible]	140210.5	2.1	290202.1	290202.1
12	147J	450211.3	160824.5	0.3002	443.02	160824.5	1406	50211.3	190602.1
13	196B	122804.3	160824.5	0.9874	83.95	160824.5	122804.3	140	[illegible]
14	245F	140650.4	790402.1	0.1706	445.29	140650.4	490402.1	790	[illegible]
15	20B	140629.4	160824.5	0.3469	225.67	160824.5	140629.4	450	[illegible]
16	216D	140206.5	140628.5	0.5288	173.97	140206.5	140406.5	140	[illegible]
17	194B	442210.5	160824.5	0.2859	453.91	160824.5	442210.5	544240.3	852604.3
18	138K	640228.5	160824.5	0.3041	419.43	160824.5	640228.5	442608.4	541822.2

Sweep 2: Find replacement injuries



1. Find new Pinj and Sinj from next-highest non-head injuries

2. Compute new S(ratwtg*PFatal)

Total Fatals = 5060/yr

	CASEID	Pinj	Sinj	Hypothet Pinj	Hypothet Sinj	Hypothet PFatal	RATWGT	i1	i2	i3	i4
2	85H	140629.4	541820.2	541820.2	250800.2	0.1603	2613.42	140629.4	150200.3	160699.2	250800.2
3	141F	140206.5	140210.5	441410.4	450222.3	0.0876	346.78	140206.5	140210.5	140628.5	140652.4
4	224J	140210.5	160822.5	851814.3	290804.2	[illegible]	[illegible]	140210.5	160822.5	140670.3	851814.3
5	69J	140206.5	140210.5	851800.3	8520	[illegible]	[illegible]	206.5	140210.5	140454.3	851800.3
6	10E	140628.5	890600.1	890600.1	8	[illegible]	[illegible]	.5	160606.2	830699.2	190602.1
7	156K	140628.5	160824.5	544228.5	4	[illegible]	[illegible]	.5	140628.5	544228.5	441410.4
8	164J	121202.4	140656.5	441410.4	441	[illegible]	[illegible]	24.5	140656.5	140608.4	140640.4
9	178B	992032.6	140629.4	992032.6	442202	[illegible]	[illegible]	992	140629.4	442202.3	
10	134K	140650.4	160804.4	441406.3	441406.3	0.0071	493.01	14067	40650.4	140608.4	160804.4
11	170A	140210.5	290402.1	290402.1	790202.1	0.0236	306.21	140210.5	2.1	290202.1	290202.1
12	147J	450211.3	160824.5	450211.3		0.1113	443.02	160824.5	1406	450211.3	190602.1
13	196B	122804.3	160824.5	650228.3	650204.2	0.0029	83.95	160824.5	122804	40458.3	650228.3
14	245F	140650.4	790402.1	790402.1	490402.1	0.0010	445.29	140650.4	490	[illegible]	[illegible]
15	20B	140629.4	160824.5	450222.3		0.0174	225.67	160824.5	140	[illegible]	[illegible]
16	216D	140206.5	140628.5	450214.3	441402.3	0.1359	173.97	140206.5	140	[illegible]	[illegible]
17	194B	442210.5	160824.5	442210.5	852604.3	0.1361	453.91	160824.5	442	[illegible]	[illegible]
18	138K	640228.5	160824.5	640228.5	541822.2	0.1480	419.43	160824.5	640	[illegible]	[illegible]

Attributable Fatality Estimate

10,106 – 5060 = 5046 Fatalities/year attributable to head injuries.

Figure 7: Methodology used to estimate 5046 annual fatalities due to head injuries.

Table 2. Estimates Of Annual Incidence.

Measure	**Annual Incidence**	
1. Fatalities due to head injuries.	5046	
2. Fatalities due to rotationally-induced brain injuries.	1381	842
3. Fatalities due to rotationally-induced brain injuries with a presumed low HIC.	529	85
	(Assume all LOC is Rotationally-induced)	(Conservative Estimate)

CONCLUSIONS

About 16% of motorists who suffer head injuries sustain only a type of brain injury that is thought to be rotation-induced. At least 17% of fatalities due to head injuries are caused by rotationally-induced brain injuries. That amounts to an estimated 842 fatalities per year, with the side impact mode the predominant type of crash. In at least 10% of these fatalities, the motorists did not show any evidence of skull fractures or other contact-type of head injuries consistent with high translational acceleration. Therefore, it is presumed that they would have had low HIC values (if HIC could have been measured somehow).

In keeping with NHTSA's data driven research philosophy, three remarks may be put forth as a result of this analysis:

1. Efforts to prevent rotationally-induced brain injuries in car accidents are worthwhile.
2. Anthropomorphic Test Dummies should be able to measure angular head acceleration.
3. A potential of 842 lives per year could be saved from a metric that accounts for rotationally-induced brain injuries. Motorists who are involved in side impacts are particularly vulnerable to these types of brain injuries.

