INFLUENCE OF CRASH SEVERITY ON VARIOUS WHIPLASH INJURY SYMPTOMS: A STUDY BASED ON REAL-LIFE REAR-END CRASHES WITH RECORDED CRASH PULSES

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Paper Number: 05-0363

ABSTRACT

Whiplash injuries resulting from rear impacts are one of the most important injury categories with regard to long-term consequences. Most rear impacts lead to no injury or to symptoms that are temporary. Impacts where the duration of symptoms differs need to be separated in analyses in order to isolate representative rear impact conditions in which more long-lasting whiplash injuries occur.

The aim of this study was to evaluate the influence of crash severity on symptoms duration of Whiplash Associated Disorders, WAD, separated for males and females, and for different grades of WAD (1-3) according to Quebec Task Force.

Since 1995, approximately 60 000 vehicles on the Swedish market have been equipped with crash pulse recorders measuring the acceleration time history in rear impacts. With the inclusion criteria of single rear-end crashes with a recorded crash pulse, and front seat occupants with no previous long-term AIS1 neck injury, 207 front-seat occupants in 150 crashes remained to be analyzed in this study, where the change of velocity and the crash pulse were measured.

A correlation was found between duration of symptoms and crash severity measured as mean acceleration and change of velocity. The risk of WAD symptoms for more than one month was found to be 20% at a change of velocity of approximately 8 km/h and at a mean acceleration approximately 5 g. A correlation was also found between grades of WAD and crash severity measured as mean acceleration and change of velocity. Out of all crashes with a recorded crash pulse only one out of 207 occupants sustained WAD symptoms for more than one month at mean acceleration below 3.0 g. Given the same crash severity, females had a higher risk of initial WAD symptoms than males.

INTRODUCTION

In the last decade some studies have been presented showing influence of duration of symptoms on crash severity in rear impacts. Regarding initial neck symptoms, the following studies describe the impact severity when no injury or short-term consequences occur. Hell and Langwieder (1998) found that most occupants sustained symptoms in impacts where the change of velocity was 10-15 km/h. 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.

The influence of crash severity on more long-lasting symptoms is rarely studied. Based on a follow-up questionnaire with 65% answering frequency, Jakobsson (2004) found that 21% sustained long-term consequences in rear impacts with Volvo cars where the impact severity was defined as moderate. The impact severity "moderate" represented impacts in which the WHIPS recliner would have been activated. When the Volvo data was grouped according to whether the impact area involved rear members (reflecting a probable increase in the crash pulse amplitude) there was a tendency of higher initial AIS 1 neck injury risk for those with engaged rear members as compared to those with impact area outside rear members. Another study that tried to reflect the influence of the crash pulse on the injury outcome was Krafft (1998). It was found a relationship between the crash pulse on the neck injury risk in rear impacts, by showing 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.

The influence of the crash characteristics on whiplash injury based on crash recording in real life rear impacts, has been presented earlier (see for example Krafft et al. 2002, and Kullgren et al. 2003). In these studies it was found that for the vast majority occupants that sustained symptoms for more than one month, mean acceleration was more than 4.5g and change of velocity higher than 10 km/h. Mean acceleration was found to be the best candidate to predict duration of symptoms compared to change of velocity and peak acceleration.

There is a need to further study the influence of crash pulse characteristics on AIS1 neck injury risks in rear impacts, both regarding kind of whiplash symptoms and duration of these symptoms. Furthermore, there is a need to separate the injury risk for gender. Several studies have shown that whiplash injuries occur more frequently among females than males (Berglund 2001, Maag et al 1993). However, there is always a problem with real-life data to handle the exposure problem concerning crash severity. With crash recorder data the outcome will be controlled for crash severity.

Based on more data from crash recorded 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.
- the influence of crash severity on whiplash symptoms classified according to Quebec Task Force.
- the influence of crash severity on the neck injury risk separated for males and females.

MATERIAL AND METHODS

Since 1995 crash recorders have been mounted under the driver or front passenger seat to document rear impacts in 60,000 vehicles in eight different car models of the same make. The models do not share the same seat type but are not separated in the analysis. All rear impacts since 1995 were reported to the insurance company Folksam, irrespective of repair cost. The inclusion criteria were single rear-end crashes with a recorded crash pulse, and front seat occupants with no previous long-term AIS1 neck injury. Out of 254 reported crashes, 150 crash pulses were recorded, in where 207 front seat occupants were involved. Out of these, 90 were men, 105 women, and in 12 cases the sex was unknown (10 were front seat passengers that were uninjured and 2 were drivers with initial symptoms but recovering within one month).

