CRASH PULSE RECORDERS IN REAR IMPACTS - REAL LIFE DATA.

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ABSTRACT

AIS 1 neck injuries have become the most common injury in vehicle crashes, especially rear impacts. Reserch has shown that there are variations in rear impacts causing initial symptoms and residual disability to the neck. Therefore impacts in which the duration of symtoms differ need to be separated in analyses. Concerning AIS 1 neck injury, crash severity is usually measured as change of velocity. The correlation between injury risk and impact severity parameters based on acceleration levels is to a high extent unknown. In this study, the results from crash recording of real life rear impacts are presented where the change of velocity and the crash pulse is measured. Out of 22 impacts, it was shown that most of the occupants that sustained symptoms the shape of the crash pulse varied considerably and the peak acceleration varied from 2.7g to 14.7g. In one impact the occupant had whiplash symptoms six month after the collision (peak acceleration 14.7g) and in another impact , two months after, when this article was written (peak acceleration 12.6g). Also, high change of velocity (>20km/h) does not have to cause disability to the neck at least when the mean acceleration is less than 7g and no clear peaks exist.

INTRODUCTION

The main public-health problems concerning neck injuries AIS 1 are those leading to long-term consequences. Nygren (1984) and Norin et al. (1996) found that 1 out of 10 occupants sustained medical disability a year after a collision. The need of preventive measures against long-term disability outcome are important since accident data collected for the initial symptoms of neck injuries AIS 1 seem not to predict the risk factors for long-term consequences (Krafft, 1998; Ryan et al, 1994). A new mathematical model that predicts neck injuries has been proposed. The Neck Injury Criterion (NIC) includes parameters such as seat-back design, change of velocity and crash pulse (Boström et al, 1996, Boström et al, 1997).

Neck injuries in rear impacts mostly occur at low impact-velocities, typically less than 20 km/h (Romilly et al 1989, Olsson et al 1990). Mc Connel et al (1995) performed a series of low-speed rear-end crash tests with seven male volunteers, with velocity changes of up to 10.9 kph, but the crash pulse was not mentioned. No one sustained neck injury symptoms after a few days. In another study with volunteers (Eichberger et al, 1996) where the sled impact velocities were 8-11 km/h and the mean decelerations 2.5g, the volunteers suffered whiplash symptoms for approximately 24 hours. In one of these test, the volunteer sustained symptoms for about two weeks. Olsson et al (1990) showed that the duration of neck symptoms caused by rear end collisions seems to correlate with the degree to which the impacted vehicle is deformed, provided that one of the rear side bumper was activated.

Descriptions in the literature of the influence of the crash pulse and stiffness of the structure in low-speed rear-impacts are rare. It has been shown that for vehicles equipped with a tow-bar, the pulse and the risk of disability to the neck increase compared to vehicles without. Also, the disability risk increases in the struck vehicle if the striking vehicle has a longitudinally mounted engine instead of a transverse one (Krafft, 1998). The link between injury risk and impact severity parameters based on acceleration levels remains unknown, since such measurements require on-board measurement techniques. This paper presents results from real-life rear impacts with vehicles equipped with a low-cost one dimensional crash recorder, the Crash Pulse Recorder (CPR), (Kullgren et al, 1995).

The aim of the study was to present crash pulse and change of velocity measured in real life rear impacts related to short- and long-term consequences from AIS 1 neck injuries.

MATERIAL AND METHOD

Since 1996 the crash recorder has been mounted in 10,000 vehicles in two different car models. The recorder was mounted under the driver seat. All rear impacts within this period were reported to the insurance company Folksam, irrespective of repair cost. However, only twenty-two rear impacts have been evaluated due to uncertain reporting procedures. All 22 crashed vehicles were inspected where the extent of seat-back deformations were investigated. Injury details were obtained from medical notes, and questionnaires were sent to the occupants. A follow-up of possible medical symptoms was done at least six months after the collision. Symptoms that still remained after half a year are referred to as "long-term consequences" and earlier recoveries are referred to as "short-term consequences".

The CPR is based on a spring mass system where the movements of the mass in a rear impact is measured. The displacement of the mass is registered on a photographic film. The circuit has its own power cell and does not need an external power unit. The CPR has a trigger level of approximately 3g.

