REAL-WORLD REAR IMPACTS RECONSTRUCTED IN SLED TESTS

Astrid Linder [1,2], Matthew Avery[1], Anders Kullgren[3], Maria Krafft[3]

[1] The Motor Insurance Repair Centre, Thatcham, United Kingdom
[2] Monash University Accident Research Centre (MUARC), Australia
[3] Folksam Research, Sweden

ABSTRACT

The risk of soft tissue neck injuries as a result of rear impacts is influenced by both vehicle specific features and the impact severity of the crash. Links between real-world neck injury symptoms and dummy readings as well as neck injury criteria obtained from crash test dummies needs to establish for test methods that evaluate protection against theses injuries.

This study identifies average values of neck injury criteria and dummy readings that correspond to the risk of an adult sustaining soft tissue Neck Injury Symptoms (NIS) persisting for more than one month (NIS>1). Of the real-world crashes in the Folksam database, 25 were selected according to risk levels of NIS>1 associated with mean acceleration intervals: 0% risk and 0-3 g; 0-15% risk and 3-4.5 g; 15-60% risk and 4.5-6 g. The acceleration pulses from the vehicles were reproduced in detail on a sled with a dummy in the same type of seats as in the impacted vehicles.

Various levels of NIC, Nkm, forces from the upper neck load cell and T1 x-acceleration corresponded to the average risk levels of NIS>1 in each interval; 0%, 10% and 30%. The results provide a link between real-world NIS>1 and average dummy readings as well as neck injury criteria obtained from a crash test dummy in sled tests.

Keywords: Whiplash, Rear impact, Real-world crashes, Sled tests, Injury criteria

REAR IMPACTS resulting in soft tissue neck injuries, which are commonly called *whiplash injuries*, are both common and costly to society. The total annual monetary cost for soft tissue neck injuries in the United States (population of 268 million) has been estimated at US$ 7 bn (O'Neill 2000), while Ryan and Gibson (2000) estimated the annual cost for whiplash associated disorders in Australia (population of 19 million) at approximately AU$ 540 m. In the United Kingdom, British Insurers report that whiplash costs are in excess of UK£ 1.2 bn annually (ABI, 2002).

Watanabe et al. (2000) reported that 43.5% of all injuries from vehicle crashes were from rear impacts and, of these injuries, approximately 90% were to the neck. The vast majority of occupants who suffer initial soft tissue neck injuries recover fully. However, between 8.6 % and 44 % of the occupants with initial neck injury symptoms continue to have symptoms a year later (Nygren 2000). It has been shown that there is a considerable difference in risk of long-term neck injuries in vehicles of the same weight class (Krafft 2002, Hell et al. 2003). Recently, anti-whiplash systems that are designed to reduce the risk of soft tissue neck injuries have been installed in several vehicles (Viano and Olsen 2001, Jakobsson 2004). The introduction of anti-whiplash systems and the large variation in the risk of sustaining such injuries in the vehicle fleet (Krafft 2002, Farmer et al. 2003, Hell et al. 2003) necessitate the implementation of laboratory test methods that can evaluate occupant protection in rear impacts.

Rear impacts causing soft tissue neck injuries most frequently occur at delta-Vs (changes of velocity) below 30 km/h in the struck vehicle (Parkin et al. 1995, Hell et al. 1999, Temming and Zobel 2000, Krafft et al. 2002). Furthermore, it has been shown that mean acceleration influences the risk of AIS 1 neck injuries (Krafft et al. 2002). Dummy responses in crash tests have been shown to vary depending not only on the delta-V but also on the duration of the crash pulse for a given delta-V (Linder et al. 2001). Therefore, the manner in which the delta-V was generated is of significance when attempting to link real-life injury outcomes to readings and injury criteria obtained from crash test dummies in laboratory tests.

It is essential to establish dummy readings and injury criteria that correspond to the risk of such injuries when designing impact severities for sled test methods that evaluate the protective performance of seats in rear impacts. Attempts have been made by Kullgren et al. (2003) and Eriksson and Kullgren (2003), where 79 real-life crashes in the Folksam database were reconstructed using Madymo mathematical computer simulations. Correlations between dummy readings and injury criteria and real-life whiplash injury risk were presented. However, the Madymo model was not fully validated to cover the whole dynamic phase of the crash. There is a need for further studies to establish dummy readings and injury criteria that correspond to risk of whiplash injury.

At the moment test methods that evaluate the protective performance of seats in rear impacts are in use (Folksam and SNRA 2003, ADAC 2003, IIWPG 2004), and several others are under development Cappon et al. (2001), Muser et al. (2001), IIHS (2001), Langwieder and Hell (2002) and Linder (2002) and under discussion in groups such as IIWPG (International Insurance Whiplash Prevention Group), EuroNCAP (European New Car Assessment Program), EEVC (European Enhanced Vehicle Safety Committee) Working Group 20 and ISO (International Organization for Standardisation) TC22/SC10/WG1.

Crash pulse recorders in vehicles exposed to crashes can provide time history information on how the delta-V was generated and this information together with knowledge of the injury outcome for the occupants in the crash can form the basis for linking real-world data to dummy readings in the crash laboratory.

