THE CORRELATION BETWEEN CRASH PULSE CHARACTERISTICS AND DURATION OF SYMPTOMS TO THE NECK – CRASH RECORDING IN REAL LIFE REAR IMPACTS

Maria Krafft, Anders Kullgren, Anders Ydenius Folksam Research, Sweden
Claes Tingvall, Swedish National Road Administration, Sweden
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ABSTRACT

AIS 1 neck injuries has become the most common disabling injury in vehicle crashes. Research has shown that there are variations in rear impacts causing short- and long-term disability to the neck. Therefore impacts in where the duration of symptoms differ need to be separated in analyses. 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.

Since 1995, approx. 15,000 vehicles on the Swedish market have been equipped with crash pulse recorders measuring the acceleration time history in rear impacts. In the present study, the results from crash recording of 34 real life rear impacts were analysed where the change of velocity and the crash pulse were measured. The injury status of the 49 front occupants was classified as no symptoms, or symptoms less or more than 1 month after the impact. Also injury risk functions were calculated for different duration of symptoms correlated to the crash severity parameters.

Most of the occupants that sustained symptoms more than 1 month, the change of velocity was higher than 15 km/h and the mean acceleration more than 5g. The average impact speed and mean acceleration for this group were 23km/h and 5.4g. Furthermore, the crash pulses form a corridor with acceleration between 5 and 10g and duration between 80 and 150ms. Those occupants that sustained symptoms less than 1 month, the average change of velocity were 10 km/h and the mean acceleration was 3.5g. When designing test methods for evaluating vehicle safety concerning AIS 1 neck injuries, the acceleration pulse will differ considerably depending on focusing short- or long term consequences.

INTRODUCTION

Few studies have distinguished between the duration of the symptoms and the influence of the crash severity. For 12 months Olsson et al (1990) followed the progress of 33 occupants involved in rear impacts in Volvo cars. No clear relationship was found between impact speed (measured as EBS) and the initial spectrum of symptoms or the duration of symptoms. However, EBS (Equivalent Barrier Speed) or change of velocity calculated with retrospective methods has too low accuracy to predict the crash severity (Kullgren 1998), especially in low speed impacts (Lenard et al. 1998). A slight correlation was claimed between the duration of neck symptoms caused by rear impacts and the degree to which the impacted vehicle was deformed when on the rear side members had been activated. Krafft et al (1999) found a relationship between the crash pulse on the neck injury risk in rear impacts, by studying the same car model with and without tow-bar. It was found that a tow-bar on the struck car increased the risk of long-term consequences with approximately 20% than without. The definition of long-term consequences was symptoms at least one year after the impact. An earlier study, Krafft (1998) showed that a longitudinally mounted engine (compared with a transversal one) in the striking car also increased the risk of long-term consequences in the struck car.

Following studies describe the impact severity when no injury or short-term consequences occur. Mc Connell et al (1995) performed low-speed rear impacts with seven male volunteers, with velocity changes of up to 10.9 km/h. None of the volunteers reported whiplash symptoms after a few days. Ono and Kaneoka (1997) and Siegmund et al (1997) found similar results from volunteer tests. In another study with volunteers (Eichberger et al 1996), where the sled impact velocities were 8-11 km/h and the mean deceleration 2.5g, the volunteers suffered whiplash symptoms for approximately 24 hours.

There is a need to further study the influence of crash pulse characteristics on AIS1 neck injury risks in rear impacts. The aim of this study was to evaluate the influence of crash severity on the duration of symptoms of AIS1 neck injury in rear impacts. Crash severity was measured with a one-dimensional crash-recorder fitted in 4 car models.

MATERIAL AND METHODS

Since 1996 the crash recorder has been mounted under the driver seat to document rear impacts in 15,000 vehicles in four different Toyota car models. The models do not share the same seat type but are not separated in the analysis. All rear impacts during 1996- 2000 were reported to the insurance company Folksam, irrespective of repair cost. Out of 95 reported crashes, 34 crash pulses were recorded, where 49 front seat occupants were involved. Of technical reasons (see below) 61 impacts were unrecorded and therefore excluded in this study.