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APPENDIX

Brain injury codes in the CDS by type (R – rotationally-induced, T- translationally induced; B-induced by either translation or rotation) and computed Survival Rate (SR). See AAAM (1998) for code descriptions.

Code	Type	SR
113000.6	T	1.000
115099.7	B	0.143
115299.7	B	0.279
115999.7	B	1.000
120202.5	R	0.765
120402.5	R	0.765
120499.5	B	0.765
120602.4	R	0.401
121002.5	R	0.748
121004.4	R	0.401
121099.3	B	0.150
121202.4	R	0.399
121299.3	B	0.150
121402.5	R	0.746
121406.3	B	0.150
121602.4	R	0.401
121606.3	B	0.150
121802.5	R	0.746
122202.4	R	0.401
122802.5	R	0.746
122804.3	R	0.150
122899.3	B	0.150
130204.2	B	0.001
130299.2	B	0.001
130404.2	B	0.001
130602.2	B	0.001
130606.2	B	0.001
130699.2	B	0.001
130802.2	B	0.001
130804.2	B	0.001
130899.2	B	0.001
131002.2	B	0.001
131099.2	B	0.001
131204.2	B	0.001
131299.2	B	0.001
131402.2	B	0.001
131499.2	B	0.001
131602.2	B	0.001
131604.2	B	0.001
131699.2	B	0.001
132099.2	B	0.001
132699.2	B	0.001
140202.5	B	0.833
140204.5	B	0.833
140206.5	R	0.833
140208.5	B	0.833
140210.5	R	0.833
140212.6	B	1.000
140214.6	B	1.000
140216.6	B	1.000
140218.6	B	1.000
140299.5	B	0.833
140402.3	B	0.402
140403.3	B	0.019
140404.4	B	0.433
140405.5	B	0.463
140406.5	R	0.463
140410.4	B	0.433
140414.4	B	0.433
140418.4	B	0.433
140422.5	B	0.463
140426.4	B	0.433
140430.4	B	0.433
140438.4	R	0.433
140442.4	R	0.433
140446.5	B	0.463
140450.3	B	0.019
140454.3	B	0.019
140458.3	B	0.019
140462.3	B	0.019
140466.3	R	0.019
140470.3	B	0.019
140474.4	B	0.433
140499.3	B	0.402
140602.3	T	0.083
140604.3	T	0.083
140606.3	T	0.001
140608.4	T	0.400
140610.5	T	0.585
140611.3	T	0.083
140612.3	T	0.083
140614.3	T	0.001
140616.4	T	0.400
140618.5	T	0.585
140620.3	T	0.083
140622.3	T	0.001
140624.4	T	0.400
140626.5	T	0.585
140628.5	R	0.585
140629.4	R	0.414
140630.4	B	0.414
140632.4	B	0.400
140634.5	R	0.585
140636.5	B	0.585
140638.4	B	0.414
140640.4	B	0.400
140642.4	B	0.400
140644.4	B	0.400
140646.5	B	0.585
140648.5	B	0.585
140650.4	R	0.414
140652.4	R	0.400
140654.5	R	0.585
140656.5	R	0.585
140660.3	B	0.083
140662.3	B	0.001
140664.4	B	0.400
140666.5	B	0.585
140668.3	R	0.001
140670.3	B	0.001
140672.4	B	0.400
140674.5	B	0.585
140676.3	B	0.001
140678.4	R	0.400
140680.3	B	0.001
140682.3	T	0.001
140684.3	R	0.001
140686.3	B	0.001
140688.4	T	0.400
140690.5	B	0.585
140699.3	B	0.083
140799.3	T	0.002
150000.2	T	0.529
150200.3	T	0.001
150202.3	T	0.001
150204.3	T	0.001
150206.4	T	0.435
150400.2	T	0.043
150402.2	T	0.001
150404.3	T	0.136
150406.4	T	0.937
150408.4	T	0.937
160202.2	B	0.001
160204.3	B	0.001
160206.3	B	0.001
160208.4	B	0.032
160210.4	B	0.032
160212.5	B	0.137
160214.5	B	0.137
160402.1	R	0.001
160404.2	B	0.001
160406.2	B	0.001
160408.3	B	0.001
160410.2	B	0.001
160412.3	B	0.001
160414.2	B	0.001
160416.3	B	0.001
160499.1	R	0.001
160602.2	B	0.001
160604.3	B	0.082
160606.2	B	0.001
160608.3	B	0.082
160610.2	B	0.001
160612.3	B	0.082
160614.3	B	0.082
160616.4	B	0.100
160699.2	B	0.001
160802.3	B	0.076
160804.4	B	0.027
160806.3	B	0.001
160808.4	B	0.027
160810.3	B	0.001
160812.4	B	0.027
160814.4	B	0.027
160816.5	B	0.244
160818.5	B	0.244
160820.4	B	0.027
160822.5	B	0.244
160824.5	B	0.244
160899.3	B	0.076
161000.2	R	0.001

DISCUSSION

PAPER: **Incidence of Head Injuries Attributable to Rotation**

PRESENTER: ***Peter Martin, NHTSA***

QUESTION: *Guy Nusholtz, DaimlerChrysler*
As I understand your presentation, about two-thirds of the injuries are basically due to linear acceleration and one-third is due to rotational acceleration?