The remaining 104 rear impacts the trigger level of the CPR was not reached. In these crashes no acceleration pulse was measured, and they were not included in the analysis of this study.

Injury details were obtained from medical notes and interviews with the occupants. The interviewer had no information about the crash severity in each individual case. A follow-up of possible medical symptoms was carried out at least six months after the collision. The questionnaire of symptoms and the process of defining injury severity were structured in co-operation with a medical doctor. The symptoms noted were those associated with pain, stiffness and musculoskeletal signs, and with neurological symptoms, such as numbness. The duration of symptoms was defined as follow: no injury, symptoms less than one month, symptoms between one and six months, and for more than 6 months. The symptoms were also defined according to the Quebec Task Force on Whiplash associated Disorders (Spitzer et al. 1995).

WAD 0 – No complaints
WAD 1 – Neck complaints: pain, stiffness, or tenderness only
WAD 2 – Neck complaints and musculoskeletal signs
WAD 3 – Neck complaint and neurological signs

The Crash Pulse Recorder measures the acceleration time history in the principal direction of force during the time of impact. The crash pulses were filtered at approximately 100 Hz. The crash pulse recorder (CPR) has a trigger level of approximately 3g.

The development and accuracy of the CPR is described by Kullgren et al. (1995). Change of velocity and mean and peak accelerations were calculated from the crash pulse.

To visualize the influence of impact severity on risk of WAD, two kinds of plots were used. Injury risk versus impact severity was calculated for occupants with different duration of symptoms and for occupants classified in different grades of WAD. Injury risk was calculated as the proportion of injured occupants in each interval of impact severity. Intervals with less than 3 observations were excluded in the plots. In order not to force the injury risk curve into a specific shape, no mathematical function was used. The risk values for all intervals were connected using “smooth” curve fit in the software KaleidaGraph (Synergy software 2000).

In the second type, injury status in terms of duration of symptoms and grades of WAD, was, for all occupants, correlated with both change of velocity and mean acceleration in one plot.

RESULTS

Out of 207 front seat occupants in 150 rear impacts where the acceleration pulse was measured, 132 were uninjured, 75 reported initial symptoms whereof 51 recovered within a month, 7 sustained symptoms between one and six months and 17 had symptoms for more than six months after the impact. Out of the 207 occupants 49 were classified as WAD Grade 1, 20 as Grade 2 and 6 as Grade 3. In Table 1 the occupants are also divided according to seating position.

Table 1. Numbers of drivers and front seat passengers with different duration of symptoms and grades of WAD.

	Driver	FSP	Total
All	150	57	207
Uninjured	98	34	132
Symptoms < 1m	34	17	51
1m<symptoms<6m	7**	0	7
Symptoms > 6m	11*	6*	17
WAD grade 1	31	18	49
WAD grade 2	17	3	20
WAD grade 3	4	2	6

* One lumbar spine injury
** Two thoracic spine injuries

The occupants were also separated according to gender and seating positions. Table 2, 3 and 4 presents the number of male and female drivers, fronts seat passengers and front seat occupants together. It was found that the average impact severity was significantly higher for those occupants, both males and females, with symptoms for more than one month compared to the uninjured occupants.

Table 2. Numbers of male and female drivers and front seat passengers and average Δv and mean acceleration for different symptom durations.

	Males			Females		
	N	Δv	Mean acc.	N	Δv	Mean acc.
All	90	10.6	3.7	105	10.4	3.7
Uninj.	64	9.0	3.4	58	9.0	3.5
< 1 m	17	12.5	4.2	32	9.6	3.6
1-6 m	2	13.5	4.6	5	17.3	5.6
>6 m	7	19.9	5.2	10	17.6	5.1

Table 3. Numbers of male and female drivers and average Δv and mean acceleration for different symptom durations.

	Males			Females		
	N	Δv	Mean acc.	N	Δv	Mean acc.
All	75	10.3	3.7	73	10.2	3.6
Uninj.	55	9.2	3.4	43	8.9	3.3
< 1 m	13	12.3	4.2	19	8.9	3.5
1-6 m	2	13.5	4.6	5	17.3	5.6
>6 m	5	15.7	5.0	6	18.3	4.8

Table 4. Numbers of male and female front seat passengers and average Δv and mean acceleration for different symptom durations.