Injury details were obtained from medical notes and interviews of the occupants. The interviewer, a nurse, had no information about the crash severity in each case. A follow-up of possible medical symptoms was done at least 6 months after the collision. The duration of symptoms was defined as follow: no symptoms, symptoms less than 2 weeks, less than 3 month and more than 6 months.

The crash pulse recorder (CPR) has a trigger level of approximately 3g. In this study, only the impacts with recorded acceleration pulse were used.

The CPR is based on a spring mass system where the movements of the mass in a rear impact are 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.

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 30 km/h was 2 km/h. The standard deviation concerning mean acceleration was 0.5g, and for peak acceleration it was 1.4g. The CPR has not been validated in low-speed impacts below 25 km/h.

Injury risk was calculated as the number of crashes with injured front seat occupants in relation to the total number of front seat occupants, in each interval of crash severity.

RESULTS

Out of 49 front seat occupants in 34 rear impacts where the acceleration pulse was measured, 27 were uninjured, 10 sustained AIS 1 neck symptoms less than 2 weeks, 5 recovered between 2 weeks and 3 months and 7 occupants had symptoms more than six months after the impact (see Table 1).

Table 1.
The Rear Impacts Included in the Study

Case No.	Driver /Pass.	Delta-V (km/h)	Mean acc. (g)	Peak acc. (g)	Symptoms
29727	D	33	6.0	12.3	> 6 months
	P	33	6.0	12.3	> 6 months
29533	D	28.2	5.8	10.1	1 month
	P	28.2	5.8	10.1	> 6 months
29602	D	26.0	6.4	12.6	> 6 months
	P	26.0	6.4	12.6	>6 months
29577	D	23.3	6.7	14.7	> 6 months
29732	D	19.5	4.0	9.2	No
	P	19.5	4.0	9.2	No
29876	D	17.6	5.0	12.4	< 3 months
	P	17.6	5.0	12.4	< 3 months
29739	D	17.1	4.6	12.1	> 6 months
	P	17.1	4.6	12.1	< 2 weeks
29521	D	14.7	5.5	9.0	<1month
29869	D	12.7	4.2	16.0	No
29878	D	12.4	3.4	9.9	< 2 weeks
29693	D	12.4	4.0	11.2	< 2 weeks
29614	D	12	3.2	7.5	No
	P	12	3.2	7.5	< 2 weeks
29733	D	11.1	4.0	7.4	No
29737	D	10.7	2.9	5.3	< 2 weeks
29776	D	9.7	3.4	5.1	< 3 months
29652	D	9.4	3.3	8.1	No
	P	9.4	3.3	8.1	< 2 weeks
29807	D	9.1	3.1	6.9	No
29741	D	8.1	3.1	6.1	No
	P	8.1	3.1	6.1	No
29706	D	7.7	2.9	5.7	No
29778	D	7.3	2.8	4.8	No
29781	D	7.3	2.7	6.3	No
	P	7.3	2.7	6.3	No
29780	D	6.5	3.3	6.8	< 2 weeks
	P	6.5	3.3	6.8	< 2 weeks

29491	D	6.1	2.3	6.1	No
	P	6.1	2.3	6.1	< 2 weeks
29908	D	5.8	2.3	5.4	No
29677	D	5.8	2.3	5.1	No
29880	D	5.4	2.5	4.4	No
29784	D	5.1	2.1	5.2	< 2 weeks
29773	D	4.9	3.1	4.7	No
	P	4.9	3.1	4.7	No
29601	D	4.3	2.1	3.7	No
29911	D	4.3	2.5	5.1	No
29849	D	4.2	2.2	4.1	No
29795	D	4.0	2.3	4.8	No
	P	4.0	2.3	4.8	No
29687	D	2.9	1.3	3.2	No
	P	2.9	1.3	3.2	No
29716	D	2.4	1.6	3.2	No

Further 61 rear impacts were reported during the same period of time, where the trigger level of the CPR was not reached, no acceleration pulse were measured, and they are not presented in this study. The occupants in these 61 low severity impacts were mostly uninjured or sustained symptoms less than two weeks.