AIM

The objective of this study was to identify average values of neck injury criteria and dummy readings that correspond to various risks of an adult sustaining soft tissue Neck Injury Symptoms which persist for more than one month (NIS>1) by reconstructing real-world rear impact crashes using sled tests. The real-world data used were acceleration pulses registered in the vehicles in combination with knowledge about the injury outcomes in terms of neck injury symptoms of the front seat occupants.

MATERIALS AND METHOD

Of the real-world crashes in the Folksam Database, 25 were selected to be reconstructed in sled tests. The cases were selected according to levels of mean acceleration intervals and the crashes were reconstructed in sled tests where the real-world acceleration pulses from the vehicles were reproduced using a HyperG sled. Similar seats to those found in the impacted vehicles were placed on the sled with a BioRID IIc crash test dummy representing the occupant. The dummy was thus exposed to a similar impact as the occupants in the crash.

FOLKAM CPR CASES: The cases that were reconstructed were obtained from the Folksam database (Krafft et al. 2002) which provided both Crash Pulse Recorder (CPR) and injuries outcome data. The injuries to the occupants were traced and followed up by Folksam using the following method: The body shop assessing the vehicle reported to Folksam Research that a CPR-fitted vehicle insured by Folksam had been involved in a crash. The CPR was sent to Folksam Research for further analysis, the body shop filled in a detailed questionnaire about the damage to the vehicle and a further questionnaire was sent to the occupants of the car. If any occupants of the car reported neck injuries, interviewers from Folksam would follow up with telephone interviews conducted at 1, 3 and 6 month intervals after the crash. Where the occupants no longer reported neck injuries, no further interviews were conducted. It was firmly established that the answers or comments made by the occupants were independent of any claim or financial settlement made by Folksam and therefore had no bearing on any compensation awarded.

The Folksam database (Krafft et al. 2002) contained 68 cases with 97 occupants subjected to rear impacts whilst in Toyota vehicles, Table 1. The vehicles featured were mostly two different Toyota Corollas and some Toyota Yaris. The vehicles were all 5 door hatchbacks.

The cases in the Folksam database were divided into three groups (A, B and C) according to the levels of mean acceleration that were measured in the crash. Mean accelerations below 3 g were classed as Group A, Group B was 3 g - 4.5 g and Group C was between 4.5 g and 6.0g. The risk of sustaining soft tissue Neck Injury Symptoms for more than one month (NIS>1) was calculated as the proportion of injured occupants within each interval of mean acceleration, Figure 1. The risks of sustaining soft tissue Neck Injury Symptoms for more than one month (NIS>1) corresponding to the range of mean accelerations for the three groups were:

Group	Mean acc. Interval	Risk Interval	Average Risk
A	(0.0-2.9g)	0% risk of NIS>1	0% risk of NIS>1
B	(3.0-4.4g)	0-15% risk of NIS>1	10% risk of NIS>1
C	(4.5-6.0g)	15-60% risk of NIS>1	30% risk of NIS>1

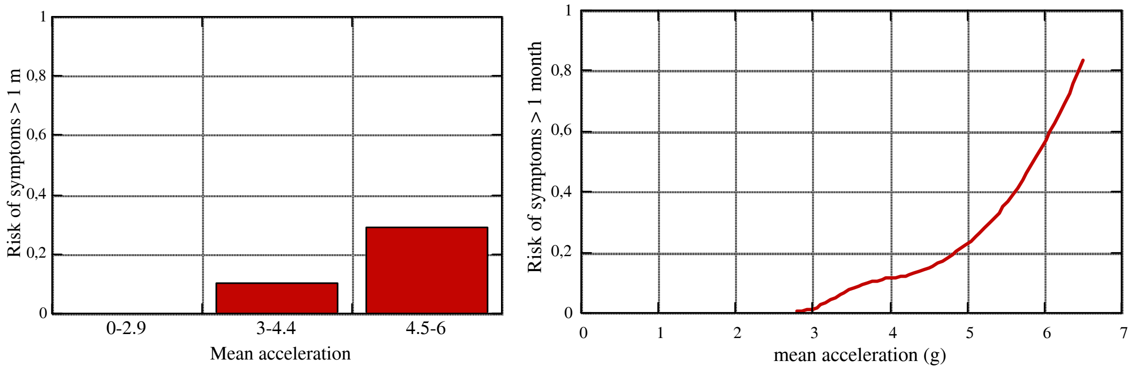

Figure 1. Risk of neck injury symptoms > 1 month versus mean acceleration, from the data in Krafft et al. (2002).

The risk figures were calculated based on the cases in Krafft et al. (2002). Cases where the occupant reported a previous neck injury were excluded from the calculation of the risk figures. It should be noted that the risk figures were calculated as average values for three seats in the study; Toyota Corolla 93-97, Corolla 98-02 and Toyota Yaris.

Table 1. The injury outcome for front seat occupants of 68 crashes in the Folksam database (Krafft et al. 2002), divided into three groups according to mean acceleration (Group A <3 g, Group B 3 g – 4.5 g and Group C 4.5 – 6 g).

