Evaluation guideline for whiplash associated disorders in rear-end car-to-car minor crashes

Version 0.9

September 23, 2022

Note: This document, a compilation of the research results of many institutes including European Spine Society, biomechanical research centers, RCAR centers and so on, is not intended to definitively determine the injury risk to occupants in individual car-to-car minor crashes, but to help understand the evaluation of the injury risk to occupants in car-to-car minor crashes.

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1. Motivation

The neck pain claims have become a major research topic because these sorts of claims mainly include initial symptoms like pain, stiffness or tenderness about the neck but no physical signs such as musculoskeletal sign, neurological sign and fracture or dislocation. These symptoms are frequently claimed after minor rear-end crashes with low changes of velocity (ΔV) in the struck vehicle.

The first problem is that these symptoms cannot be diagnosed even with modern medical imaging devices such as MRI[1] or CT[2]. Therefore, physicians primarily rely on the subjective statements of passengers to provide medical treatment, without methods to objectify the claimed symptoms. The second problem is that the causal connection of the claimed symptoms and the accident can't be proven neither by an insurance nor by the claimant.

Where insurers have to compensate for such non-objectifiable claims, the system is at risk to be misused which would cause higher insurance premiums for other consumers. Despite significantly improved seats and better occupant protection, neck pain claims are still not negligible in some countries. As an example for the relevance ABI reports the UK's situation that claims of initial symptoms cost the insurance industry more than 2 billion pounds a year and add 90 pounds to the average annual motor insurance premium[3].

Like the UK, excessive insurance compensations in minor rear-end crashes have been social issues in some other countries as well, and many efforts are being made to improve it.

With this document RCAR intends to compile major findings which have mostly been published in local markets only, as well as established evaluation methods and make it available for interested parties.

1 Magnetic Resonance Imaging

2 Computer Tomograph

3 Source : 'ABI RESPONSE TO REFORMING THE SOFT TISSUE INJURY('WHIPLASH') CLAIMS PROCESS', JAN 2017

2. Introduction – history of research

In the1980s insurers registered increasing numbers of so called whiplash claims in some European countries. With better passive safety due to increased vehicle structures and sophisticated restraint systems, less severe bodily injury became more visible. In particular neck pain complaints got into the focus. RCAR, a community of insurance related research centers initially focusing on automotive repair research, set up a working group on neck associated disorders in the late 1980s. The aim of this International Insurers Whiplash Prevention Group (IIWPG) was to investigate in this topic in collaboration with physicians and universities. Based on third parties' and own research IIWPG delivered background for the technical understanding of the occupant loadings in accidents with forward acceleration of the struck vehicle, i.e. rear endings.

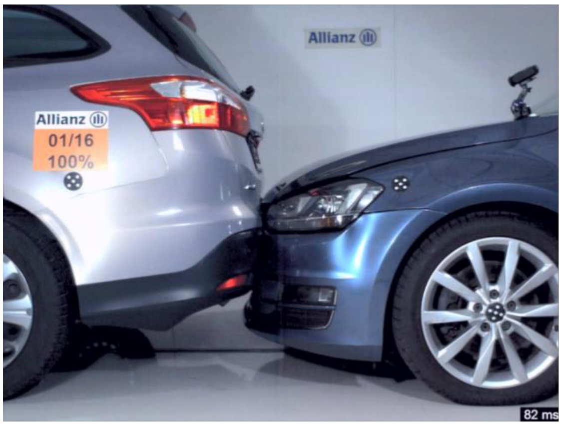

Fig. 1 Full overlap rear-end collision

It was found that the seat design and in particular the layout of the head restraint have a decisive influence on the relevant occupant loadings. As of 1997 the IIWPG collaborated with Swedish Chalmers University and dummy supplier Denton COE in the evaluation and development of a dedicated rear impact dummy, the BioRID II, which got into serial production in 2004. Concomitantly IIWPG proposed a dynamic test and rating criteria which was first implemented as an insurers' test as of 2004. This test allowed seat designers first to objectify the protection potential of their seats and to improve occupant safety in a purposeful way.

Today, static and dynamic evaluation methods have been adopted by most of the New Car Assessment Programs (NCAP) around the world. It is important to understand that the test criteria could not be based on values for human limits as it is common for high speed tests, e.g. the NCAP front crash tests, because such criteria did not exist for this low impact severity and still does not exist.

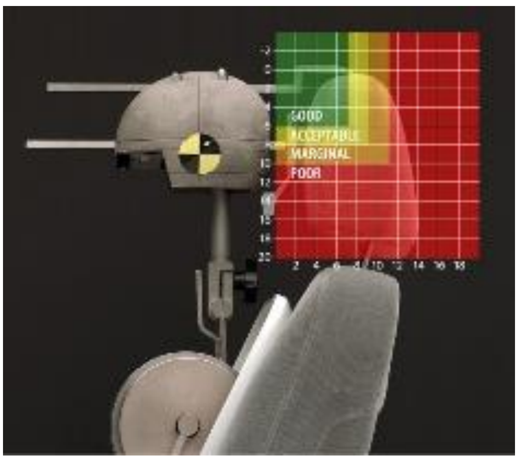

Fig. 2 Static evaluation by HRMD

Fig. 3 Dynamic evaluation

The IIWPG proposal rather relied on the statistical evidence of the superior real life performance of both the Volvo Whips seat and the Saab SARS seat. The idea is that a seat performing better in real life could be used as a bench mark, comparing the parameters that have been found relevant for neck loadings. With improved seats these rating parameters have been adopted over time, driving seat designers to reduce neck loadings to a minimum. The complete evaluation of a seat eventually consists of a static rating and a subsequent dynamic test.

The IIWPG test comprises a method to adjust seats for good reproducibility of tests and required the development of a static Head Restraint Measuring Device (HRMD), which helps evaluate the safety of the head restraint by giving accurate measurements of the head restraint position.

Eventually today we can see seats on the market that do not allow for rearward head displacement at all in a rear impact.

With these efforts of IIWPG, along with the efforts of car manufacturers, the vehicle and seat structure have been continuously improved and now offer a significantly higher level of protection than ever before. The modern vehicle is equipped with the safer head restraint which moves closely to the back of occupant's head or the seat which alleviate the impact on the occupant by moving backward like the baseball glove to prevent whiplash injury in the case of the rear-end collision.

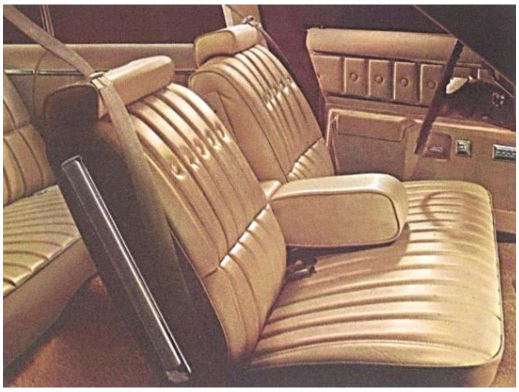

Fig. 4 Seat/head restraint of old car

Fig. 5 Seat/head restraint of modern car

3. Current situation

Neck pain claims caused by an accident are to be compensated in many countries.

In South Korea, the injury severity due to the traffic accident is classified into 14 grades according to the law. Grade 1 of the heaviest severity has injuries such as the brain damage with severe neurological symptoms and the spine damage with the paralysis while grade 14 of the lightest severity has the minor injuries such as the joint sprain of fingers or toes and the bruise of arms or legs.

According to the statistics of treatment period for the patients with grade 14 injury severity, the 5th percentile is a day while the 95th percentile is 14 days which shows big difference.

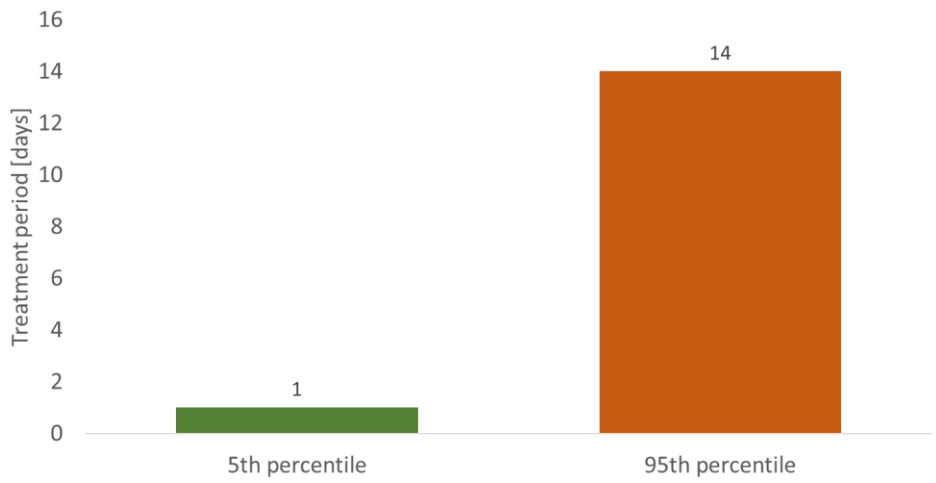

Fig. 6 Comparison of treatment period
(5th and 95th percentile within grade 14 of minor injury group)

When we compare the medical expenses for symptoms such as the cervical sprain and the lumbar sprain, there are huge difference between the motor insurance and the national health insurance. Any bodily injury due to the traffic accident is compensated by the motor insurance.