	Males			Females		
	N	Δv	Mean acc.	N	Δv	Mean acc.
All	15	12.3	3.8	32	10.9	4.0
Uninj.	9	7.8	3.2	15	9.4	3.9
< 1 m	4	13.2	4.2	13	10.8	3.7
1-6 m	0	-	-	0	-	-
>6 m	2	30.4	5.9	4	16.8	5.3

In the 104 rear impacts where the trigger level of the CPR was not reached and no crash pulse was recorded, one of the occupants had symptoms for more than six months, and one had symptoms between one and six months. None of the occupants was classified as WAD grade 3, but two as WAD grade 2. All other occupants were either uninjured or reported initial symptoms, but recovered within a month. As the trigger level of the CPR is approximately 3 g, the mean acceleration must in these crashes be below 3 g.

The numbers of occupants with different duration of symptoms and those classified in different grades of WAD, is presented in intervals of impact severity in Figures 1 to 4. The information in these figures is used to calculate the injury risk in each interval of impact severity, presented in Figures 5 to 8. In the interval 5-10 km/h 7 occupants had symptoms for more than 1 month. Out of these occupants 6 had a mean acceleration above 3.3 g, and all had a mean acceleration above 2.8g, see Figure 9. From the information in Figures, 1, 2 and 9 it appears like mean acceleration to a higher extent than change of velocity influences risk of WAD.

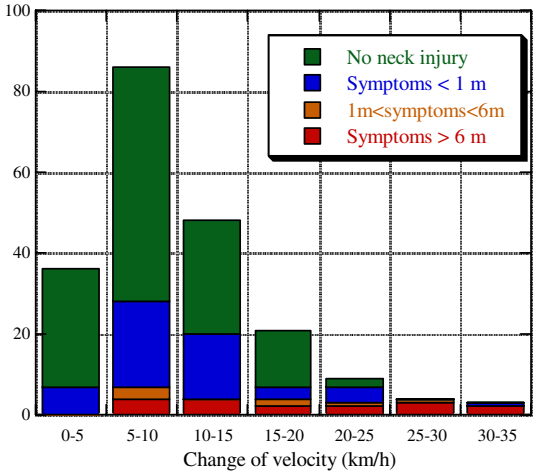

Figure 1. Numbers of injured and uninjured occupants in intervals of change of velocity.

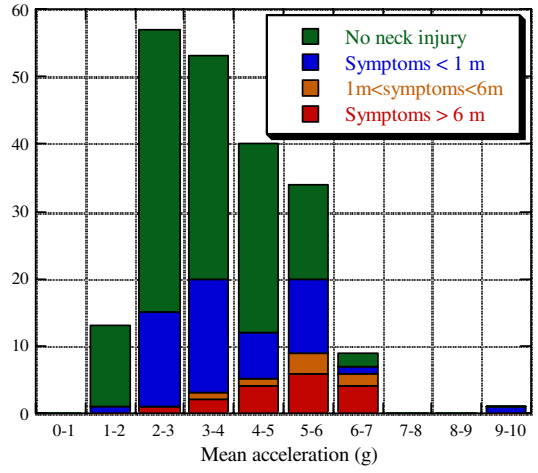

Figure 2. Numbers of injured and uninjured occupants in intervals of mean acceleration.

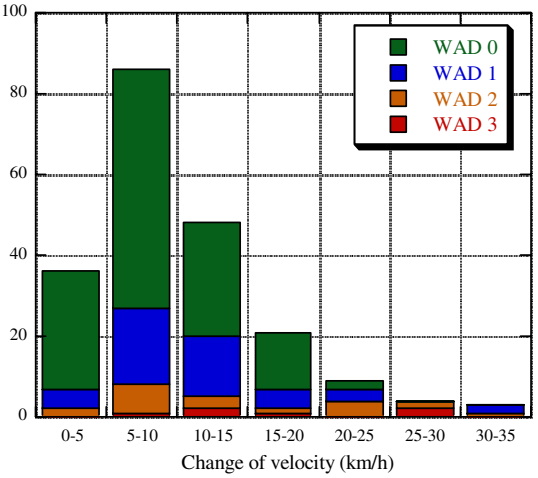

Figure 3. Numbers of injured and uninjured occupants in intervals of change of velocity.