Figure 1 shows the AIS 1 neck injury risk versus change of velocity for occupants that sustained symptoms less than or more than 1 month. 50% of the occupants sustained symptoms more than one month if the change of velocity were more than 15 km/h. The injury risk was 1 when delta-v was more than 20 km/h. Below 15 km/h, 50% sustained symptoms less than 1 month. For most of these occupants the symptoms disappeared after a few days.

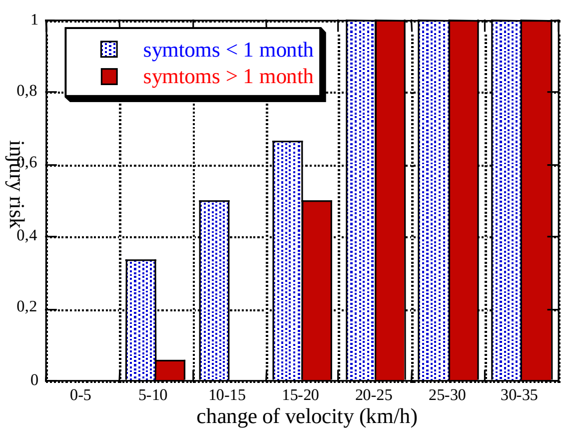

Figure 1. Injury risk in intervals of change of velocity for occupants with symptoms less than or more than 1 month.

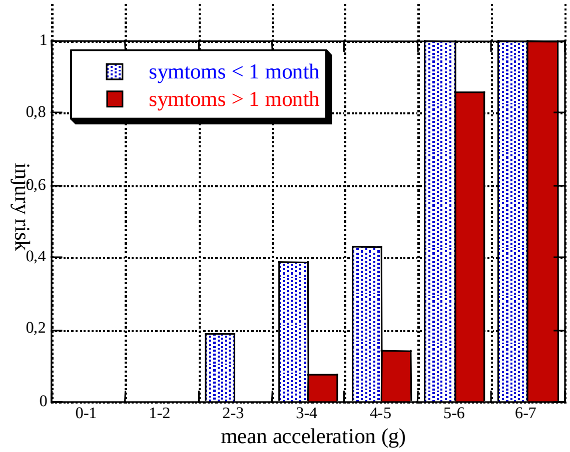

Figure 2. Injury risk in intervals of mean acceleration for occupants with symptoms less or more than 1 month.

There was a strong correlation between injury risk and mean acceleration and Figure 2 shows that the injury risk, symptoms more than 1 month, were rare when the mean acceleration were less than 4g.

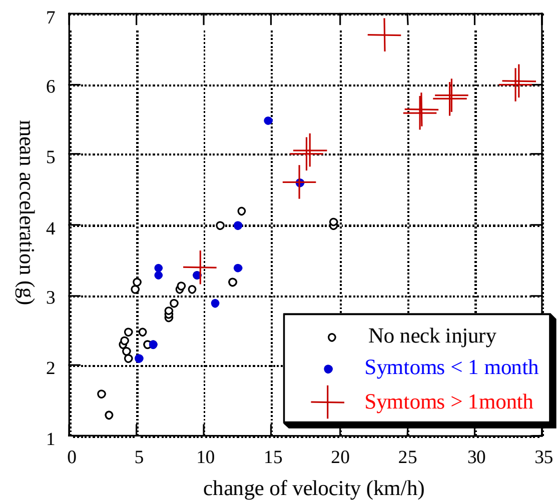

Figure 3. Change of velocity versus mean acceleration for occupants with no symptoms and those with symptoms less than or more than 1 month.