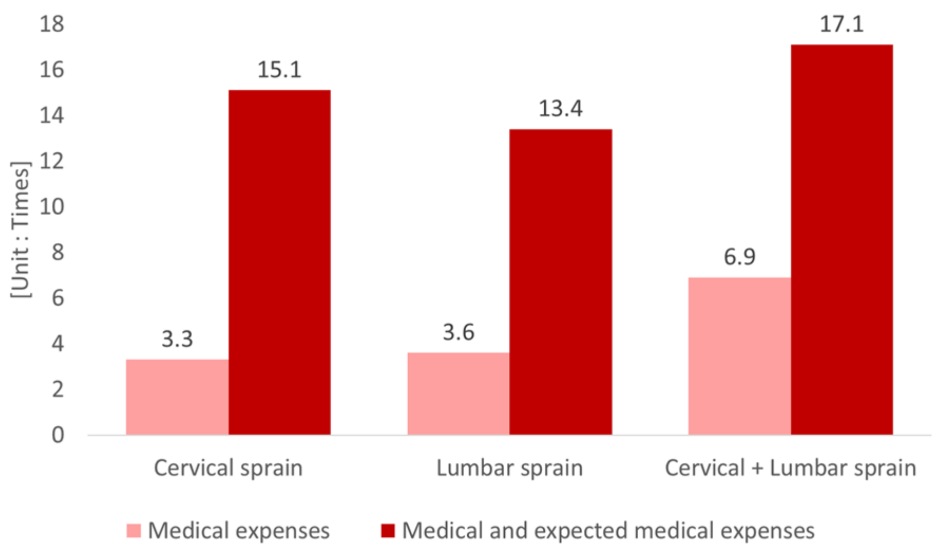

Fig. 7 Average compensation ratio (motor insurance divided by national health insurance)

The medical expense difference between the motor insurance and the national health insurance might be caused by the following features of each of them.

For the motor insurance,

- The driver with the higher fault ratio for the accident cause has to pay for the whole amount of the medical expenses of the opposite occupants including the driver with the lower fault ratio, which means they can take the medical treatments without any expenses even with some fault ratio, not zero.
- In the settlement between the occupants of the struck vehicle and the opposite motor insurance company, the occupants are paid for the additional medical treatments expected until the recovery. This compensation for the additional treatments for the future recovery is called "expected treatment expenses" and the more the expenses get for the actual medical treatments, the more "the expected treatment expenses" is compensated.

For the national health insurance,

- It supports a certain amount of the medical expenses and the patient has to pay the remaining amount of the expenses.
- If the total amount of the medical expenses gets increased, the amount of the expenses paid by the patient gets increased as well.

In case of the UK, although the Legal Aid, Sentencing and Punishment of Offenders Act (LASPO) 2012 clearly reduced the costs of civil litigation for whiplash claims, problems in the market persisted. In 2016/17, ABI(Association of British Insurers) data showed that the number of road traffic accident claims was around 50% higher than in 2006/07, despite a fall in reported accidents and improvements in the safety of vehicles. Whiplash related claims were also still accounting for around 85% of all road traffic accident claims. So the government sought to create a simplified, more efficient and cost-effective compensation system.

On 31 May 2021, the Whiplash Reform Programme was implemented for low value road traffic accident (RTA) related personal injury claims, which includes:

- a fixed tariff of compensation for whiplash injuries that last up to 2 years, which will provide clarity and certainty to claimants about the amount of personal injury damages they will receive for whiplash injuries.
- a ban on settling whiplash claims without medical evidence.
- an increase to the Small Claims Track (SCT) limit for RTA related Personal Injury claims from 1,000 to ?5,000 via amendments to the Civil Procedure Rules.
- the Official Injury Claim service to enable all claimants, with or without legal representation, to make and settle their own claim.

The statistics in a year since its implementation shows some figures in the claims.

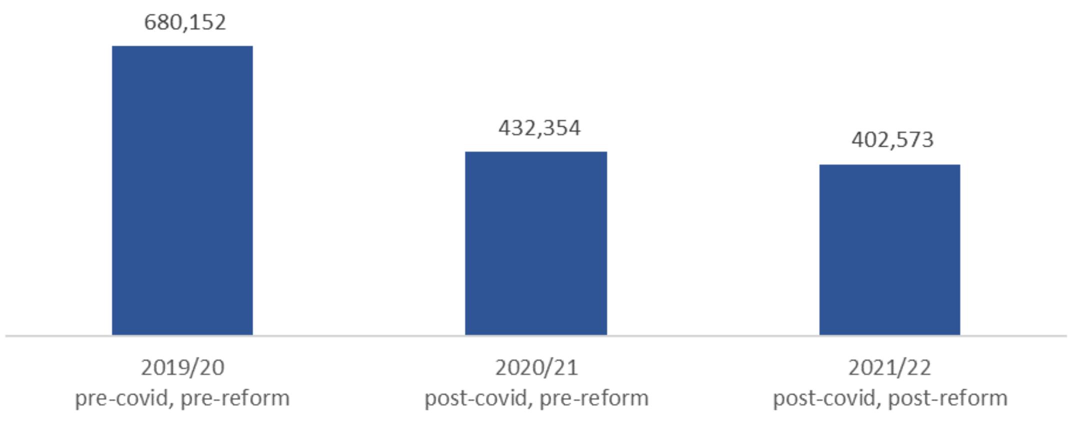

Fig. 8 Annual claims changes since implement of Whiplash Reform Programme

Ministry of Justice of the UK evaluates that while there is no doubt some reduction in whiplash claims is due to reduced travel etc. during periods of COVID, proportionally whiplash claims have reduced (compared to all personal injury claims) so the consensus is that the reforms seem to be working.

4. Glossary

- **ΔV** : The change of the velocity of a car between pre-collision and post-collision

  - ΔV can be calculated according to the technical reference of ISO/TR 12353-3.

Pre-collision V_{pre} = 10 km/h

Collision

Post-collision V_{post} = 15 km/h

$$\Delta V = V_{post} - V_{pre} = 15 \text{ km/h} - 10 \text{ km/h} = 5 \text{ km/h}$$

Fig. 9 Example of ΔV

- **Minor crash** : A car-to-car crash of low velocity change of the struck vehicle which typically produces scratches, minor deformations of cosmetic panels like the bumper cover

- **Passenger** or **Occupant** : The person who sits on any seat of a struck car.

- **Mean Acceleration** : The average acceleration experienced by a car body during an impact with another car or object
  - Mean acceleration can be calculated according to the technical reference of ISO/TR 12353-3.

- **WAD** (Whiplash-Associated Disorder[4]) : The collection of symptoms affecting the neck triggered by an accident with an acceleration-deceleration mechanism

Table 1. WAD symptom of each grade

Grade	Clinical Presentation
WAD 0	No complaint , no physical sign(s)
WAD 1	Neck complaint of pain, stiffness, or tenderness only, no physical sign(s)
WAD 2	Neck complaint and Musculoskeletal sign(s)
WAD 3	Neck complaint and Neurological sign(s)
WAD 4	Neck complaint and Fracture or dislocation

- **No injury** (defined only in this document) : WAD 0

- **Initial symptom (defined only in this document)** : WAD 1

- **Injury** (defined only in this document) : WAD 2+

4 Source : QTF(Quebec Task Force)

5. Scope

Fundamental

From a biomechanical point of view, during a rear-end collision, the cervical spine is subject to a load due to the impact from the rear, resulting in a difference in the movement of the torso and the head. Generally speaking, changes in the occupant's movements are always transmitted through the lower seatback in the pelvic area, and then through the upper seatback in the torso or shoulder area, and then finally through the head restraints to the head itself.

③ Head supported by the head restraint

② Acceleration of the torso by the seatback

① Transmission of force from the structure to the seat bracket

Fig. 10 Application of force to an occupant in a rear impact

When an impact is transmitted to the shoulder, the inertia of the head causes relative movements between the cervical spine vertebrae, the deep muscles of the neck, and the muscles of the upper neck. The faster the load is transferred, the less the muscles get to play a role in maintaining homeostasis of the sitting posture. Basically, when the load transmission is slow, the occupant can hold the head reflexively and responsively. However, the higher the gradient of load transmission is, the more limited the effect of the muscle becomes with respect to the relative movement of the head.

The form of this relative movement is initially translational (Fig. 11, phase 1); the head remains behind the torso and the cervical spine deforms into an S-shape. The head is then rotated rearward (extension of the cervical spine, Fig. 11, phase 2) and pulled forward by the neck, and then accelerated forward (flexion, phase 3). This process is similar to the movement of a whip. That's why the cervical spine injury of the rear-end collision has also been called "whiplash injury”.

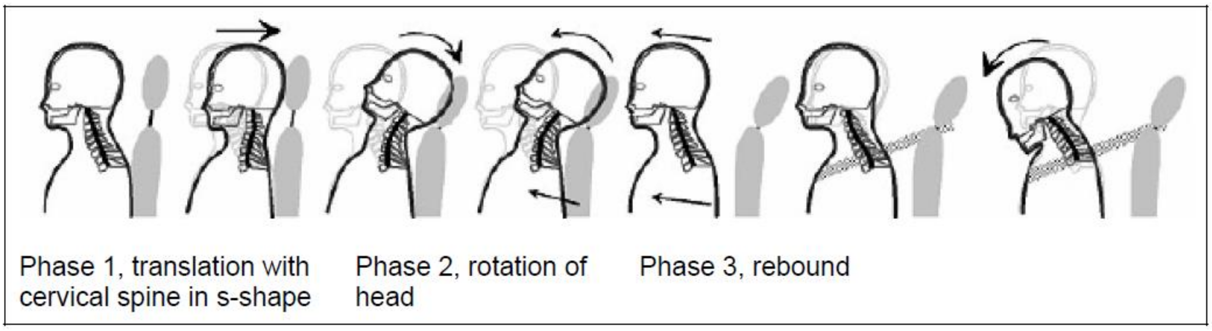

Fig. 11 Schematic illustration of distortion of the neck when thoracic spine accelerates without head support (according to Horion, LMU Reference? Number and linked source in “References”)

Fig. 12 Actual movement of head in a rear impact situation without head rest supporting the head (AZT Automotive GmbH)

Phase 2, however, is very unlikely in the modern car due to the head restraint, which limits the movement of the head in relation to the torso by the beginning of phase 2 at the latest. But in cases where the user can tentatively misadjust the head restraint, the protection potential of the seat might be reduced.