Group	Number of cases	No neck injuries symptoms	Short-term neck injuries symptoms	Long-term neck injuries symptoms	Previous neck injuries	Total number of occupants
A	28	28	7	0	1	36
B	24	22	10	1	2	35
C	16	6	10	10	0	28
Total	68	56	27	11	3	97

SELECTED CPR CASES: For the reconstruction of real-world crashes in sled tests, only 25 cases were selected due to the cost associated with the reconstruction. Cases where the occupants had a previous neck injury and impacts with delta-Vs below 4 km/h and above 30 km/h were all excluded as suitable for reconstruction in the sled tests. The higher level of delta-V (30 km/h) and mean acceleration (6 g) were chosen as the upper limit for the dummy used in the reconstruction, the BioRID IIc, to be used without the risk of any components breaking. The lower level (i.e. Delta-V 4 km/h) was chosen based on the limitations of the HyperG sled to reconstruct the delta-V below 4 km/h with the +/-5 % tolerance. With the cases from Krafft et al. (2002) and the exceptions mentioned above, there were a total of 56 cases from which to select for this study: 13 cases in Group C, 22 cases in Group B and 22 cases in Group A. The selected cases to be reconstructed in the sled tests were those that best represented a 6 o'clock rear impact. Cases where the seat back collapsed and cases with multiple impacts were also excluded. The CPR cases from the Folksam database selected to be reproduced in the sled and the impact severity and the injury outcome for the occupants in the selected cases are shown in Table 2.

Table 2. Impact severity and injury outcome for front seat occupants in cases selected from the Folksam database for reconstruction in sled tests where LT is NIS>1, ST is NIS<1 and N is NIS=0.

Case No.	Vehicle	Delta-V (km/h)	Mean acc. (g)	Peak acc. (g)	Driver/Pass. Male/Fem.	Injury	Pulse duration (ms)
29533	TC 1996	28.2	5.8	10.1	D-F/P-M	LT/LT	140
30013	Yaris	24.1	5.7	12.0	D-F/P-M	LT/N	120
30049	Yaris	20.1	5.6	13.0	D-F	ST	101
29521	TC 1997	14.7	5.5	9.0	D-M	LT	77
30032	TC 2000	20.4	5.2	12.8	D-F/P-M	ST/ST	111
29967	TC 2000	14.7	5.2	10.8	D-M/P-F	ST/ST	79
30052	TC 1998	10.4	5.1	10.5	D-M/P-F	N/N	57
29876	TC 2000	17.6	5.0	12.4	D-M/P-F	LT/LT	100
29739	TC 1999	17.1	4.6	12.1	D-M/P-F	LT/ST	102
29965	TC 2000	16.9	4.2	8.7	D-M	N	112
29732	TC 1999	19.5	4.0	9.2	D-M/P-F	N/N	134
29693	TC 1998	12.4	4.0	11.2	D-F	ST	60
29652	TC 1997	9.4	3.3	8.1	D-M/P-M	N/ST	87
29780	TC 1998	6.5	3.3	6.1	D-F/P-M	ST/ST	52
29614	TC 1997	12.0	3.2	7.5	D-M/P-F	N/ST	109
29706	TC 1998	7.7	2.9	5.7	D-F	N	68
29778	TC 1998	7.3	2.8	4.8	D-F	N	75
29781	TC 1998	7.3	2.7	6.3	D-F/P-M	N/N	78
29975	TC 1995	5.9	2.7	10.0	D-M/P-M	N/N	54
29945	TC 1995	4.5	2.7	4.7	D-M	ST	43
29911	TC 2000	4.3	2.5	5.1	D-M	N	50
29677	TC 1996	5.8	2.4	5.1	D-M	N	72
29849	TC 1999	4.2	2.2	4.1	D-M	N	54
29924	TC 1996	4.6	1.9	3.6	D-M/P-F	N/N	68
29601	TC 1996	4.3	1.8	3.7	D-M	N	65

The distribution of the delta-V as a function of mean acceleration for the 25 selected cases and the cases from Krafft et al. (2002) with a delta-V between 4 and 30 km/h and mean acceleration below 6 g is shown in Figure 2.

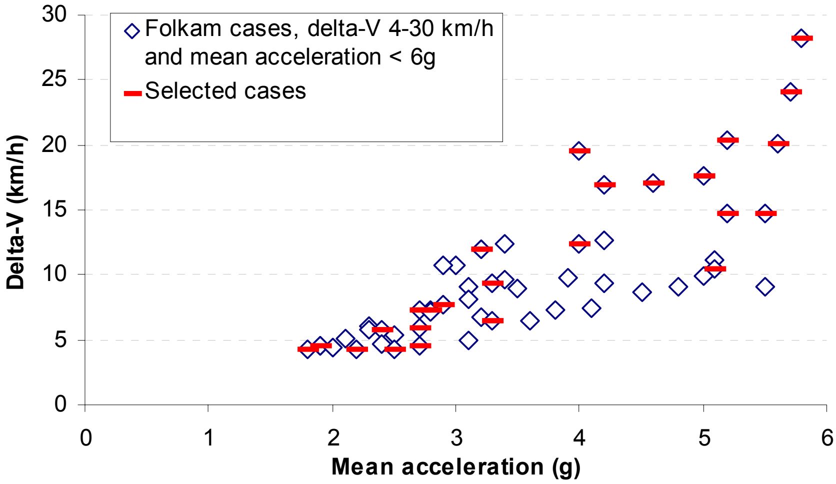

Figure 2. Delta-V as a function of mean acceleration for the cases in the Folksam database (Krafft et al. 2002) with delta-V's between 4 and 30 km/h and mean acceleration below 6 g and the 25 selected cases that were reproduced in the sled.