When the characteristic parameters for each CPR have been measured, such as spring coefficient and frictional drag, and with knowledge of the displacement time history, the acceleration time history can be calculated. The crash pulses are filtered at approximately 100 Hz. Change of velocity and mean and peak accelerations were calculated from the crash pulse.

The accuracy of the CPR was validated in 21 frontal full-scale crash tests (Kullgren et al, 1995). The average standard deviation for change of velocity in tests below 30km/h was 2.0 km/h. The standard deviation concerning mean acceleration was 0.5 g, and for peak acceleration it was 1.4 g.

RESULTS

Out of 22 cases of rear impacts, there were 11 cases where a crash pulse could not be fully determined, cases L-V in Table 1. They did not reach the trigger level, but the inidividual trigger levels were measured. In this group three out of eleven sustained short-term consequences. In cases G-K the trigger levels were reached, but the displacement of the mass was too short for determination of a crash pulse. However, it was possible to measure the peak acceleration. In the impacts where a peak acceleration was calculated, cases A-K, the g-level reached from 2.7g to 14.7g. In nine of these cases, the occupants sustained short-term consequences and in one impact (case B) the occupant sustained long-term consequences. The occupants in case D still had symptoms from the neck, two months after the collision when this article was written, and may sustain long-term consequences.

Table 1.
Results from 22 rear impacts with Crash Pulse Recorder

Case	Change of velocity	Trigger level or peak accele-ration	Collision partner/ object	Occu-pants Female, Male	Initial symp-toms	Symptoms after 6 months.
A	28.2 km/h	10.1g	Truck	F+M	Yes	No
B	23.3 km/h	14.7g	Volvo 244 -82	F	Yes	Yes
C	14.7 km/h	9.0g	Skoda Pickup	M	Yes	No
D	26.0 km/h	12.6g	Ford Scorpio	M+4F	Yes	*
E	4.3 km/h	3.7g	BMW 530 -87	M+F	Yes	No
F	6.1 km/h	6.1g	Chrysler Voyager -89	M	No	No
G	-	2.9g	BMW 318 -81	M	Yes	No
H	-	3.3g	Volvo 245	M+F	Yes	No
I	-	4.3g	Toyota Carina -97	M	No	No
J	-	3.4g	VW Passat -97	M+F	Yes	No
K	-	2.7g	BMW 750 -88	M	Yes	No
L	-	3.3g	Nissan Sunny -93	M+2F	No	No
M	-	3.3g	Pole		No	No
N	-	3.2g	Pole	M	No	No
O	-	2.8g	Volvo 140	F	No	No
P	-	3.0g	Volvo 760 -83	M+F	Yes	No
Q	-	3.0g	Trolley	2 M	No	No
R	-	2.8g	Ford Fiesta -90	M	No	No
S	-	2.8g	Ford Escort -88	M	Yes	No
T	-	2.4g	Honda Accord -88	F	Yes	No
U	-	2.7g	Volvo 944 -92	M+F	Yes	No
V	-	2.8g	Tree	F	No	No

Deformation/collapse of the seat backs were only found in case B and D.
* The occupants still had whiplash symptoms 2 months after the impact when this paper was written.

In the six cases A-F, where the crash pulse and change of velocity were recorded, A-D is shown below in figure 1 to 4 and cases E and F are shown in the appendix.

Case A.

Changeof velocity:	28.2 km/h
Mean acceleration:	5.8g
Peak acceleration:	10.1g
Striking vehicle:	truck 28 000kg
Driver:	belted male, 26 years
Front passanger:	belted male, 26 years
Symptoms:	Initial whiplash symptoms; both occupants recovered within a month.

Other:
The driver was aware of the impending impact and leaned forward just before the collision. The front passenger was unaware. Both front seats were intact after the impact. No collapse or deformations were found on the back rests.