In Figure 3 the relationship between mean acceleration and change of velocity for rear impacts leading to no symptoms, symptoms less than or more than 1 month is shown. It was found that out of 11 occupants, 10 sustained symptoms 1 month or more when the change of velocity was more than 15 km/h and the mean acceleration was higher than 4.5g. No difference was found between the uninjured occupants and those who had symptoms less than 1 month. However, the majority of uninjured occupants were represented in the excluded impacts where no acceleration pulse could be measured because of to low crash severity.

There was also a relationship between peak acceleration and change of velocity as well as peak and mean acceleration, see Figures 4 and 5. Nearly all sustained neck symptoms more than one month when delta-v was higher than 15km/h and the peak acceleration more than approximately 10g (see Figure 4). Except one occupant, no one sustained symptoms more than 1 month when the mean acceleration was less than 5g and the peak acceleration less than 10g (see Figure 5).

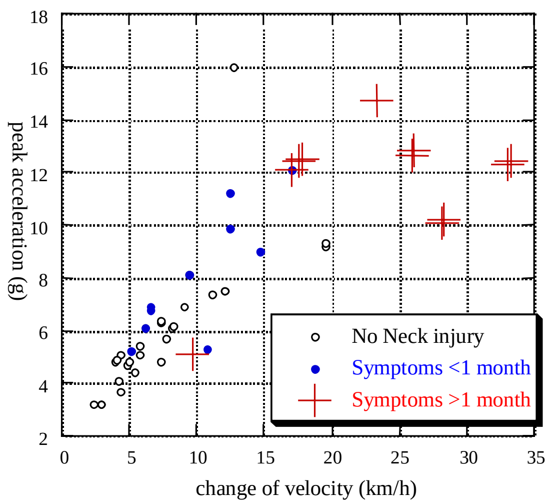

Figure 4. Change of velocity versus peak acceleration for occupants with no symptoms and those with symptoms less than or more than 1 month.

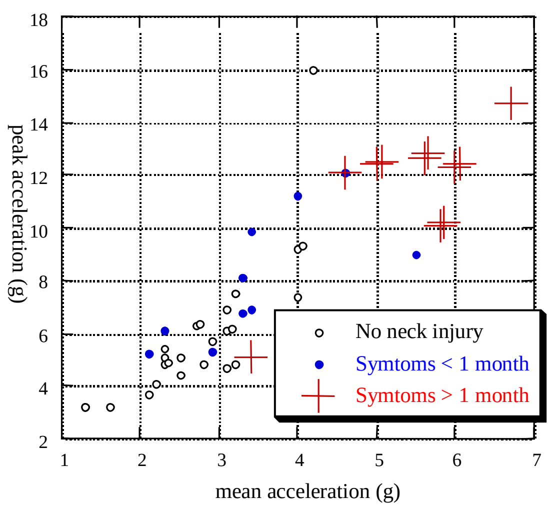

Figure 5. Mean acceleration versus peak acceleration for occupants with no symptoms and those with symptoms less than or more than 1 month.

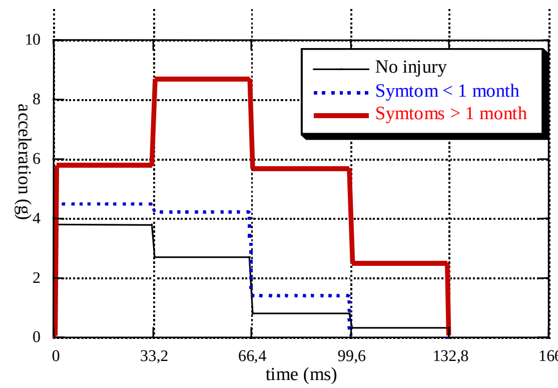

Figure 6. Mean acceleration crash pulses for the occupants with no symptoms, symptoms less than or more than one month.

Figure 6 shows average mean accelerations for different time intervals of the crash pulse for occupants with different duration of symptoms. The mean crash pulse for the occupants that sustained symptoms more than one month was considerably higher compared to occupants that sustained no injury or symptoms less than 1 month.