SLED TESTS: The crash pulses from the CPRs were reconstructed in detail on the HyperG sled at Thatcham, UK. The sled had the ability to reproduce the variations of the acceleration pulse of the CPR in great detail as shown in Figure 3. The velocity and duration of the pulse from the CPR were all reproduced within the tolerances of +/- 5 %. The acceleration pulse from each crash recorder was applied to the sled.

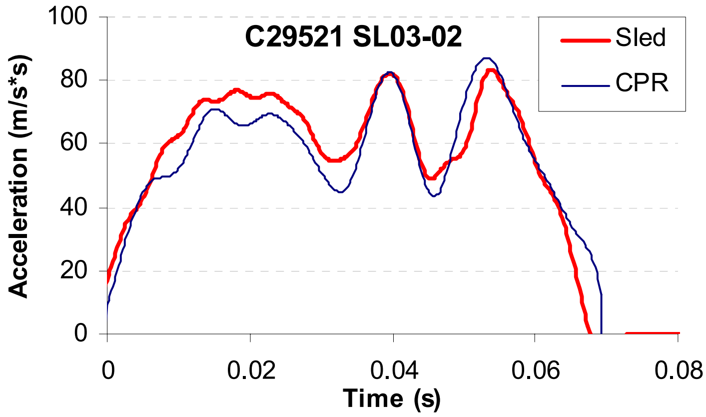

Figure 3. An example of the crash pulses from the CPR and the same pulse reproduced on the Hyper G sled.

A 50th percentile BioRID IIc dummy was positioned in the seat (Figure 4) and set up according to the BioRID seating procedure V1.4. The horizontal and vertical position and angle of each seat was closely matched to that of the individual model featured in the study. A B-Pillar and brackets for each seat were manufactured and a belt system with similar geometry was also used. The dummy was seated with a generic three point belt from the appropriate Toyota vehicle. The seats were attached to the sled via a solid bracket that gave the seat the same angle relative to the horizontal plane as that found in the real-world crashed vehicles. The seat was placed in its mid position. The head restraint position in the real-life crashes was not known. Therefore, in the reconstructions of the crashes the same head restraint position was chosen to be the same for all tests. The head restraints on all seats were set in the fully retracted and rearward position representing the most commonly adjusted position in real-world use (IIHS 2001). Newly manufactured seats of Toyota Corolla 1993-97, Toyota Corolla 1998-2002 and Toyota Yaris were used in the sled tests. For each test a new seat was used.

Figure 4. The BioRID II c placed in a Toyota Corolla seat on the Hyper G sled.

Accelerometers were placed in the head, at C4, T1, T8 and the pelvis. The transducer data was sampled at 10,000 Hz and filtered according to SAE J211 recommendations. The C1, T1 and T8 acceleration was filtered with CFC 60. The head to head restraint contact time was measured by the use of aluminium contact foil placed on the back of the dummy head and on the surface of the head restraint. The dummy head was also equipped with an upper neck load cell.

Two neck injury assessment parameters, the Neck Injury Criterion (NIC) and the Nkm were calculated. The NIC (Boström et al. 1996) used in this study was the peak NIC value during the first 150 ms (Boström et al. 2000). For the Nkm calculations (Schmitt et al. 2002) the absolute values of the force and moment were used. Other parameters assessed were upper neck shear force (Fx) and tension force (Fz), T1 x-accelerations and the time when head-to-head restraint contact occurred.

REPEATABILITY: In order to ascertain the repeatability of the test set-up, a number of repeat tests using the same test conditions were performed. The same pulse was applied to three new Toyota Corolla '98 seats with the dummy positioned identically in all three tests. The repeatability was calculated as the difference between the maximum peak value for any of the tests and the average peak value for the three tests.

RESULTS

The results of the dummy readings and injury criteria calculated as the average values for the three groups with different risk of injuries are found in Table 3. Note that the associated risk figures were calculated based on the crashes included in Krafft et al. (2002) within each interval of mean acceleration and not on the crashes included in this study. NIC, T1 x-acceleration, Nkm, Fx rear and Fz all increased with increased risk of neck injury symptoms for more that one month, Table 3.

Table 3. Average dummy readings and injury criteria and for the three groups with different risk of injuries for the driver.

Group	n	Ave. Delta-V (km/h)	Ave. Mean acc. (g)	Associated average risk of neck symptoms > 1 month	Ave. NIC (m^2/s^2)	Ave. T1 x-acc. (g)	Ave. Nkm	Ave. Fx rearward (N)	Ave. Fz (N)	Ave. Occurrence of head restraint contact (ms)
C	9	18.7	5.3	30%	23.3	14.9	0.52	454	1202	87
B	6	12.4	3.6	10%	16.7	9.6	0.37	178	659	87
A	10	5.6	2.5	0%	9.9	4.8	0.18	113	204	95

Dummy readings and injury criteria from each test are found in Tables 4a and 4b. The results are presented in two tables for the ease of reading. NICmax, Nkm, T1 x-acceleration and upper neck loadings versus mean acceleration are presented in the Appendix.