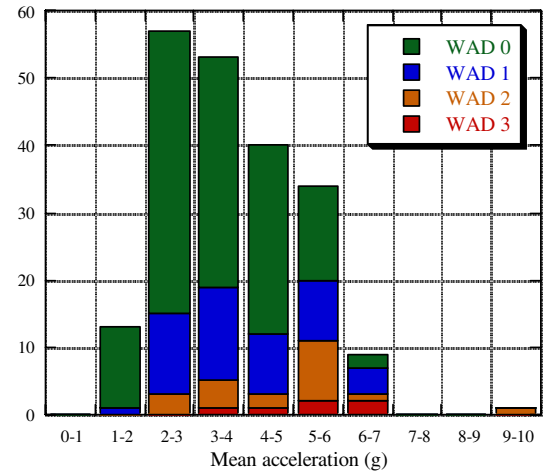

Figure 4. Numbers of injured and uninjured occupants in intervals of mean acceleration.

A correlation between injury risk and change of velocity was found for initial and more long lasting symptoms, see Figure 5. At a change of velocity above 20 km/h the risk of long lasting symptoms increase with a high rate. Risk of symptoms for more than one month was found to be 20% at approximately 18 km/h.

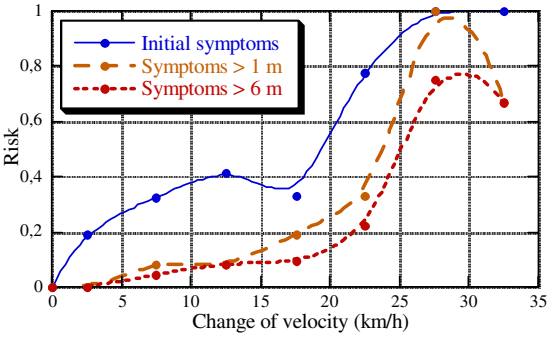

Figure 5. Injury risk in intervals of change of velocity for occupants with initial and long-term symptoms.

Injury risk and mean acceleration was also found to be correlated, see Figure 6. The risk of symptoms for more than one month was 20% at a mean acceleration of 5 g. Above 5 g the risk increases with a higher rate than below 5 g. In Figure 6 the occupant with initial symptoms at a mean acceleration of 9.1 g is not included.

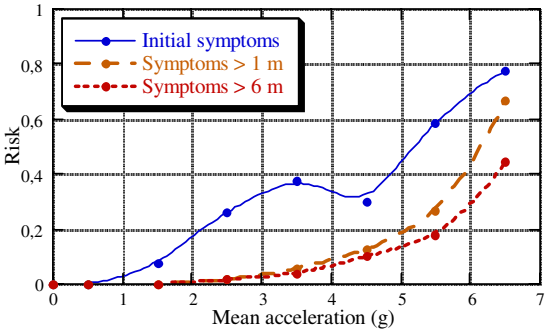

Figure 6. Injury risk in intervals of mean acceleration for occupants with initial and long-term symptoms.

Increased impact severity, both in terms of change of velocity and mean acceleration, was found to increase the risk of WAD symptoms, see figures 7 and 8. Furthermore, the risk of neurological symptoms of WAD, grade 3, was found to be lower than for grade 1 and 2 for the whole range of both change of velocity and mean acceleration. The risk of symptoms of grade 2 appears to increase above 17 km/h or 4.5 g.

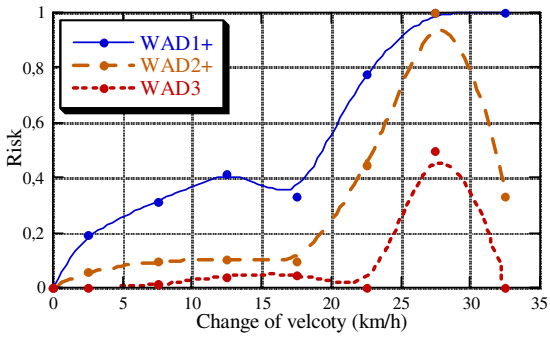

Figure 7. Injury risk in intervals of change of velocity for occupants classified as different grades of WAD.