For the eleven occupants who sustained symptoms more than 1 month, the 7 individual crash pulses are shown in Figure 7. It can be seen that the crash pulses form a corridor with acceleration between 5 and 10 g and duration between 80 and 150 ms.

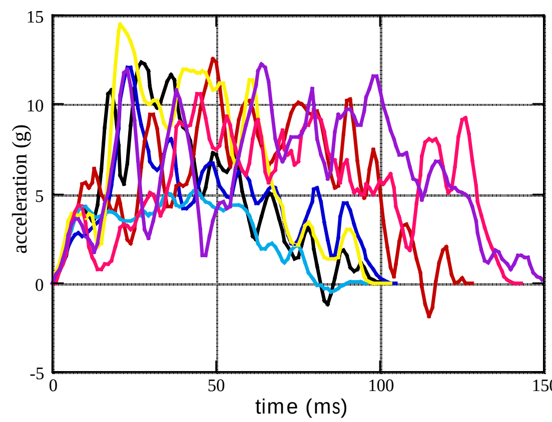

Figure 7. Crash pulses for the vehicles with occupants that sustained symptoms more than 1 month.

The average crash pulse characteristics for the three injury categories are presented in Table 2. Both average change of velocity and mean acceleration were significantly higher for the occupants with symptoms more than 1 month compared to the other injury categories.

Table 2.
Average Values for the Three Injury Categories

Injury category	Delta-V (km/h)	Mean acc. (g)	Peak acc. (g)
No symptoms	7.6	2.8	6.1
Symptoms < 1 month	10.1	3.5	8.0
Symptoms > 1 month	23.6	5.4	11.5

DISCUSSION

The material used in this study mean an unique chance to analyses the acceleration pulse during real-life rear impacts correlated to the injury outcome, which have never been possible earlier. In an earlier study (Krafft et al 1999) the crash pulses from 13 cases in rear impacts have been presented but this time the data is more comprehensive and therefore further conclusions can be drawn. Today there is a lack of information concerning AIS 1 neck injury and its correlation to crash severity which complicate the construction of effective anti-whiplash systems and test methods. The combination of valid and reliable impact severity measurements and medical information at different times after the collision made it possible to study relations which would otherwise be impossible to obtain.

It is difficult to objectively determine the diagnoses of AIS 1 neck injuries. The question is often raised about the credibility of these injuries. Earlier, the injury data has been focused on long-term consequences, symptoms at least one year after the impact (Krafft 1998), based on doctors certificate to obtain high validity of the medical information. In this study, the injury data was mainly based on interviews of the occupants and the duration of symptoms were defined as no symptoms or symptoms less than or more than 1 month. Since few occupants sustained long-term consequences according to the classification of the insurance company or were still not estimated (Krafft 1998), another duration was chosen to make it possible to analyse the data. Better significance could be expected if only symptoms verified from a doctor were used. To minimise the risk of bias, the interviewer did not know anything about the crash severity of the impacts.

In this study, the selection of data only included impacts where the CPR was activated which means that impacts in the lower crash severity segment were underrepresented. Therefore a relatively low number of occupants were uninjured, 27 out of 49. This fact also influences the results of the figures where the correlation between crash severity and injury outcome was analysed (fig 3-5). There was no difference in risk for different crash severity, between the group that sustained no symptoms and symptoms less than 1 month. However, in the impacts where no crash pulse could be measured, most occupants were uninjured and no occupant sustained symptoms more than two weeks.
The number of occupants that sustained symptoms more than 1 month were 11 out of 49. More data is necessary to increase the reliability for different crash severity parameters correlated to injury outcome.