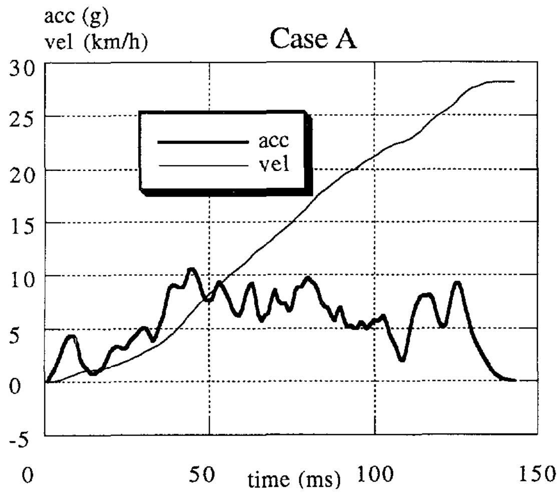

Figure 1. The change of velocity and acceleration in a rear impact, case A.

Case B.

Change of velocity:	23.3 km/h
Mean acceleration:	6.7g
Peak acceleration:	14.7g
Striking vehicle:	Volvo 244, 1400kg
Driver:	Belted female, 58 years
Symptoms:	After six months, there was still neck pain and headache.

Other:
The back rests collapsed and the front doors were jammed.

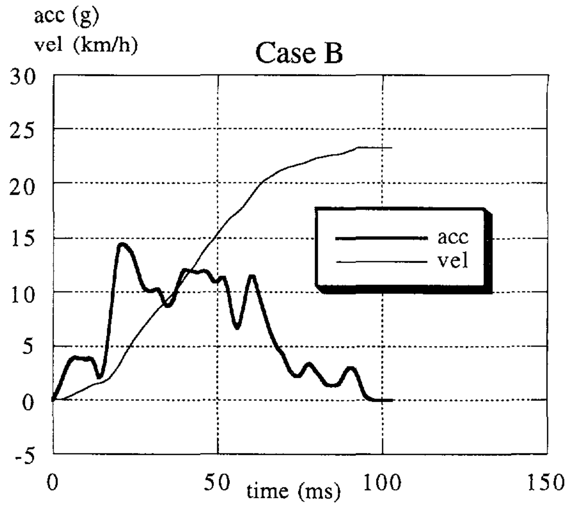

Figure 2. The change of velocity and acceleration in a rear impact, case B.

Case C.

Velocity change:	14.7 km/h
Mean acceleration:	5.5g
Peak acceleration:	9.0g
Striking vehicle:	Skoda Pickup-97, 1000 kg
Driver:	Belted male, 35 years
Symptoms:	Initial whiplash symptoms; recovery within a month.

Other:
The driver was not aware of the impending impact. The back rest was intact after the collision.

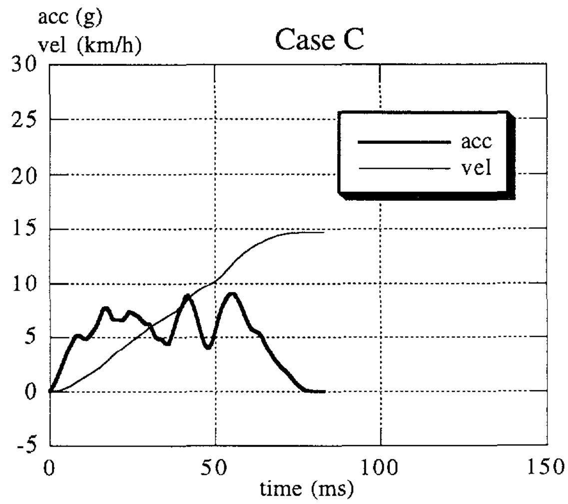

Figure 3. The change of velocity and acceleration in a rear impact, case C.

Case D.

Change of velocity:	26 km/h
Mean acceleration:	6.4g
Peak acceleration:	12.6g
Striking vehicle:	Ford Scorpio, 1500kg
Driver:	Belted male, 57 years
Front passanger:	Belted female, 57 years
Rear passengers:	Two children under 5 years of age and one female, 33 years. They were all belted
Symptoms:	All adult occupants still have typical whiplash symptoms two months after the collision.

Other:
The front passenger turned her head before the impact, to check on the passengers in the rear seat.