Table 4a. Dummy readings and injury criteria from the 25 Folksam CPR real-world crashes reconstructed in sled tests.

Test ID	Folksam ID	CPR Delta-V (km/h)	CPR mean acc. (g)	NIC (m*m/s*s)	HR contact (ms)	Head x-acc. (g)	T1 x-acc. (g)	Max T1-Head x-acc. (g)	Max T1-Head x-acc. @ (ms)	Min T1-Head x-acc (g)	Min T1-Head x-acc @ (ms)
SL03-01	**30013**	24.1	5.7	20.2	71	22.6	19.6	9.1	71	-18.5	106
SL03-02A	**29521**	14.7	5.5	18.8	113	19.6	10.6	7.7	85	-21.9	129
SL03-02B	**29521**	14.7	5.5	21.6	94	20.5	11.9	6.9	91	-23	134
SL03-02C	**29521**	14.7	5.5	20.7	97	21.4	11.4	7.1	94	-24.2	134
SL03-03	**29677**	5.8	2.4	10	96	5.7	4.9	4.4	80	-5.9	143
SL03-05	**29924**	4.6	1.9	7.6	90	4.7	3.9	3.2	78	-4.8	143
SL03-06	**29965**	16.9	4.2	15.3	71	24.3	13	6.4	71	-20.2	107
SL03-07	**29967**	14.7	5.2	23.1	82	31.8	14.2	8.6	81	-33.7	101
SL03-08	**30032**	20.4	5.2	23.8	88	30.9	14	9.7	81	-21.2	139
SL03-10	**29693**	12.4	4.0	27.8	79	25.6	11.4	10.3	78	-22.6	104
SL03-11	**29911**	4.3	2.5	7.1	98	5.3	3.7	3.3	72	-5.2	120
SL03-12	**29781**	7.3	2.7	15.2	81	14	7	6.9	69	-13.1	110
SL03-13	**30052**	10.4	5.1	26.3	79	21.3	11.4	11.7	70	-19.9	104
SL03-15	**29849**	4.2	2.2	8.1	100	5.5	4.3	3.7	77	-5.3	121
SL03-16	**29706**	7.7	2.9	14.3	85	12.8	6.4	5.4	80	-11.5	117
SL03-17	**29876**	17.6	5.0	28.5	81	36.3	17.6	12.3	70	-34.4	102
SL03-19	**29945**	4.5	2.7	6.3	114	3.1	3.4	2.9	77	-3.8	141
SL03-20	**29975**	5.9	2.7	11	90	5.8	5.2	4.8	72	-5.4	135
SL03-21	**29780**	6.5	3.3	12.6	87	10.5	5.7	5.4	75	-9.1	114
SL03-22	**29739**	17.1	4.6	25.7	81	36	21.3	9.7	77	-40.3	106
SL03-24	**29533**	28.2	5.8	17.9	115	11.3	7.7	6.8	89	-7.7	159
SL03-25	**29652**	9.4	3.3	16.2	91	11.9	7.1	6.3	81	-13	128
SL03-26	**29601**	4.3	1.8	4.8	124	2.9	2.6	2.2	75	-3.2	152
SL03-27	**29614**	12	3.2	14.8	104	14.1	6.4	5.1	102	-14.2	144
SL03-28	**29732**	19.5	4.0	18.2	79	29.4	16.5	7.4	73	-26.3	115
SL03-29	**30049**	20.1	5.6	22.7	87	26.1	16.2	9.2	83	-18.6	107
SL03-30	**29778**	7.3	2.8	13.3	87	13.6	6.1	5.4	83	-13.3	118

Table 4b. The remaining dummy readings and injury criteria from the 25 Folksam CPR real-world crashes reconstructed in sled tests.

Test ID	My ext. (Nm)	Fx rearward (N)	Fz (N)	Fx forward (N)	Nkm @ HR contact	Nkm @ HR contact @ (ms)	Nkm after HR conatct	Nkm after HR contact @ (ms)	Initial HR x-dist. (mm)
SL03-01	31.2	646	1223	303	1.02	117	0.65	352	46
SL03-02A	17.8	248	854	161	0.49	124	0.37	391	40
SL03-02B	17	256	915	153	NA	NA	NA	NA	NA
SL03-02C	17.1	294	968	159	NA	NA	NA	NA	NA
SL03-03	9	160	208	73	0.26	130	0.17	351	35
SL03-05	7.2	122	165	65	0.21	129	0.15	357	40
SL03-06	13.3	114	784	252	0.27	107	0.58	319	70
SL03-07	6.6	271	1309	251	0.57	108	0.54	319	80
SL03-08	36.4	893	1167	245	1.19	115	0.57	342	80
SL03-10	10.4	209	894	220	0.31	106	0.48	326	80
SL03-11	2.8	84	141	63	0.12	120	0.14	313	75
SL03-12	2.8	118	343	130	0.15	116	0.29	343	80
SL03-13	4.8	159	717	179	0.21	107	0.39	329	75
SL03-15	2.7	90	130	60	0.13	131	0.15	314	86
SL03-16	3.6	122	292	122	0.15	122	0.26	354	75
SL03-17	7.3	476	1703	269	0.65	112	0.56	338	75
SL03-19	5	95	93	41	0.17	143	0.09	405	40
SL03-20	8.2	120	206	70	0.22	124	0.16	380	40
SL03-21	2.6	108	293	98	0.14	115	0.21	349	85
SL03-22	6.7	409	1919	231	0.56	110	0.47	350	80
SL03-24	22	246	600	186	0.47	158	0.4	519	40
SL03-25	15.5	223	523	110	0.38	121	0.23	362	40
SL03-26	5.2	97	89	37	0.15	168	0.09	420	40
SL03-27	16.2	249	609	149	0.45	138	0.33	400	40
SL03-28	12.6	148	1029	238	0.31	158	0.53	332	75
SL03-29	41.8	815	1097	334	1.25	117	0.8	353	60
SL03-30	4.3	126	340	110	0.16	121	0.22	353	75