A lot of efforts have been invested in research on neck pain – but why? In a real accident the occupant's loading depends on a variety of parameters. Firstly the vehicle mass ratio is important for the energy share of the involved cars. The energy absorption capability of the vehicle's crash management system has an influence on the amount of energy that can be transferred to the occupant. And finally the individual seat's elasticity and the upholstry's energy absorption again influences the occupant's loading. The seat design finally is decisive for the neck loading and the eventually the occupant health status plays a major role for his or her vulnerability. This list is not complete and therefore it is easy to understand that research has not been limited to medical interest.

Hence researchers often focused on a reduced test setup, because only this method allows for the investigation in a certain aspect of the complex system. The current research results are consequently only to apply for passenger cars according to UNECE type M1[5]. The interest also focusses on minor accidents, i.e. where a relatively low ΔV occurs and typically the vehicle does not show structural damage, hereinafter referred to as "minor crash".

Applicable Accident

This guideline is applicable only to the minor crash, defined in the part of "2. Glossary", of the car-to-car rear-end single collision, not the multiple collision.

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5 TRANS/WP.29/2000/14 (unece.org)

6. Summaries of research and publications

Many institutions including European Spine Society, Biodynamic Research, Association for the Advancement of Automotive Medicine, as well as universities and independent researchers have produced considerable research results and this paper tries to collect some relevant studies.

The results are arranged according to their character as “accidentology research”, “experimental research” and “evaluation methods for whiplash associated disorders” and will be presented in a brief abstract also in the appendixes.

From today’s point of view it’s not surprising that most results show no or very low injury risk in the rear-end minor crash. When evaluating existing studies it is necessary to understand that older studies refer to contemporary seats, i.e. with the poor protection potential of their time.

One of the major aims of the studies was to figure out parameters of (rear impact) accidents that correlate with an injury risk. Overall the ΔV of the struck car has been widely accepted as a scale that can be used for examination of claims. Vehicle acceleration was found to be appropriate in some studies, but the actual occupant loading is mainly depending from the seat and thus only indirectly from the vehicle structure. Furthermore one of the basic information required for the examination of a certain case is the accident analyst’s information on accident severity. The only parameter that can be estimated from accident analysis is the ΔV. Very seldom the car’s acceleration can be determined and if so, only the average acceleration will be available. Hence the determining parameter ΔV has primarily to be considered for whiplash injury probability.

Accidentology research includes,

- 'Report on whiplash injuries in frontal and rear-end crashes (© Folksam, Sweden, 2012)' shows the analysis result of 175 cases of real-road rear-end collisions. WAD2+ is observed in the risk curve to increase rapidly at ΔV between 10 km/h and 15 km/h.

Table 2. Occupants incidence for each WAD grade out of 242 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+	
	No.	%	No.	%	No.	%
0-5	30	97	1	3	0	0
5-10	61	60	30	30	10	10
10-15	31	48	26	40	8	12
15-20	12	50	7	29	5	21
20-25	2	18	5	45	4	37
25-30	2	29	1	14	4	57
30-35	0	0	0	0	3	100
35-40	0	0	0	0	0	0

- 'Analysis of whiplash associated disorder claims using real-world data retrieved from event data recorders: a case-control study (© IRCOBI[6], AXA Winterthur et al., Switzerland, 2016)' which is based on 168 cases of real-road rear-end collision accidents says that the statistical threshold of initial WAD symptoms is 10 km/h of ΔV. However, it says that in addition to ΔV, individual cases need to be assessed with regard to other parameters such as a medical history of previous complaints on neurological symptoms because the finding is from a purely statistical observation.

6 International Research Council on Biomechanics of Injury

Table 3. Occupants incidence for each WAD grade out of 172 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+		Unknown	
	No.	%	No.	%	No.	0%	No.	%
0-40	108	63	18	11	23	13	23	13

Experimental research with human subjects includes,

- 'Human Subject Kinematics and Electromyographic Activity During Low Speed Rear Impacts(ⓒ Society of Automotive Engineers,Inc., Biomechanical Research & Testing,LLC, USA, 1996)' points out that any one of 10 subjects exposed to vehicle-to-vehicle rear-end tests at ΔV of 7.5-10 km/h did not sustain injury or complain of pain during the two week period following the impact.

Table 4. Subjects incidence for each WAD grade out of 10 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+		Symptoms duration
	No.	%	No.	%	No.	%	
7.5-10.0	10	100	0	0	0	0	-

- 'Human Head and Neck Kinematics After Low Velocity Rear-End Impacts-Understanding „Whiplash" (ⓒ Society of Automotive Engineers,Inc., Biodynamic Research Corp., USA, 1995)' says that ΔV of 8 km/h seems to be a convenient threshold for assessing injury potential based on test series with seven human subjects of whom four subjects were exposed to three test runs each, one subject had four test exposures and two subjects were exposed only once.

Table 5. Subjects incidence for each WAD grade out of 18 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+		Symptoms duration
	No.	%	No.	%	No.	%	
5.8-10.9	2	11	16	89	0	0	≤ 4 days

- 'The relationship between clinical and kinematic responses from human subject testing in rear-end automobile collisions(ⓒ Elsevier Science Ltd., AAAM[7], USA, 1999)' reports the results of the statistical analysis on vehicle collision tests with 42 human subjects. Each of the subjects was exposed to about two tests and total 81 tests were condected which had 42 at ΔV of 4 km/h and 39 at ΔV of 8 km/h. But there were six of incomplete kinematic data which left final 75 of valid tests. The paper says that there were 23 subjects with symptoms out of 75 valid tests which included 9 subjects at ΔV of 4 km/h and 14 subjects at ΔV of 8 km/h. It reports that all of the symptoms of 23 subjects disappeared within 5 days.

Table 6. Subjects incidence for each WAD grade out of 75 valid exposures

ΔV [km/h]	WAD0		WAD1		WAD2+		Symptoms duration
	No.	%	No.	%	No.	%	
4	Unknown	Unknown	9	Unknown	0	0	≤ 5 days
8	Unknown	Unknown	14	Unknown	0	0	
Total	52	69	23	31	0	0	

- 'Human Occupant Kinematic Response to Low Speed Rear-End Inmpacts(ⓒ Biodynamics Engineering, Inc., USA, 1994)' shows the result of six of vehicle-to-vehicle rear-end collision

7 Association for the Advancement of Automotive Medicine

tests with five human subjects. Three of the subjects had cervical and/or lumbar spinal degeneration(MRI scan) before the tests. Only one subject reported transient, minor neck stiffness.

Table 7. Subjects incidence for each WAD grade out of 7 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+		Symptoms duration
	No.	%	No.	%	No.	%	
8	6	86	1	14	0	0	≤ 1 day

- ’The Movement of Head and Cervical Spine During Rear-End Impacts(ⓒ Institute for Mechanics, University of Graz et al., Austria, 1994)‘ shows the result of 37 of sled tests with 25 human subjects. None of the subjects reported the initial symptoms.

Table 8. Subjects incidence for each WAD grade out of 37 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+		Symptoms duration
	No.	%	No.	%	No.	%	
6-12	37	100	0	0	0	0	-

- ’Analysis of Human Test Subject Kinematic Responses to Low Velocity Rear End Impacts(ⓒ Biodynamic Research Corp., USA, 1993)‘ shows the result of 10 vehicle-to-vehicle tests with four human subjects. Three subjects reported the initial symptoms which disappeared 3-4 days after the onset.

Table 9. Subjects incidence for each WAD grade out of 10 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+		Symptoms duration
	No.	%	No.	%	No.	%	
3.0-7.8	7	70	3	30	0	0	≤ 4 days

- ’Comparative Analysis of Low Speed Live Occupant Crash Test Results to Current Literature(ⓒ TSI Sulutions Inc., USA, 2004)‘ shows the result of the literature research on the crash tests at ΔVs below 12 km/h which involved 767 human subjects. Of these 767 exposures, 27 reported the initial symptoms which disappeared 1 day(25 subjects) or 2 weeks(2 subjects) after the onset.

Table 10. Subjects incidence for each WAD grade out of 767 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+		Symptoms duration
	No.	%	No.	%	No.	%	
≤ 12	740	96.4	25	3.3	2	0.3	≤ 1 day(WAD1) 2 weeks(WAD2+)

- 'Do “whiplash injuries” occur in low-speed rear impacts? (© Springer-Verlag, European Spine Society, 1997)' says that the biomechanical “limit of harmlessness” in two-car rear-end collisions lies at ΔV between 10 and 15 km/h based on bumper-car-riding tests and real car-crash tests with 19 human subjects. One female and three male subjects out of the real car-crash tests reported symptoms or the minor soft tissue injuries which disappeared within 3 days or less. The other male subject suffered a reduction of rotation of the cervical spine to the left of 10 ° for 10 weeks.

Table 11. Subjects incidence for each WAD grade out of 19 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+		Symptoms duration
	No.	%	No.	%	No.	%	
8.7-14.2	14	74	4	21	1	5	≤ 3 days(WAD1) 10 weeks(WAD2+)

- 'Rear Impact Tests with Bumper Cars (© GDV supported by AZT Automotive GmbH, Germany, 2009)' shows the result of the bumper-car-riding tests with 16 human subjects. It says that the rear-end collision of the bumper car is comparable to that of the passenger car in terms of kinematics, but occupants experienced higher neck loads in bumper cars. Thanks to the high potential protection offered by the head restraints and seats in (modern) passenger cars, the intensity of motion is less and the loading values are lower in passenger cars than in bumper cars during comparable impacts. None of the subjects reported any discomfort and there were no clinically relevant findings after the tests below ΔV of 10 km/h.