All occupants in the study had neck symptoms more than one month at delta-v's of more than 20 km/h, when the mean acceleration was 6-7g or more and the peak acceleration 10g or more. Only one occupant sustained symptoms more than two weeks (less than 3 months) when the change of velocity were less than 10km/h. Also, the injury risk was low when the mean acceleration were less than 4g. Different test methods have been proposed to evaluate and to develop more effective anti-whiplash systems (Hell et al 1999, Langwieder et al 2000). The impact speed is often recommended to be 15km/h but also a less severe test has been suggested, 10 km/h (Langwieder et al 2000)**.** The lower speed should represent a velocity change where the highest frequency of neck distortions. 10 km/h is relevant if a test criterion should cover the frequency where most impacts occur but not necessarily leads to an injury or neck symptoms that sustain for a few days. However, more severe AIS 1 neck symptoms that might disable the occupant for many years or life long are represented in rear impacts where the crash severity is considerably higher. It is important that anti-whiplash systems are optimised for a crash severity segment where more long-term consequences occur otherwise there is a risk of sub-optimisation if a to low crash severity level is in focus.

Comparing the crash test pulse corridor proposed by Langwieder et al. (2000) with the mean crash pulses for occupants with symptoms more and less than one month found in this study, it seems like the proposed corridor falls in between these two mean crash pulses, see Figure 8. To create conditions for a robust anti-whiplash system and to avoid the risk of sub-optimisation, it is advisable to have at least two tests at different crash severity in terms of change of velocity and mean acceleration. The mean crash pulse for those occupants with symptoms more than one month seems to be in the order of 20-25 km/h in change of velocity and 5-7 g in mean acceleration. Therefore, in addition to a test in 15 km/h it would be desirable to also have a test at higher severity to represent the more long-term symptoms.

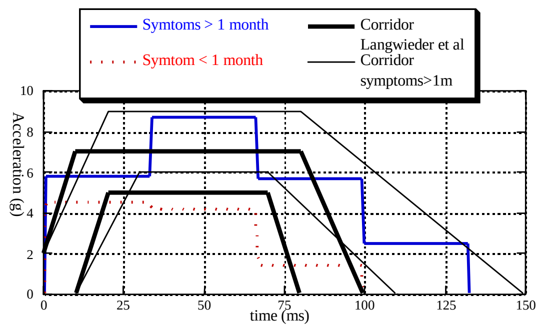

Figure 8. Mean crash pulses from Figure 6, a proposed pulse corridor for occupants with symptoms > 1 month and a pulse corridor proposed by Langwieder et al. (2000).

The results found indicate that change of velocity and mean acceleration is stronger correlated to the risk of symptoms more than 1 month than peak acceleration, see Table 2. The differences in average values were larger for change of velocity and mean acceleration compared to peak acceleration. The indication can also be seen in Figure 6, showing average crash pulses for different injury categories. The findings indicate that pulse shape or peak acceleration not is that important for the injury outcome. It appears to be the total change of velocity or mean acceleration that better correlates with the injury outcome.

The results are based on four different models from one car manufacturer. The relation between crash severity and injury outcome depends on both the injury tolerance level of the occupants and the passive safety of the car, such as the construction of the car seat. Other injury outcomes might have been the result in another car model. The limits in crash severity for different injury levels may therefore be different for other vehicles. It is therefore important to conduct further studies with more car models included.

When more data is available, further studies have to be undertaken to evaluate the neck injury risk in with narrower time intervals of the crash pulse, and also to separate the injury risk for males and females. Furthermore, to study the crash severity levels for occupants that sustain symptoms for six months and one year. It would also be of interest to relate the findings in this study to different measurements such as NIC (Neck Injury Criteria) and the angular acceleration and velocity of the head relative to the thorax since they address different injury mechanisms.

CONCLUSIONS

There was a correlation between crash severity and duration of neck symptoms.

10 out of 11 occupants that sustained AIS 1 neck symptoms more than 1 month, the change of velocity was more than 15 km/h and the mean acceleration higher than 5g. Below an impact speed of 15 km/h and a mean acceleration less than 4g nearly all occupants were uninjured or had symptoms less than two weeks.

The average change of velocity for those occupants with symptoms more than 1 month was found to be approximately 23 km/h and the mean acceleration was 5.4 g. The corresponding figures for occupants with symptoms less than 1 month was 10km/h and 3.5 g.

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