In this study, the occurrence of two proposed injury criteria, NICmax and Nkm, was monitored. The maximum NIC occurred several tens of milliseconds before the maximum Nkm, as shown for test SL03-07 in Figure 5. The maximum NIC occurred around the time for head-to-head restraint contact whereas the maximum Nkm during head restraint contact occurred around maximum rearward motion of the head.

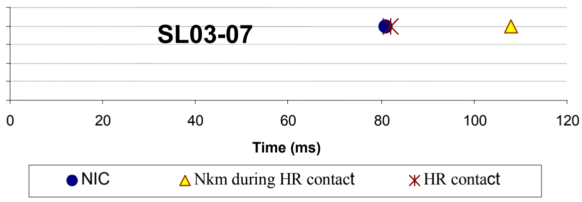

Figure 5. The occurrence of maximum NIC, maximum Nkm during head restraint contact and head-to-head restraint contact time in test SL03-07.

An examination of the two types of Corolla seats that were tested at delta-Vs of 14.7 and 17.6 km/h in tests SL03-02B and SL03-17 showed that the resulting deformations of the seats were either negligible or non-existent in these tests.

The repeatability tests showed a difference of 4 - 12 % between average peak x-acceleration of the head and T1, peak Fx rearward, Fz and My, Head restraint contact, NIC and the test results for the three tests (Figure 6).

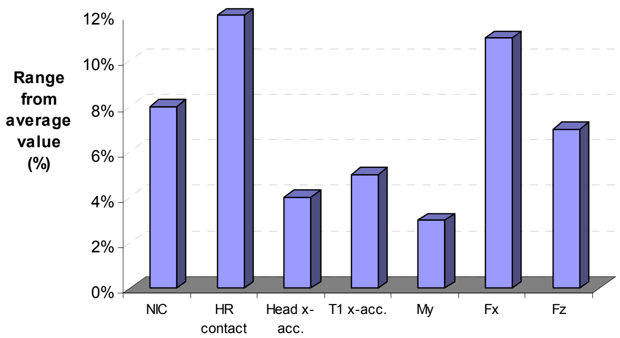

Figure 6. Repeatability of the test set-up from three identical tests. The same pulse applied to three new seats with the dummy positioned in the same way in the three tests.

DISCUSSION

When designing sled test methods that evaluate the protective performance of seats in rear impacts, it is essential to establish crash severity that in real-life crashes correspond to a level that causes injury, and to establish dummy readings and injury criteria that correspond to the risk of such injuries. Several test method have been developed, for example at IIWPG, Folksam/SNRA and ADAC. Although crash severity, dummy readings and injury criteria varies in the different methods, the results in general all point in the same direction. It is, however, important to study how the rating results correlate with real-life injury outcome to be able to adjust the test methods.

The data in this study provide a link between real-world neck injury symptoms and average dummy readings as well as neck injury criteria obtained from a crash test dummy following reconstructions of real-world crashes. Average dummy readings and neck injury criteria corresponding to 0%, 10% and 30%, average risks of long-term neck injury symptoms in real-life crashes were identified from the reconstructed cases.

In this study, the influence of the impacting vehicle and its interaction with the impacted vehicle was taken into consideration since the crash pulse recorded under the front seat in the impacted vehicle was reconstructed in the sled. However, the variation in occupant size was not considered in this study, as there is only one dummy size (a 50th percentage male weighting 76.5 kg) for low velocity rear impacts Furthermore, it was not possible to place the dummy in the same position as that of the injured occupant nor was it possible to set the head restraint in the position set during the real-world crash since the occupant and head restraint position at the time of the impact was not monitored and thus not part of the information available in the Folksam database.

The influence of backset and headrest height on whiplash injury risk curves was however, investigated using mathematical simulations (Eriksson and Kullgren, 2003) for all cases in the Folksam database. The study showed a spread in the risk curves for Nkm and NIC values due to the spread in backset and headrest height. From the simulations it was found that the spread due to both seat geometry and sitting posture was not in the order of magnitude to overshadow the results which indicated that Nkm and NICmax were robust criteria for estimating long-term soft tissue neck injuries from rear impacts (Eriksson and Kullgren, 2003).