Table 12. Subjects incidence for each WAD grade out of 32 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+		Symptoms duration
	No.	%	No.	%	No.	%	
6.9-8.8	32	100	0	0	0	0	-

Aside from GDV's study supported by AZT Automotive GmbH, there is the 'limit of no or low risk' of ΔV = 10 km/h generally accepted in German society. In case of a suit between the claimant and the insurer, the judge considers some factors such as witness statements, ΔV based on the accident analysis, the biomechanical analysis and medical opinions. Based on scientific knowledge, the judge accepts the threshold of ΔV = 10 km/h as 'limit of no or low risk' in the absence of better information and if there is no other individual factor like e.g. pre-existing conditions.

- 'A Study of Impact on Head and Neck Using Human Volunteer Low-Speed Impact Tests (© Korean Journal of Legal Medicine, National Forensic Service et al., South Korea, 2013)' shows that the result of the sled tests at ΔVs below about 8 km/h which simulated the rear-end minor collisions. 50 human subjects participated in the tests and six of them reported symptoms after the tests which disappeared within 2 days or less.

Table 13. Subjects incidence for each WAD grade out of 50 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+		Symptoms duration
	No.	%	No.	%	No.	%	
4.7-8.1	44	88	6	12	0	0	≤ 2 days

- 'Occupant's Injury Risk in Rear-end Minor Collision (© KIDI/KART, South Korea, 2021)' shows the result of the vehicle-to-vehicle rear-end collision tests with 24 human subjects. 16 tests were conducted with the subjects on the driver seat and the back seat at ΔVs below 10 km/h. Eight of the subjects reported initial symptoms after the tests which disappeared 7-10 days after the onset of the symptoms.

Table 14. Subjects incidence for each WAD grade out of 24 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+		Symptoms duration
	No.	%	No.	%	No.	%	
1.5-9.4	16	67	8	33	0	0	7-10 days

Individual factors such as the seat/head restraint, the posture of the occupant, the seating position and the gender should be considered to evaluate the injury risk in the rear-end collision accident because the extent of the risk has been shown to vary according to these factors. The whiplash risk will decrease if a vehicle is equipped with a good-rated seat/head restraint[8] and an occupant has a proper posture at the moment of an accident. And a front seating rather than a rear seating and a male driver rather than a female would help decrease the risk as well.

However, the researches show relatively different results at least in the low-ΔV accident.

- Seat/head restraint and posture of occupant

  The seat/head restraint can take its role of reducing the whiplash risk when the head of an occupant is located in the range covered by a head restraint. If the head is out of position, the head restraint gets to be meaningless. That's why it's needed to check the posture of an occupant at the moment of the accident to see whether or not the head was protected by the head restraint.

  GDV supported by AZT Automotive GmbH has confirmed that the kinematic maneuver of the rear-end collision between 2 bumper cars is comparable to that between 2 vehicles. And it showed through bumper-car-riding tests that there was not any injured human subject at ΔV up to 10 km/h. And according to GDV's survey supported by AZT Automotive GmbH, out of almost 900,000 bumper car rides at Oktoberfest in 2007 and 2008, only one clinically relevant case was found for each year; both cases had a history of impairment.

  To sum up, the rear-end collision at low ΔV of two vehicles is comparable to that of two bumper cars. And the collision of two bumper cars doesn't produce any whiplash risk even though the bumper car has the worse seat-geometry without the head restraint than the vehicle with the head restraint.

  Accordingly, it's reasonably inferred that the factors of the seat/head restraint and the posture of the occupant have little effect on the whiplash injury risk at ΔV of 10 km/h or less in the rear-end crash if the vehicle has the head restraint which is adjustable to the head position of the occupant.

- Seating position

  Most of seats of passenger cars have head restraints. If the seat is equipped with the head restraint which is adjustable to the occupant's head position, it would provide even better protection than the bumper car without the head restraint.

  Therefore, the seating position doesn't have to be considered for evaluation of the injury risk in the low ΔV rear-end collision if the seat has the adjustable head restraint. This finding is supported as well by the vehicle tests result of KIDI/KART which had eight pairs of subjects in the driver seat and the back seat. Four out of eight subjects in the driver seat had the initial symptoms and no injury after the tests like four out of eight subjects in the back seat.

- Gender

  The data compared between males and females in the papers quoted shows that females generally have the higher possibility for the initial symptoms than males in the low-ΔV rear-end collisions.

8 NCAP(New Car Assessment Program) in some countries conducts the test as one of vehicle-safety evaluations which rates the protective performance of the seat/head restraint against the whiplash injury.

However, it needs to be noted that under the given condition of the low-ΔV, the female's higher possibility is generally limited to the initial symptoms, not the injury, which disappear within a few days without medical intervention.

- 'Report on whiplash injuries in frontal and rear-end crashes' shows females have the higher risk of WAD1+ and WAD2+ in the ΔV interval of 0-20 km/h.

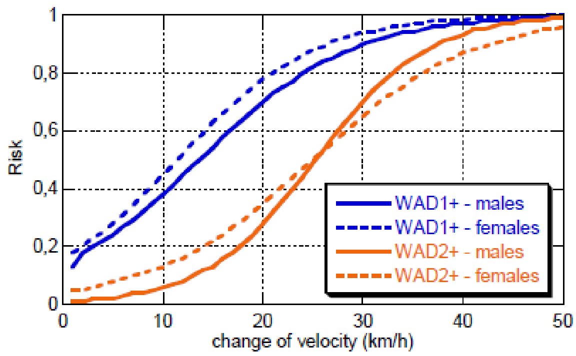

Fig. 13 Risk of various degrees of WAD with respect to change of velocity in rear-end impacts for male and female front seat occupants.

- 'Analysis of whiplash associated disorder claims using real-world data retrieved from event data recorders: a case-control study' also mentions that the females' higher risk was observed for the initial WAD symptoms based on 168 cases of real-road rear-end collision accidents.

- 'Human Occupant Kinematic Response to Low Speed Rear-End Impacts' shows almost of males and females with WAD0 except for a female with WAD1.

Table 15. Comparison between male and female for each WAD grade out of 7 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+	
	No. (M/F)	% (M/F)	No. (M/F)	% (M/F)	No. (M/F)	% (M/F)
8	3/3	100/75	0/1	0/25	0/0	0/0

- 'Do "whiplash injuries" occur in low-speed rear impacts?' shows males had slightly higher incidence for the initial WAD symptoms than females.

Table 16. Comparison between male and female for each WAD grade out of 19 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+	
	No. (M/F)	% (M/F)	No. (M/F)	% (M/F)	No. (M/F)	% (M/F)
8.7-14.2	10/4	72/80	3/1	21/20	1/0	7/0

- 'Occupant's Injury Risk in Rear-end Minor Collision' has the result that females have higher incidence for the initial symptoms than males.

Table 17. Comparison between male and female for each WAD grade out of 24 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+	
	No. (M/F)	% (M/F)	No. (M/F)	% (M/F)	No. (M/F)	% (M/F)
1.5-9.4	13/3	81/38	3/5	19/62	0/0	0/0

- ‘Rear Impact Tests with Bumper Cars’ shows neither males nor females had the initial symptoms.

Table 18. Comparison between male and female for each WAD grade out of 20 exposures

ΔV [km/h]	WAD0		WAD1		WAD2+	
	No. (M/F)	% (M/F)	No. (M/F)	% (M/F)	No. (M/F)	% (M/F)
7.5-10.0	10/10	100/100	0/0	0/0	0/0	0/0

7. RCAR's recommendation

The majority of neck pain claims after rear impacts is assigned to accidents with relatively low changes of speed and this type of complaint is not objectifiable by medical diagnosis. Very often no symptoms can be found and in other cases the found symptoms like e.g. movement restrictions or abnormalities in the cervical spine can't be doubtlessly related to the accident, because they are often related to ageing and can also be found in people not affected by an accident. In order to provide a fair method for evaluating the causality of complaints after an accident, it is therefore inevitable to include additional information like engineering and biomechanical analysis besides the medical symptoms into an evaluation procedure.

The necessity of an evaluation procedure results from the fact that in many countries neck complaints after an accident are subject to compensation by the causing party of the accident. In the absence of impartial diagnostics such a legal system is prone to fraud, because it is very easy to claim neck pain if there is no possibility of prove. In fact this would invert the established rule that a claimed damage has to be documented and verified by the claimant. Several countries see/saw raising costs for neck pain claims, while other countries did not experience such claims, despite comparable traffic situations. Research therefore focused on the parameters that allow for checking the plausibility of such claims. A basic information for this purpose is the intensity of the claimed event, i.e. was the impact severity appropriate for the claimed distortion. Several other aspects which are described in the listed sources have to be considered.

Eventually today there is a common understanding that the ΔV plays a decisive role. This is caused by the fact that it directly describes the energy transferred into the struck vehicle, while e.g. a medium acceleration does not consider damping effects of the seat. Furthermore only the ΔV can be evaluated by accident analysts with today's possibilities. Accident analysts mainly work based on damage patterns and comparison with reference information for their evaluation. Consequently it's appropriate to look at the car's damage for a first indication of the plausibility of neck complaints.

However, damage patterns depend on several influences, e.g. a good interaction of two cars' bumper systems can transfer more energy without spectacular damage than overriding cross members just sliding of and producing deep intrusions at low energy transfers. Also the lateral offset of two colliding cars can have a significant influence. Other facts like vehicle mass ratio can have relevant influences. This implies that not only the struck car needs to be evaluated but also the striking car needs to be included.

Major studies in the last decades of research focused on the question of a so called harmlessness limit, which would exclude a certain low impact severity from further investigation as not relevant for distortion of the cervical spine. This however would be in conflict with several legal systems which do not allow for such a systematic exclusion on claims and require an individual evaluation. This legal baseline correctly considers the fact that human beings can have individual vulnerability, e.g. due to former injury to the cervical spine or due to ageing.

Still there is an established common understanding that neck distortion is unlikely for normal occupants under a certain ΔV. This threshold is not clearly defined as researchers found changes of speed of up to 15 km/h not to be harmful. Still there are studies showing that neck pain complaints can occur at speeds below ΔV = 10 km/h [1]. Hence the individual case has to be seen in it's entirety. As a reference a baseline of ΔV = 10 km/h has been established as common scientific understanding in Germany and is widely accepted by judges in claims, if there is no evidence for a higher vulnerability of the claimant.