ANSWER: Well, if I turn it around and said, "Okay. Let's look at translational acceleration. How many could we say for sure are translationally or linear caused?" I have the same problem with all the injuries in the Both category as I do for rotation. The Both category, which is both either/or -- we don't know which -- encompasses most of the injuries. I would say that a third are for sure caused by rotation. The other two-thirds: maybe some translation, maybe some rotation. If it’s Both, then I'm just not sure about it.

Q: Okay. So it could--it could be two-thirds or it could be much less than that due to translational. Of the one-third that you have, which is rotational, how many of those didn't have a hard contact?

A: Well, all the one-third that I showed were rotational only and so, the hard contact--I didn't look into the case to see if there was a hard contact. A lot of times, that information is very vague, but I do know that none had the types of injuries you would expect with a hard contact like a skull fracture. They were all types of injuries consistent with rotationally-induced.

Q: If you don't know whether they had hard contact, how do you know they had low HICs?

A: Excuse me? How I know--?

Q: How do you know they have low HICs?

A: I am speculating that they would have low HICs because those types of injuries that they do have only are associated with rotational type of accelerations. So if there's no type of injury associated with translation on the record, then I--that's where I come up with the speculation that they would have had low HICs.

Q: But I think--I think that's sort of a circular reasoning -- that since it's rotation, it has low HICs, and because it's low HICs that have rotation. And I don't think you have, really, any justification, because even in cases where dummies are flying through the air, you can have relatively high HICs without hard contact. And typically in any type of situation, you're gonna have some type of contact of the head with some object. Even though you don't have a skull fracture, you can still have high HICs. You can get 3,000 HICs without skull fractures, so you could still have fairly high HICs in most of the cases that you're talking about. I don't know that your results tend to lead to your conclusion.

A: Okay.

Q: Thanks.

A: Thanks.

Q: *Dave Meaney, University of Pennsylvania*
I just wanted to follow up a little bit on the categorization issue that you talked about. You said that some of these injuries are rotational, others are translation and yet others are both. Did you have a chance to do what I would think is a sensitivity analysis that if you sorted some of these questionable ones in different categories, did your results change dramatically?

A: Well, we started off doing it the other way and being very unconservative, and the majority of the injuries were--seemed to be rotationally-induced. And, it went up by about…I showed a third in the presentation - this, again, is conservative…it showed something like 50%. But what I'd like to do is more of a sensitivity analysis on the injuries that we do know: the DAI's versus the concussions and the hematomas to see, within those, where the problem really lies, and what work is left to be done. Thank you.

Q: *Tahsin Ali, University of Virginia*
I did a little work in trying to investigate the effect of rotation on HIC values. So, I made a 2 degree-of-freedom model, which actually translates and rotates as it moves and then the HIC values come, depending on the situation, on where it goes and hits and the kind of counter-measure. I mean, the HIC values could come as low as 30% lesser than pure translation motion. So, I mean, that--I mean that makes me think that you can have cars which can actually give you lower HIC values but still because of the rotation, there could be injuries. So, why don't we have any kind of standards or regulations, which take care of the injuries induced by angular acceleration?

A: Well, this presentation was supposed to support that idea.

Q: Yeah, I mean. [chuckle] I mean, it's kind of a general inquiry. I mean, I'm just wondering why--Why don't we have anything? We have a HIC criterion for translational induced injuries, but why don't we have anything for rotational induced injuries?

A: I'm not a NHTSA policy maker, so I can't answer that question. Sorry.

Q: *John Melvin, Tandelt, Inc.*
Just a comment on that. The problem is: there's all combinations of angular and translational acceleration in any head hit so the idea that you should separate them out and look at them is really not the way to go. You've got to do a brain model where it's all built in. Just one other comment: In NASCAR in the last year or so, we've had two or three serious brain injuries. They've all been related to hitting the top of the helmet tangentially during impact. So, you can get a hard contact and get head rotational easy. And so, I don't know how you separate all that out because you can't, en masse, figure out exactly how they got hit; but, you can get rotation in hard contact.

A: Yeah again, we were just trying to look at the injury record and make a distinction whether that person had injuries that were--that we know are attributable to rotation only. And those that did--and there were a lot of them, those are the ones that we concentrated on, and as it turned out, it's a third of the problem. And it's something we can do something about.