When testing vehicle seats on a sled, the influence of the rear structure of the car on whiplash injury risk is not reflected if the same generic pulse is used for all seats. Both stiffness and mass of the vehicle have been shown to influence real-life whiplash injury outcome (Avery 2000, Krafft 1998). However, the performance of different seats has been shown to create considerable dynamic response and the main efforts within the car industry to minimise whiplash injuries in rear impact has been concentrated to changes of the seat, including the head restraint. Therefore testing the seats is probably to date the most effective way to evaluate the protective performance of cars in rear impacts.

The seats in these tests were attached to the sled via a solid bracket that gave the seat the same angle relative to the horizontal plane as that found in the vehicles. Thus, the floor of the seat was regarded to be rigid in the tests. This assumption was regarded as acceptable since tests previously performed with a body in white of a Toyota Corolla with CPR pulses from delta-V between 9.4 km/h to 28.2 km/h and mean accelerations from 3.3 g to 10.1 g have shown no ruptures in the attachments of the seat to the floor (Linder 2002).

In this study new seats were used while in the real-world cases, the seats would have been used up to a certain degree. A comparison between the dynamic performance of the new seats and used seats could be made for four of the Folksam cases reproduced in this study. These four cases had earlier been reproduced in sled tests in a HyGe sled (Linder 2002). In Linder (2002), the BioRID II was placed in a used Toyota seat in a body in white and the acceleration pulse from the crash recorder in the real-world collision was reproduced. The comparison between the used and new seats did not show any trend towards a major difference in dummy readings and injury criteria between the two types of seats (Table 5). However, head-to-headrest contact time was higher in all tests with new seats.

Table 5. Comparison between the results from tests from Linder (2002) (tests AL) and the same Folksam cases reproduced in this study (tests SL).

Test ID	Seat Type	CPR Pulse	Folksam ID	NIC	HR contact (ms)	Head x-acc. (g)	Pelvis x-acc.(g)
SL03-02A	New 93	14.7	**29521**	18.8	113	19.6	7.8
AL20385	Used 93	14.7	**Case 3**	20	82	20.1	12.5
SL03-24	New 93	28.2	**29533**	17.9	115	11.3	13
AL20384	Used 93	28.2	**Case 1**	21.4	87	13.6	16.2
SL03-25	New 93	9.4	**29652**	16.2	91	11.9	5.4
AL20388	Used 93	9.4	**Case 8**	15	84	14.1	5.8
SL03-27	New 93	12	**29614**	14.8	104	14.1	6.4
AL20387	Used 93	12	**Case 7**	11.4	93	13.8	9.9

Dummy readings and injury criteria will depend on the dummy used in the tests, if all other test conditions in this study were to be replicated. This study was performed with the BioRID IIc. In a comparison between BioRID and other dummies, Zellmer et al. (2002) showed that both NIC, Nkm and forces and moment from the upper neck load cell will vary between the dummies when exposed to the same test configuration. Therefore, the average dummy readings and injury criteria for the three injury risk groups can be expected to be somewhat different if a dummy other than the BioRID were utilised for the tests or if a version of the BioRID with fundamental different dynamic performances than the BioRID IIc were used.

One of the unique features of the Folksam database compared to other databases with real-world crashes where injuries have occurred is that the Folksam database consists of crashes where injuries occurred as well as crashes where no injuries occurred. Since both injury-causing crashes and non-injury-causing crashes were reconstructed it was possible to identify thresholds for dummy readings and the injury criterion that represents a non injurious level (Table 3). The average injury criterion for the group of cases where the average risk of long term injury was 0% was a maximum NIC of 9.9 and a maximum Nkm at head restraint contact of 0.18 (Table 3). The average delta-V and mean acceleration for these cases were within the range of delta-V and mean acceleration where volunteer tests have been performed (Linder 2002).

The number of reconstructed crashes was in this study relatively low (25 crashes). Some indications could, however, be identified. The results partly correspond to previous findings using mathematical Madymo simulations of 79 crashes in the Folksam database (Kullgren et al. 2003, Eriksson and Kullgren 2003), where it was indicated that NICmax and Nkm could predict whiplash injuries. However, the Madymo model used in those studies was not fully validated to measure neck loadings in the later phase of the crash. The results in this study give further knowledge regarding correlation between for example neck loads, such as Fx and Fz, and risk of neck injury symptoms for more than 1 month. Such risk levels could be used when designing impact severities for sled test methods that evaluate the protective performance of car seats, but more tests are necessary to further establish such risk levels and to find injury criteria and dummy readings correlating to injury outcomes.

The risk of whiplash injury is determined by a large number of varying factors such as occupant age and stature, seating posture, vehicle model, structural engagement, crash severity etc. The results in this study are based on real-life injury risk principally from two car models. Therefore no general thresholds for all seat and vehicles could be identified for the studied dummy readings and injury criteria.

CONCLUSIONS

Twenty-five real-world crashes were reproduced in sled tests. The results from the tests provide a link between real-world neck injury symptoms and average dummy readings as well as neck injury criteria obtained from the crash test dummy.