In order to evaluate best evidence for an accident's causality for a claimed neck pain it is necessary to consider the following:

- Engineering analysis can be used along with medical diagnosis to determine the injury risk to occupants in minor crashes, and an effective engineering factor is ΔV of the struck car.
- According to the research discussed in this paper, the range of ΔV with no/low injury risk varies within the studies. Therefore this paper does not recommended a certain threshold ΔV level for no/low whiplash-injury risk. This needs to be evaluated in consideration of the local circumstances such as the social acceptability, the constitution of the people and etc.
- In order to estimate the injury risk of an occupantin a minor crash, it is necessary to evaluate the following in addition to ΔV of the struck car.
  - constitution and age of the passengers in the struck car
  - previous illness or damage to the cervical spine due to an accident
  - crash/accident parameters.

Based on these considerations RCAR recommends to apply a multi-step approach in the evaluation of neck pain claims:

1. Evaluate the vehicle damage, accident circumstances and seat performance
   Certain characteristics indicate the amount of energy transferred, such as low extend of damage like
   - scratches on clear coat or/and color coat of paint
   - scratches or minor deformation of substrate on plastic parts
   - minor intrusions
   The seat's protection potential can be derived from e.g. new car assessment programs NCAP. The necessary steps require an appropriate documentation of damage on both cars (loss adjuster).
   This information delivers the first indication on the probability of a whiplash associated disorder relative to current scientific knowledge on relevant accident severity. Minor accidents typically only show peripherical but no structural damage. If there is no rear cross member installed, minor damage to the rear panel (no replacment required) still needs to be regarded non-structural. This step requires experience and is not necessarily accurate.
   A less recommendable solution would be evaluation by means of repair costs, because these depend on several other influences like car segment (expensive vs cheap parts) and presence of driver assistance system where sensors can drive costs which don't correlate with energy transfer.
   The seat is the mean energy transfer element between vehicle and occupant. Modern seats typicallly reduce neck loads to values near zero in rear impacts if correcty adjusted and can be used for guidelines regards evaluation of neck pain probability.
2. Evaluate the accident severity and parameters
   Where a more accurate investigation of the case is required, a qualified accident analyst is necessary for the calculation of ΔV, impact direction and any other relevant information on the accident.
3. Evaluate the claimants health status
   the treating physician is bound to a best possible treatment of his patient and thus has limited freedom to question patient's description of symptoms. Therefore an independant doctor needs to be involved for this step. The field of profession should be related to cervical spine expertise.
4. Evaluate biomechnical loadings
   Both the accident analyst's findings on accident severity and impact direction and the statement on the occupants relevant health situation need to be assessed by the biomechanic in order to have the best impartial result.

Appendix A. Research on neck injury risk based on accidentology

1. Report on whiplash injuries in frontal and rear-end crashes

Anders Kullgren, Helena Stigson, Folksam, Sweden, 2012, © Folksam

Key words

- the analysis of 175 rear-end crashes
- initial symptoms
- symptoms lasting longer 1 month
- symptoms lasting longer 6 months

Aim of the study

- To show incidence and risk of neck injuries in rear-end crashes

Content

- Methods

This report is based on the analysis of 175 rear-end crashes. Multiple impacts are excluded in the study. Occupants with previous whiplash symptoms before the crash under study were excluded.

Risk curves for rear-end crashes were calculated with simple logistic regression. Chi^2-tests were used to check for statistical significance between groups, for example to study influence of gender, age, stature and weight on injury outcome.

- Average crash severity

Approximately 13% of the drivers and front seat occupants in rear-end crashes sustained whiplash symptoms lasting longer than 1 month, and 9% sustained symptoms for more than 6 months.

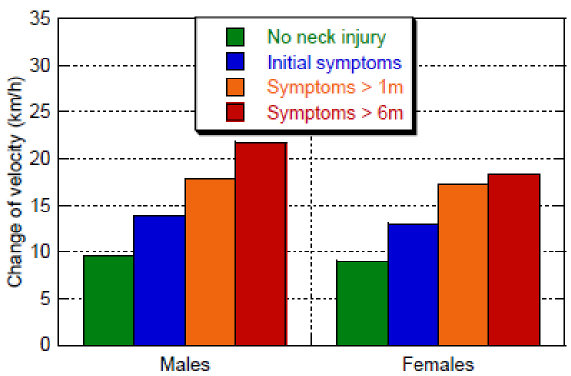

Fig. 14 Average change of velocity for male and female occupants with various duration of symptoms.

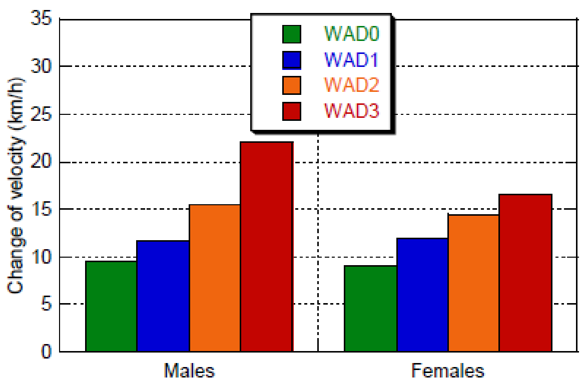

Fig. 15 Average change of velocity for male and female occupants with various degrees of WAD.

The average ΔV and mean and peak accelerations in rear-end crashes for occupants with long-term symptoms as well as those with WAD2+ symptoms were higher for males than for females, indicating that females are more vulnerable.

Occupants sustaining symptoms longer than six months were found in a range of change of velocity between 9 and 33 km/h. The same ranges were found for occupants with WAD symptoms of grade 3.

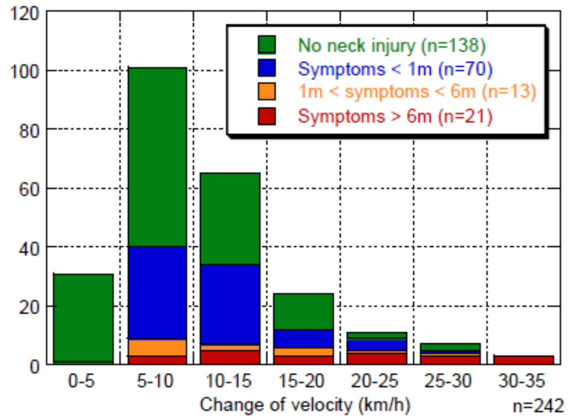

Fig. 16 Number of occupants with varying duration of symptoms in intervals of change of velocity in rear-end impacts.

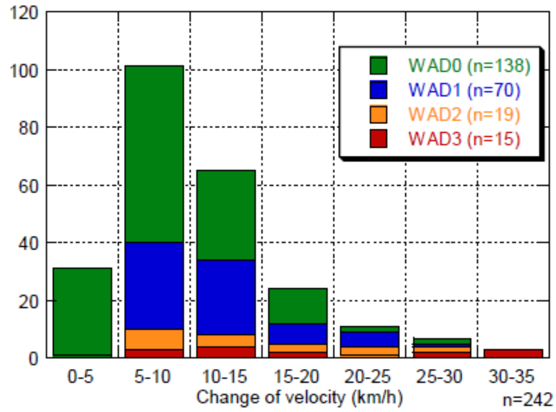

Fig. 17 Number of occupants with varying degree of WAD in intervals of change of velocity in rear-end impacts.

- Risk of AIS1 neck injury

At a change of velocity above 15 km/h the risk of symptoms for more than 6 months was found to increase rapidly for the seats included in the study.

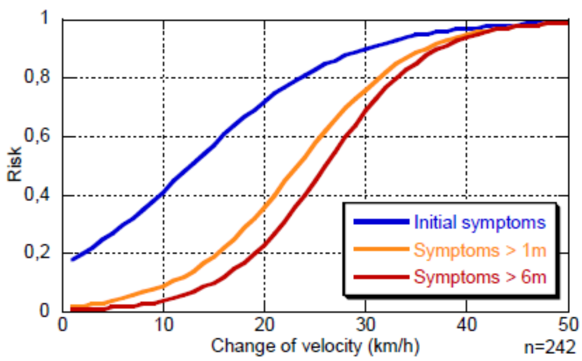

Fig. 18 Risk of initial and long-term symptoms with respect to change of velocity.

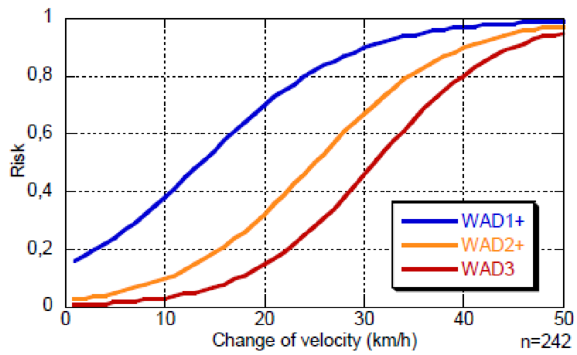

Fig. 19 Risk of whiplash injury with various degrees of WAD with respect to change of velocity.

Female front seat occupants were found to have higher risk of both initial symptoms and symptoms lasting longer than one month compared to males. The same difference could not be seen for grades of WAD.

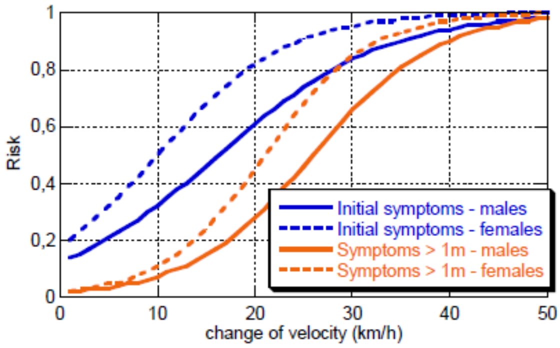

Fig. 20 Risk of initial and long lasting symptoms with respect to change of velocity in rear-end impacts for male and female front seat occupants.