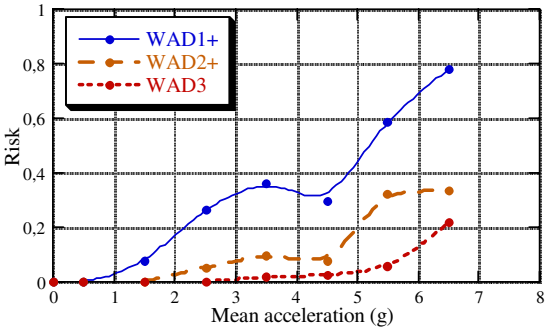

Figure 8. Injury risk in intervals of mean acceleration for occupants classified as different grades of WAD.

Only one of the 24 occupants with symptoms more than one month had a mean acceleration below 3 g (2.8 g). All other occupants with symptoms for more than one month had a mean acceleration above 3.3 g, see Figure 7.

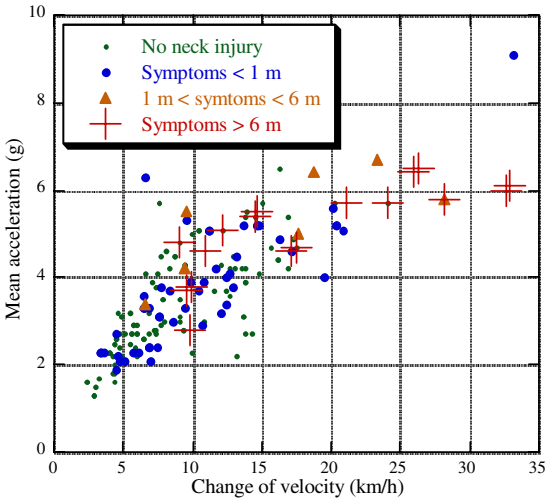

Figure 9. Change of velocity versus mean acceleration for occupants with different duration of symptoms.

Most occupants defined as WAD grade 3 had a mean acceleration above 4 g, see Figure 10. Occupants with a WAD defined as grade 2 seem to occur in a wide range of both change of velocity and mean acceleration.

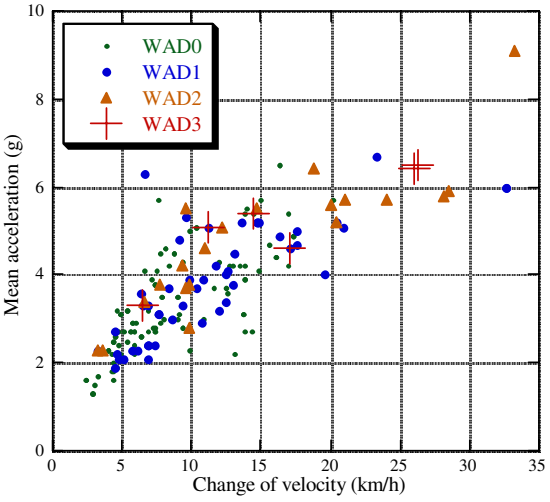

Figure 10. Change of velocity versus mean acceleration for occupants classified in various grades of WAD.

The risk of initial symptoms was found to be higher for females than males, both regarding change of velocity and mean acceleration, see Figures 11 and 12. Females appear to more often sustain initial symptoms at lower impact severity than males, especially regarding mean acceleration.

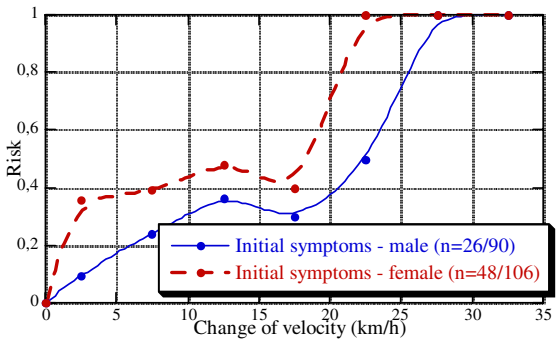

Figure 11. Risk of initial symptoms in intervals of change of velocity for males and females.