Three levels of risk of neck injury symptoms (0%, 10% and 30%) which persisted for over one month for the driver corresponded to various levels of NIC, Nkm, forces from the upper neck load cell and T1 x-acceleration.

Large differences in average dummy readings were found for the three risk groups studied. The difference between the average dummy readings corresponding to the risk levels of 0% and 30% was between a of factor 2 and 6, indicating that these dummy readings could be used to predict risk of long-term soft tissue neck injuries.

From the limited number of crashes reconstructed, indications that NICmax below 16.7, T1 x-acceleration below 9.6 g, Nkm below 0.37, Fx below 178 N and Fz below 659 N in the studied vehicle models corresponded to less than 10 % risk of neck injury symptoms persisting for more than 1 month could be identified.

ACKNOWLEDGEMENT

The authors would like to thank Toyota Motor Co. for their cooperation in this study and their generous supply of seats.

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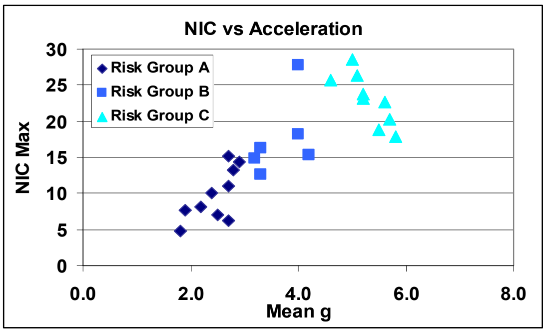
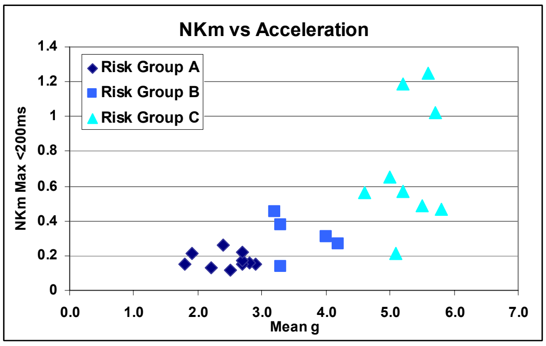
APPENDIX


NIC vs Acceleration
NIC Max
Mean g
Risk Group A
Risk Group B
Risk Group C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NKm Max <200ms
Mean g
Risk Group A
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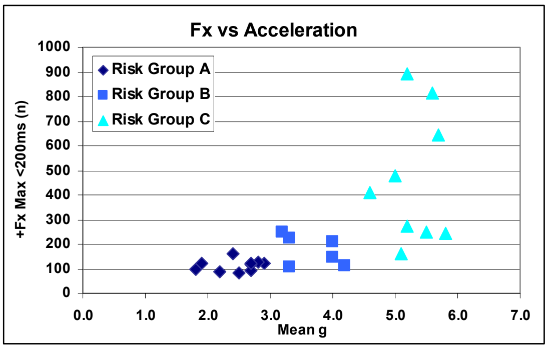
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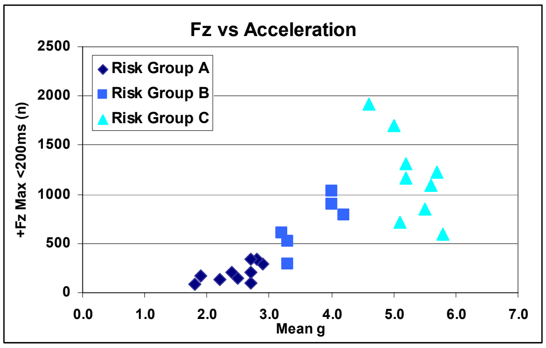
Mean g
Risk Group A
Risk Group B
Risk Group C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Mean g
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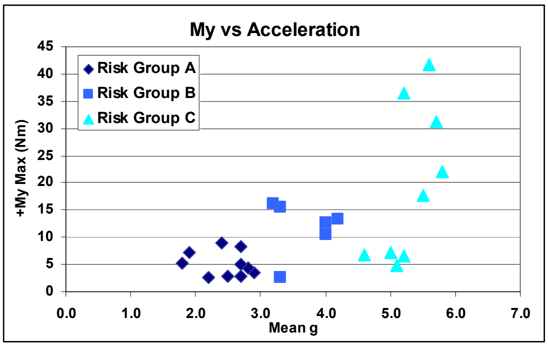
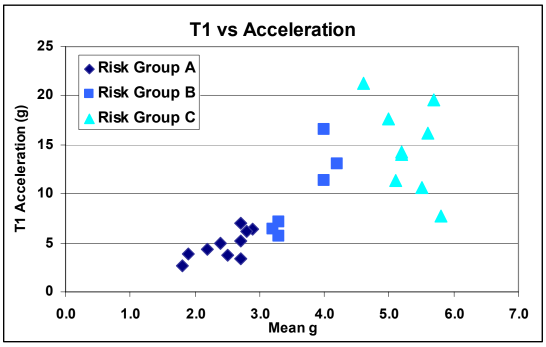

My vs Acceleration
+My Max (Nm)
Mean g
Risk Group A
Risk Group B
Risk Group C


T1 vs Acceleration
T1 Acceleration (g)
Mean g
Risk Group A
Risk Group B
Risk Group C