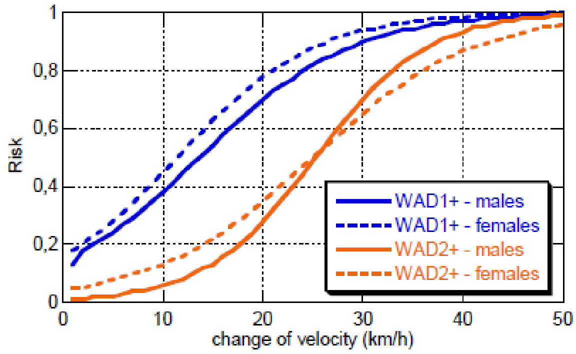

Fig. 21 Risk of various degrees of WAD with respect to change of velocity in rear-end impacts for male and female front seat occupants.

- Influence of age, stature and weight

No significant differences in average age, stature and weight were found for occupants with different injury categories, showing that age, stature and weight only may have a minor influence on the whiplash injury outcome. The significance tests showed no difference in risk between both female and male occupants below and above average stature and weight. No significant differences in risk were found between occupants up to 35 years age, occupants between 35 and 55 and those above 55 years age.

- Seats with and without whiplash protection

The risk of symptoms for more than 1 month and more than 6 months were lower in seats with WIL (Toyota's whiplash prevention system). At a change of velocity of 20 km/h the risk of symptoms for more than 1 month and more than 6 months was approximately 40% lower in seats with WIL compared to seats without.

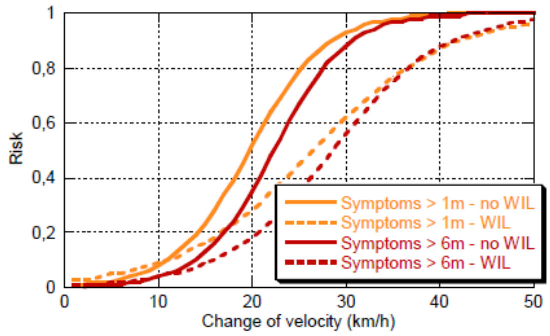

Fig. 22 Risk of long lasting symptoms in cars with and without WIL with respect to change of velocity.

Remarks

WAD data from Folksam added which is not included in the report

Table 19. Occupants incidence for each WAD grade out of 242 exposures

ΔV [km/h]	WAD0		WAD1		WAD2		WAD3	
	No.	%	No.	%	No.	%	No.	%
0-5	30	97%	1	3%	0	0%	0	0%
5-10	61	60%	30	30%	7	7%	3	3%
10-15	31	48%	26	40%	4	6%	4	6%
15-20	12	50%	7	29%	3	13%	2	8%
20-25	2	18%	5	45%	3	27%	1	9%
25-30	2	29%	1	14%	2	29%	2	29%
30-35	0	0%	0	0%	0	0%	3	100%
35-40	0	0%	0	0%	0	0%	0	0%

2. Analysis of whiplash associated disorder claims using real-world data retrieved from event data recorders: a case-control study

B. Jordan, K.U. Schmitt, D. Butzer, B. Zahnd, AXA Winterthur et al., Switzerland, 2016, © IRCOBI

Key words

- 168 real-world rear-end collisions
- EDR(event data recorder) dataset
- WAD group
- control group
- statistical ΔV threshold of 10 km/h

Aim of the study

- To identify possible predictors for WAD claims from struck car occupants using EDR and insurance data

Contents

In this study, the first large-scale EDR dataset available in Switzerland was analyzed regarding relevant WAD(Whiplash Associated Disorders) outcome variables. A total of 168 real-world rear-end collisions were analyzed. From 62 of these collisions, a total of 66 persons reported initial WAD symptoms[9], which formed the WAD group. In 106 collisions of 106 occupants, no WAD symptoms were reported. These cases formed the control group.

As anticipated, ΔV has an effect on the onset of initial WAD symptoms. Kullgren et al. stated that the WAD risk increases with ΔV values. In this study, from ΔV values between approximately 9 and 12 km/h, the risk of complaining about initial WAD symptoms starts to increase strongly with ΔV.

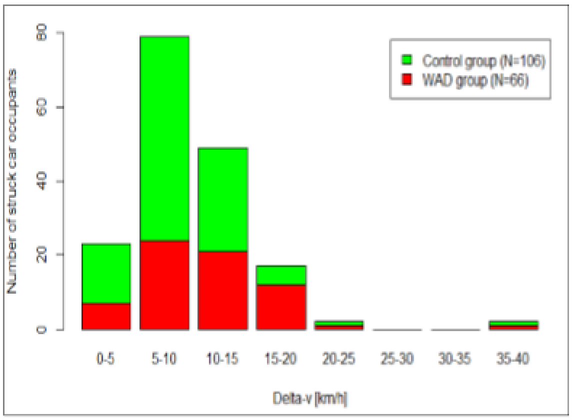

Fig. 23 Numbers of occupants suffering from initial WAD symptoms and uninjured occupants in intervals of ΔV.

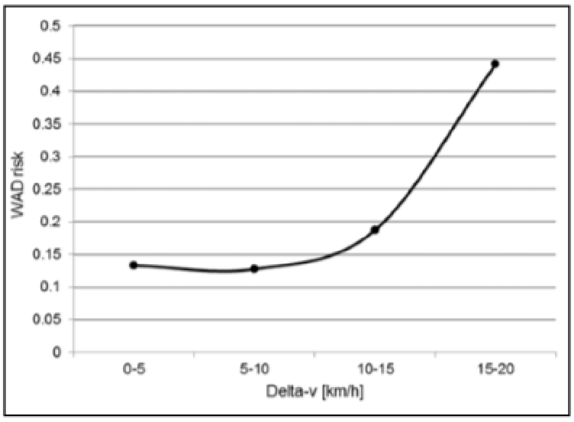

Fig. 24 Risk curve for initial WAD symptoms in intervals of ΔV (N=168).

According to Krafft et al. and Kullgren et al., longer sick leave durations were expected for higher ΔV

9 Symptoms such as headache, neck pain, dizziness, nausea and so on

values. This is true for 100% sick leave[10] as well as total sick leave duration; 100% sick leave duration rises strongly for ΔV values higher than 10 km/h.

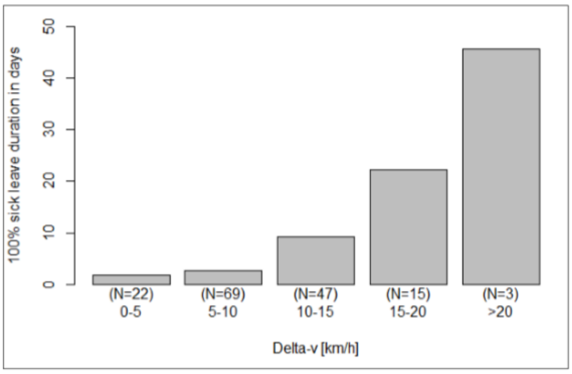

Fig. 25 Relationship between ΔV and 100% sick leave displayed as the mean of 100% sick leave duration in intervals of ΔV of the whole sample.

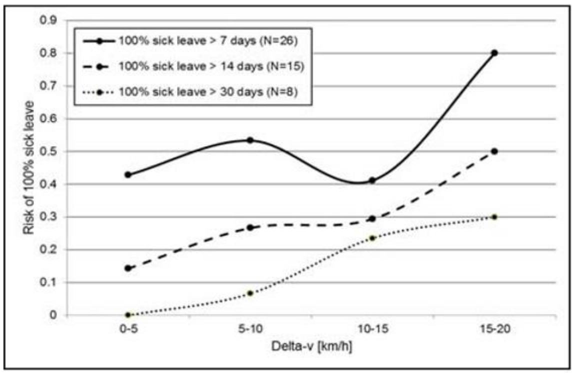

Fig. 26 Risk curves of the WAD group for different 100% sick leave time spans as a function of ΔV intervals (N=49).

This finding is in line with a threshold value as suggested by Niederer et al. The means of the two groups, with regard to initial WAD symptoms, also statistically reflect the threshold of 10 km/h, as the mean of the WAD group is above and the mean of the control group is below 10 km/h.

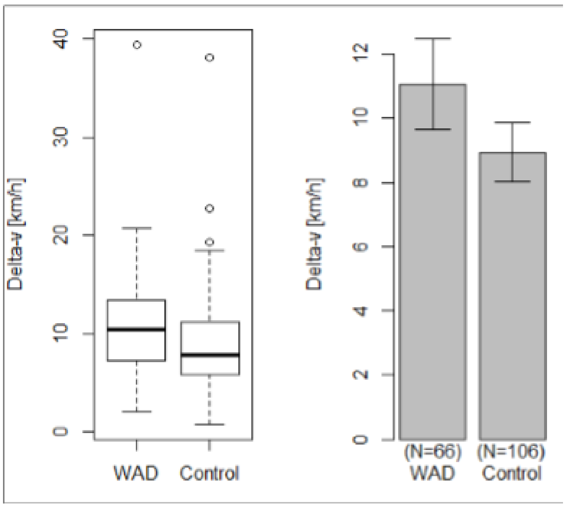

Fig. 27 ΔV of struck car compared between WAD and control group. The error bars denote the 95% confidence intervals.