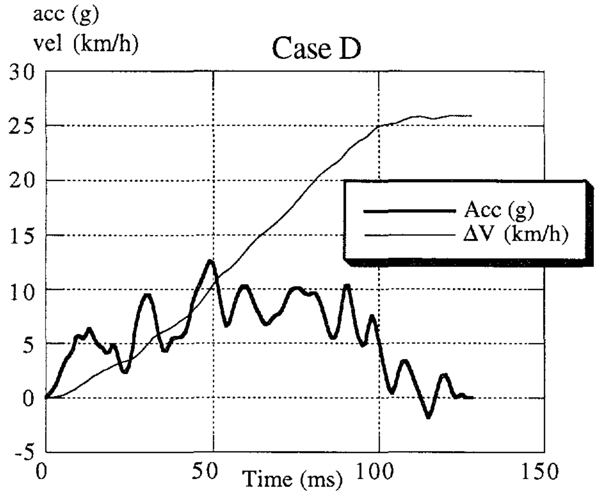

Figure 4. The change of velocity and acceleration in a rear impact, case D.

DISCUSSION

In reconstructions of rear impacts causing AIS 1 neck injuries, change of velocity is a commonly used parameter to decide the relevance of the occupants′ symptoms. However, it is still unknown whether change of velocity is a relevant predictor for long-term consequences to the neck. It does, however, seem to be a risk factor in rear impacts causing short-term consequences (Eichberger et al 1996; Krafft et al 1995; Ryan et al 1994).

The impact severity parameters used in most studies are often chosen because of the possibility to measure and estimate them. Since the majority of real-world accident data describing acceleration time histories are not available, it is rare that crash pulse characteristics are mentioned as a possible risk factor.

The CPR makes it possible to relate injuries to the measured crash pulse and change of velocity. The method is unique in traffic safety research where such on-board measurement devices have been mounted in normal traffic. Also, the CPR-mounted vehicles in this study represent only two different models from one car make which limit influencing factors on the results.

The accuracy of change of velocity calculations in frontal impacts have in several tests been shown to have large random errors, sometimes exceeding 25%, (O'Neill, 1994; Stucki and Fessahaie, 1998). In rear impacts, the accuracy can be expected to be even lower since the elastic properties of vehicles in low regions of impact severity might produce a higher change of velocity than what was previously anticipated (Romilly et al, 1989).

It is shown in this study that the shape of the crash pulse varies considerably between rear impacts. Also, relatively high changes of velocity do not have to be critical to sustain disability to the neck. In case A, the velocity change was 28 km/h and the mean acceleration was nearly 6g with no clear peaks. The occupants recovered after a few weeks. In case B, however, the change of velocity was 23km/h and the mean acceleration was nearly 7g but there were early peak acceleration of nearly 15 g after 20ms. The occupant in case B still had typical whiplash symptoms six months after the collision. Out of eleven impacts in which the peak acceleration was determined (2.7g-14.7g), few sustained long-term consequences. Most occupants recovered within a month.

The crash pulse measurments available from earlier studies are from volunteer tests where the average acceleration was 2.5g (Eichberger et al, 1996), which seems to be in the lower region compared to those reported in this study, and therefore would not be expected to lead to any serious whiplash symptoms. Boström et al (1997) presented a mathematical model (NIC) where squared shaped acceleration pulses above 2.5g reached the injury tolerance limit which is also in the lower segment compared to this study. In sled tests, Svensson (1993) used a peak acceleration of approximately 7-8g which seems to be more representative.

New anti-whiplash devices have been coming out on the market, namely active head restraints moving forward and yielding seat back rests where a controlled angular deflection occurs during the rear impact (Wiklund and Larsson, 1998; Lundell et al 1998). Since the injury mechanism is still unknown, even if different hypotheses exist, there is a need to evaluate such new solutions by looking at real-life data. There might be technical solutions that cover more than one conceivable injury mechanism, but where the injury tolerance limit is remains unknown.

It is necessary to implement more advanced measurement technique of crash severity, taking both change of velocity and acceleration measurements into account when evaluating different anti-whiplash devices. Crash recording could show the distribution of Delta-V and crash pulse characteristics for neck injuries which cause short- or long-term consequences.

This study has focused on rear impact, since it is the most common impact direction in terms of AIS1 neck injuries. Replication of these results should be sought in a larger sample. The injury also occur in frontal impacts (Ryan et al 1994; Krafft, 1998) but there is very little documentation describing injury mechanism and risk factors in this direction, and more research is necessary for all impact directions to prevent injury more effectivly in the future.