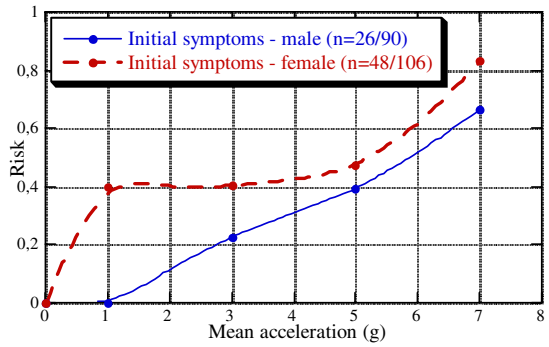

Figure 12. Risk of initial symptoms in intervals of mean acceleration for males and females.

DISCUSSION

Knowledge about the correlation between crash severity and injury risk is essential to more effectively prevent injuries in car crashes. The data used in this study mean a unique opportunity to analyze how acceleration influences the risk of whiplash injury. In a previous study (Krafft et al 2002) the crash pulses from 66 rear impacts have been presented, but in this study the data is more comprehensive and therefore more reliable conclusions can be drawn. The combination of valid and reliable impact severity measurements and prognostic injury data made it possible to study relations that would otherwise be difficult to obtain.

It is not possible to objectively determine the diagnosis of WAD, therefore the credibility of these injuries is often raised. In this study the injury data were mainly obtained by interviews with the occupants, which might influence the outcome. Better significance could be expected if only symptoms verified by a medical doctor were used. However, to minimize the risk of biased data, the interviewer had no knowledge about the crash severity in each case.

The results are based on seven different models from one car manufacturer. The limits in crash severity for different injury levels may therefore be different for other vehicles.

In all figures, the results were based on the rear impacts where fully crash pulses were recorded. This fact influences the results where the correlation between crash severity and injury outcome was analyzed. The results in Figure x-xx show no difference in crash severity for the occupants that sustained no injury and those with symptoms for less than one month. However, the impacts where no crash pulse could be recorded were not included in the study. A difference in crash severity could therefore be expected between the uninjured occupants and those with short-term consequences.

A correlation between crash severity and duration of symptoms was found. Other studies (Jakobsson 2004, Olsson et al 1990) did not find a relationship between impact speed (EBS) and the initial spectrum of symptoms or duration of symptoms. However, EBS 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).

When designing test methods for evaluating vehicle crashworthiness with regard to whiplash, the results show that the acceleration pulse differs considerably, depending on whether the focus is on short- or long-term consequences. If too low crash severity is chosen, there is a risk of sub-optimization against short-term consequences. To create conditions for a robust anti-whiplash system it is advisable to have at least two tests at different crash severity levels: one test representing the crash severity where the risk of long-term consequences is high, and another one representing a lower limit above which most of the whiplash injuries occur (symptoms more than one month).

The severity of the initial neck injury was classified according to the Quebec Task Force injury scale WAD 1-3. The duration of symptoms appears to better correlate with crash severity than WAD. This is logical since the WAD-scale is supposed to predict long-term injury outcome. Using the WAD-scale is a round-about way of describing the duration of symptoms, but less reliable. At least when the WAD classification was based on interviews with the occupants. The quality

of the classification would probably be better if it was based on medical examination of the occupants. In this study, the WAD 2 were found at all crash severity levels, but WAD 0 and 1 predominated in the lower severity segment. Whiplash injuries with neurological signs, WAD 3, occurred mostly at higher mean accelerations (above 4.5g), but they represented only six occupants.

Given the same crash severity level, females were found to have a higher risk of initial symptoms. If focusing long-lasting symptoms there is a need of more data to separate risk curves for males and females. Most studies, controlled for position, show a higher injury risk (long-term) for females (Jakobsson 2004, Krafft 1998) than males but there is no control for the exposed crash severity in the impacts. However, given the same crash severity there is a high probability that females still have a higher risk. It is important for preventative measures to determine critical crash severity levels mainly based on data related to females, ant not based on mean values for the total population.

CONCLUSIONS

- A correlation was found between duration of symptoms and crash severity measured as mean acceleration and change of velocity. The risk of WAD symptoms for more than one month was found to be 20% at a change of velocity of approximately 8 km/h and at a mean acceleration approximately 5 g.
- A correlation was found between grades of WAD according to Quebec Task Force and crash severity measured as mean acceleration and change of velocity.
- Out of all crashes with a recorded crash pulse only one out of 207 occupants sustained WAD symptoms for more than one month at mean acceleration below 3.0 g.
- Given the same crash severity, females had a higher risk of initial WAD symptoms than males.

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