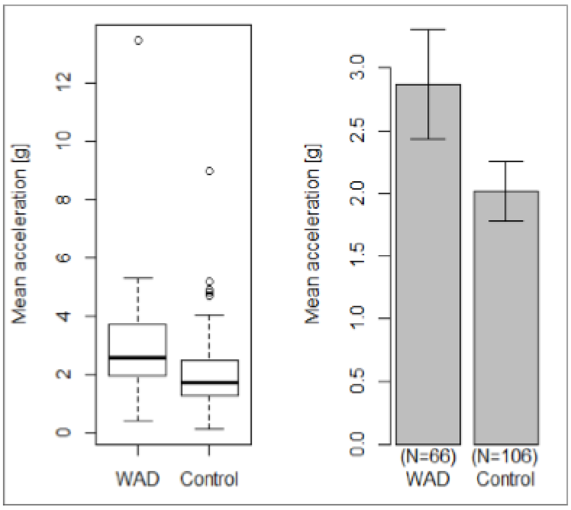

Fig. 28 Mean acceleration of struck car compared between WAD and control group. The error bars de note the 95% confidence intervals.

However, this is a purely statistical observation and thus not suitable for assessment of individual cases, which can be seen by the fact that a considerable number of occupants who experienced a ΔV below 10 km/h claimed initial WAD symptoms. These claims need to be assessed on an individual basis and also with regard to other parameters, such as a medical history of previous complaints or neurological symptoms. Thus, a biomechanical, rather than a purely technical, assessment of the event is mandatory.

10 The sick leave duration is defined as the time span in which a person is absent from paid work due to medical problems. 100% sick leave duration describes for the length of time during which the occupant could not work at all.

According to Linder et al., the injury risk for a given change of velocity increased with a shorter duration of the crash pulse. The findings of this study support this. Consequently, it can be hypothesized that underriding may have a protective effect for the occupants of the struck car, as the impact time increases.

Regarding for the age of the struck cars, the results of this study confirm the corresponding hypothesis. Kullgren et al. were able to show that the automotive industry has successfully developed whiplash protection systems. Newer cars are more likely to have such protecting systems. However, in this study no information about the seat was available.

As for gender, various studies report a higher relative whiplash injury risk for females than males. The same outcome was observed here for the initial WAD symptoms. The calculated odds ratio of 2.87 point in the same direction as the finding of Kullgren et al., i.e. that female occupants have approximately double risk of symptoms lasting longer than one month. However, as the findings of this study are based on the initial WAD symptoms, the results might not be directly comparable.

As for previous complaints, Schmitt et al. showed that symptoms were significantly influenced by the patient's medical history considering pre-existing damage of the neck or pre-existing symptoms. The results of this study indicate a tendency that sick leave duration is influenced by previous complaints, but this finding was statistically not significant. However, a larger sample size is needed for a more specific analysis.

Krafft et al. found a correlation between QTF scores and ΔV. However, in a different study previously conducted, Krafft et al. found no significant correlation between different grades of WAD and crash severity. In this study no relationship was found between ΔV and QTF scores or between mean acceleration and QTF. In addition, no positive relationship between QTF scores and 100% sick leave duration or total sick leave duration within the WAD group was found. According to these results, QTF scores should not be deemed a good predictor for sick leave. This is consistent with existing literature.

Remarks

The occupants exposed to the rear-end collisions can be summarized according to WAD grades as the table below.

Table 20. Occupants number and proportion for each group out of 172 exposures

Group	WAD0		WAD1		WAD2+		Unknown		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
WAD	2	3	18	27	23	35	23	35	66	100
Control	106	100	0	0	0	0	0	0	106	100
Total	108	63	18	11	23	13	23	13	172	100

Appendix B. Experimental research with human subjects

1. Human Subject Kinematics and ElectromyographicActivity During Low Speed Rear Impacts

Thomas J. Szabo and Judson B. Welcher, Biomechanical Research &Testing, LLC, USA, 1996, © Society of Automotive Engineers,Inc.

Key words

- laboratory study
- 1996
- Biomechanical Research & Testing LLC, in Los Angeles, CA., USA
- human subject tests
- sex male & female
- age 22 years – 54 years
- car2car tests
- aligned bumper2bumper test
- v1min = 12.9 km/h, v1max = 15.0 km/h, □vmin = 7.5 km/h, □vmax = 10 km/h
- occupant muscular activity
- electromyography measurement
- surface electromyography

Aim of the study

- To examine occupant average muscle activation time for neck flexors, kinematics and muscular activity for
  1. a standard seat-integrated head restraint and
  2. the same head restraint with 2 inches of padding added to decrease the initial head-to-head restraint horizontal distance

Content

A number of 10 car2car tests were carried out with vehicles of comparable mass and with human volunteers in the driver's seats. Seats had been adjusted by the volunteers according to their typical seating postures. Subjects have been distracted before and during tests to ensure unawareness of the approaching car as well as relaxed and normal seating posture.

Five male and female volunteers aged 22 years to 54 years were examined. Each volunteer passed two tests, one with standard head restraint and one with a modified headrest, reducing the head's distance to the headrest by 2" / 5cm.

The volunteer in the struck seat was equipped with acceleration sensors, measuring head (Frankfurt plane) and spine (L5 & C7) acceleration. Eight groups of bipolar EMG electrodes were applied to neck, shoulder and paralumbar muscles for electromyographic recording of musular activity during test. Displacements during test were measured from high-speed video in order to observe max rearward and forward motion over time. Vehicle CG acceleration was also recorded.

The study points out that no subject sustained injury or complained of pain during the two week period following the impact.

The resultant of head accelerations were found between a_{min} = 11.7 g and a_{max} = 17.2 g with the original headrest. For the padded headrest resultant values were a_{min} = 6.6 g and a_{max} = 13.1 g, respectively.

EMG readings show similar results for left and right muscles. The EMG data was calculated with the RMS (Root Mean Square) method and analyzed relative to isometric measurements of the individual subject which have been performed as reference values before the impact tests. The data show that all subjects were sitting relaxed immediately before impact.

In some cases the collision lead to RMS values above the isometric maximums in the trapezius muscles or in the cervical extensors (relative value > 100%). The study discusses this outcome, as it could either indicate higher muscular forces than in the isometric readings or represent artifacts due to higher (dynamic) responses, which can‘t occur in the isometric (static) pre-test measurements. Since other researchers found EMG readings directly correlating with muscle force for isometric readings only, the study concludes that the found values above 100% cannot be correlated with increased muscle forces.

No clear pattern of muscle recruitment could be identified and the authors state, in line with other cited studies, that there seems to be a central stimulus for all muscle groups, independent from their respective displacement. With regard to the latency times and comparing with other papers on this specific topic, the study concludes that the lumbar displacement triggers all muscle reactions simultaneously.

The addition of 2 inches of padding to the head restraint decreased head acceleration, rearward head displacement, cervical extension, and reduced the subjects' perception of impact.

Remarks

No BioRid dummy available at that time

No seat adjustment standard and tooling established at that time

Test vehicles were Volvo 242 MY1976 and Volvo 244 MY1977, not yet equipped with WHIPS seats

2. Human Head and Neck Kinematics After Low Velocity Rear-End Impacts – Understanding "Whiplash"

Whitman E. McConnell, Richard P.Howard, Jon Van Poppel, Robin Krause, Herbert M. Guzman, John B. Bomar, James H. Raddin, James V. Benedict, and Charles P. Hatsell, Biodynamic Research Corp., USA, 1995, ⓒ Society of Automotive Engineers, Inc.

Key words

- rear end impacts
- fourteen test runs
- seven human test subjects
- △V ranged from 5.8-10.9 km/h
- △V of 8 km/h as threshold

Aim of the study

- To discuss possible whiplash injury mechanisms
- To confirm △V threshold for assessing injury potential
- To see the sort of symptoms and lasted duration of human subjects

Contents

This second test series was conducted in 1993 after the first in 1991 which involved four test subjects who were exposed to a series of ten low △V(4-8 km/h) rear end impacts.

The total of 14 test-collisions were performed in the second test series using three vehicles which were the striking vehicle of a 1984 GMC C-1500 pick-up truck and the struck vehicles of a 1986 Dodge 600 Convertible and a 1984 Buick Regal Limited Coupe. Factory standard head restraints in both of the struck vehicles were normally kept in their most fully raised position. The top of the test subjects' head was from 16 to 20 cm above the top of the head restraint and the back of their heads were between 5.1 to 11.7 cm.

IRB Protocol of the University of Texas Health Science Center approved the use of human test subjects. Seven healthy fully informed volunteer male test subjects including three subjects from the first test in 1991, ages from 32 to 59 years, ranging in height and weight from 173-188 cm and 76-118 kg, completed a pre-testing medical history and physical evaluation. Four subjects were exposed to three test runs each, one subject had four test exposures and two subjects were exposed only once. Daily informal test subject checks were conducted for approximately one month after the test series and then periodically thereafter for long term subjective symptom assessment.

All test subjects reported some discomfort symptoms, however slight and/or fleeting.