CONCLUSIONS

From twenty-two Crash Pulse Recorders, the following conclusions can be drawn:

- The crash pulses where occupants sustained initial AIS 1 neck injury varied widely.
- Out of eleven rear impacts (31 occupants) with peak accelerations from 2.7g to 14.7g, occupants from nine impacts sustained short-term AIS1 neck injuries and at least one sustained long-term consequences.
- A peak acceleration of 14.7g may cause long-term AIS 1 consequences to the neck.
- High change of velocity (28 km/h) does not have to cause long-term AIS1 consequences to the neck , if at least the mean acceleration is less than 6g and there are no clear peaks.

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APPENDIX

Case E

Change of velocity:	6.1 km/h
Mean acceleration:	2.3g
Peak acceleration:	6.1g
Striking vehicle:	BMW 530 -87.
Driver:	Belted male, 68 years
Front passanger:	Belted female, 52 years
Symtoms:	The passanger had only initial symptoms
Other:	The back rests were intact

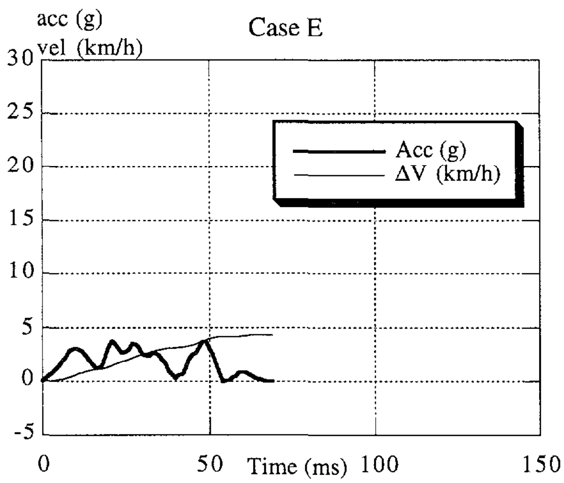

Figure I. The change of velocity and acceleration in a rear impact, case E.

Case F.

Change of velocity:	4.3 km/h
Mean acceleration:	2.1g
Peak acceleration:	3.7g
Striking vehicle:	Chrysler Voyager -89
Driver:	Belted male, 54 years
Symtoms:	No
Others:	Back rest were intact.

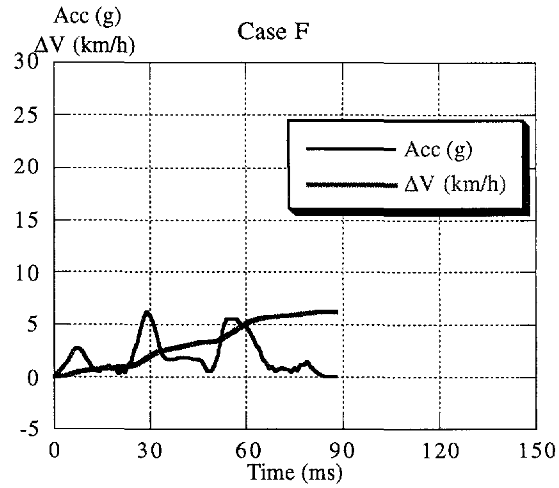

Figure II. The change of velocity and acceleration in a rear impact, case F.

Figure III. The vehicle in CaseA.

Figure IV. The vehicle in CaseB.

Figure V. The vehicle in CaseC.

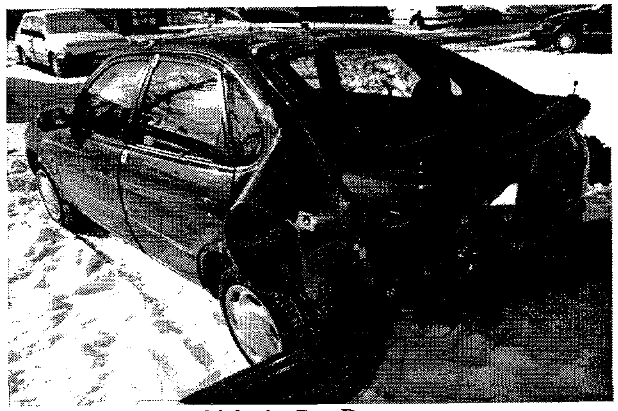

Figure VI. The vehicle in CaseD.