Table 21. Struck Vehicle Test Subject Clinical Symptoms

Test #	△V km/h	Day #	Test Subject Driver	Symptoms (Driver)	Test Subject Passenger	Symptoms (Passenger)
1 Cnv	10.3	1	#1	Supernuchal(occipital) H/A, onset 30 min, lasted 45 min.	-	-
2	5.8	1	#2	Slight "twinge" upper right	-	-

Test #	△V km/h	Day #	Test Subject Driver	Symptoms (Driver)	Test Subject Passenger	Symptoms (Passenger)
Sed			(Head left at 30 °)	trapezius muscle, onset about 45 min., lasted 5 min.		
3 Cnv	8.0	1	#3	"Sensation" at base of neck post impact, left immediately, minor H/A onset 708 hours, lasted until aspirin after 10 hours.	-	-
4 Cnv	8.0	1	#4	Transient H/A after head restraint strike, lasted 10 min.	-	-
5 Sed	7.7	1	#5	"Awareness" of posterior neck base, onset few minutes, lasted 12 hours.	#6 (no restr)	Mild neck "awareness", onset few min., lasted few hours.
6 Sed	10.0	2	#2	Mild frontal H/A, onset few minutes, lasted overnight	ATD	-
7 Sed	9.2	2	#7	Mild neck awareness, onset few min., lasted few hours.	#3	Dull H/A from head restraint strike, gone in few seconds, 1-2 hours later, mild frontal H/A, lasted few hours.
8 Sed	10.0	2	#1	Lower anterior strap muscle soreness, onset noted just before test, lasted after next test.	ATD	-
9 Sed	8.9	2	#5	Increased low posterior neck(C-7) mild discomfort, onset few min., lasted until next test. Later in evening neck was less stiff and discomfort decreased.	#4	H/A, occipital & Rt. retro-orbital, onset at impact, lasted 4 hours, soreness upper SCM muscles, onset 16 hours, lasted 2-3 days.
10 Sed	8.2	2	#2 (Head left at 45 °)	Left frontal H/A & occipital soreness, onset in few minutes, discomfort in anterior strap & lower posterior muscles, onset 15 hours, lasted 3-4 days.	-	-
11 Cnv	8.0	2	#3 (Brakes set)	H/A & residual neck extension soreness in lateral posterior muscles, onset 15 hours, lasted one day.	-	-
12 Sed	8.7	3	#5	Frontal H/A, onset few min., lasted 5 min. Continued low posterior neck mild discomfort, at(C6-7), pre-existing, lasted about 3 days.	#4	Soreness anterior strap muscles, pre-existing, lasted 1-2 more days.
13 Sed	10.9	3	#3	None reported.	ATD	-
14 Sed	10.9	3	#1	Lower anterior strap muscle soreness, lasted approximately 2 days after last test.	ATD	-

Legend : Cnv=Convertible, Sed=Sedan, (no restr)=no restraint system used

After our present experience with a higher energy test series, 8 km/h still seems to be a convenient △V threshold for assessing injury potential. For events progressively below this level, the acute muscle strain symptom likelihood decreases, probably quite rapidly, even for "thin necked" people. For single events above this level the likelihood of transient acute neck and shoulder muscle strain symptom and possible mild compressive irritation of the posterior neck may increase.

As this is written it has been more than four years since the first test series and over two years since the second test series. After analyzing both of our test series there were no observed biomechanical events that could have resulted in permanent cervical injury, and there have been no subsequent indications of any persistent "soft tissue injury" symptoms by any of our test subjects.

3. The relationship between clinical and kinematic responses from human subject testing in rear-end automobile collisions

Gunter P. Siegmund, John R. Brault, Jeffrey B. Wheeler, AAAM, USA, 1999, © Elsevier Science Ltd.

Key words

- paired data set of clinical and kinematic responses
- 42 male and female human subjects
- speed change of 4 and 8 km/h
- clinical examinations
- 23 out of 75 tests resulted in symptoms
- logistic regression
- specificity 94%
- sensitivity 57%
- positive predictive value 81%
- positive predictive value 83%

Aim of the study

- To examine the paired data set of clinical and kinematic responses and determine whether the presence or absence of clinical symptoms can be predicted from the statistical model derived by the kinematic responses of the head and neck.

Content

The data set of clinical and kinematic responses were generated using 42 male and female human subjects seated normally in the front passenger seat of a stationary vehicle struck from behind to produce vehicle speed changes of 4 and 8 km/h.

Subjects underwent a minimum of three clinical examinations for each impact test: a pre-impact examination immediately before the test, a post-impact examination immediately after the test, and a third examination about 24 h after the test. Subjects were monitored until their symptoms and clinical deficits resolved.

A total of 81 tests were conducted: 42 at the 4 km/h test and 39 at the 8 km/h test. Incomplete kinematic data were obtained from six tests[11], leaving 75 complete kinematic data sets. Of the 75 tests with complete kinematic data, 23 resulted in symptoms of less than about 5 days duration: nine at the 4 km/h level and fourteen at the 8 km/h level.

Logistic regression and backward elimination of independent variables were used to develop the prediction model. For the present analysis, the dependent variable, symptoms, was coded as either present (Y) or absent (N) based on the results of the clinical examinations. The independent variables were the magnitudes of the kinematic response peaks common to all subjects. The null hypothesis was

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11 The origin of △V(4 km/h or 8 km/h) not identified

that there was no relationship between the presence or absence of symptoms and the peak kinematic responses. The null hypothesis was tested using logistic regression. A significance level of 0.05 was used for all tests.

$$S = \frac{\exp(\beta_0 + \beta_1 x_1 + \cdots + \beta_{16} x_{16})}{1 + \exp(\beta_0 + \beta_1 x_1 + \cdots + \beta_{16} x_{16})}$$

where S is the symptoms present if ≥0.5 or symptoms absent if <0.5, β_0 is the intercept, β_i coefficient for kinematic response i which is presented in Table 22, and x_i is the kinematic response i.

Table 22. Model coefficients and standard errors for 16-parameter model

	Parameters								
	Itercept	a_z^h	a_{z2}^h	v_x^h	v_z^h	α_{y2}^h	ω_{y1}^h	θ_{y1}^h	v_x^c
β	-1.84	-5.06	3.02	-4.77	5.61	-4.51	-12.01	20.72	5.13
SE	0.55	2.30	1.09	2.37	2.46	1.99	4.28	8.37	2.17
	Parameters								
	α_{y1}^c	θ_{y1}^c	a_{x2}^{hc}	s_x^{hc}	s_z^{hc}	α_{y1}^{hc}	θ_{y1}^{hc}	θ_{y2}^{hc}	-
β	-1.60	-11.19	-3.06	-4.74	-1.31	5.46	3.76	-18.61	-
SE	0.94	5.01	1.44	1.85	0.66	2.01	1.57	7.53	-

Note) The kinematic responses are labeled as acceleration(**a**), velocity(**v**), displacements(**s**), angular acceleration(**α**), angular velocity(**ω**) and angle(**θ**). Superscript 'h' denotes absolute kinematics at the head center of mass, 'c' denotes absolute kinematics at the C7-T1 joint axis, and 'hc' denotes kinematics of the head center of mass relative to the C7-T1 joint axis. Subscript x, y and z refer to the components along each of the orthogonal global coodinate axis.

Table 23. Significance level(P-value), odds ratio, sensitivity, specificity, +PV and –PV of 16-parameter model

P-value	Odds ratio	Sensitivity(%)	Specificity(%)	+PV(%)	-PV(%)
0.0069	21.2	57	94	81	83

Table 24. Relation between actual and predicted symptoms

Symptoms		Actual	
		Y	N
Predicted	Y	13	3
	N	10	49

The statistical model correctly predicted 49 of 52 (specificity 94%) cases in which symptoms were absent and 13 of 23 (sensitivity 57%) cases in which symptoms were present, yielding an odds ratio of 21.2. The model predicted the presence of symptoms in 16 tests, 13 of which actually produced symptoms (positive predictive value=81%). The model predicted an absence of symptoms in the remaining 59 tests, 49 of which actually produced no symptoms (negative predictive value=83%).

Despite statistical significance, the model did not discriminate between the presence and absence of symptoms in all tests, and indicated that factors other than the selected peak kinematic responses influenced symptom production.

From a practical perspective, a symptom model based on kinematic response might possibly serve as a seat or vehicle design tool, but not as a clinical diagnostic tool.

4. Human Occupant Kinematic Response to Low Speed Rear-End Impacts

Thomas J. Szabo, Judson B. Welcher, Robert D. Anderson, Michelle M. Rice, Jennifer A. Ward, Lori R. Paulo, Nicholas J. Carpenter, © Biodynamics Engineering, Inc., 1994

Key words

- five human subjects
- car-to-car rear-end collisions
- ΔV of 8 km/h or less
- no objective change of cervical and lumbar spinal degeneration
- no hyperextension or hyper-flextion
- symptoms resolved spontaneously

Aim of the research

- To enhance the database of human tolerance to, and kinematics during, low speed rear-end impacts with ΔV of 8 km/h or less
- To consider both the initial spinal condition of the volunteers and female exposure to low speed rear-end impact

Content

While extensive research has been conducted on occupant response to high speed vehicular impact, relatively little data regarding human occupant response to low speed impact exists.

This study tried to investigate human kinematic response to low speed rear-end collisions.

Total 6 tests of car-to-car rear-end collisions at ΔV of about 8 km/h were conducted using five human volunteers.

The majority of volunteer research conducted to date has considered essentially health male exposure to low speed rear-end impacts. No reference to pre-existing spinal conditions, or female exposure to rear-end impacts, was found.

The human volunteers for this study were both male and female, aged 27 to 58 years, with various degrees of cervical and lumbar spinal degeneration(MRI scan) at the time of the tests.

Table 25. Pre Test MRI Results

Subject	Gender	Age	Cervical Spine		Lumbar Spine	
			Degree of Degeneration	Disk Bulge or Protrusion	Degree of Degeneration	Disk Bulge or Protrusion
A	F	27	1	1	2	0
B	M	48	0	0	2	1
C	F	58	1	2	0	0
D	M	28	0	0	0	0
E	M	31	-	-	-	-

Legend : 0-normal, 1-minor abnormality, 2-moderate abnormality, 3-severe abnormality

All volunteers were instructed to adopt a “normal” seating position, with the exception of the target vehicle driver in Test 5 (Subject C), who intentionally adopted an increased head-to-head restraint distance.

Table 26. Target vehicle seating configuration

Day	Test	Human subject's seating position	
		Driver	Right Front
1	1	A	-
1	2	B	Hybrid III dummy
2	3	C	-
2	4	Hybrid III dummy	D
2	5	C	-
2	6	A	E

Human volunteer response was monitored and analysed via accelerometers and high speed film.

As the result, in spite of the fact that human volunteers in the present study differed in sex, age, height, weight and initial spinal condition, kinematics for all occupants were similar, especially during the occupant's upper torso moved rearward relative to the vehicle(Phase I). During the subsequent rebound(Phase II), occupant responses began to diverge somewhat. This was most likely due to variations in muscle recruitment patterns during the latter stages of the event. No occupant underwent cervical spine hyperextension or hyperflexion in the tests.

Volunteers A, B, C and E described a transient headache immediately post impact, which resolved spontaneously prior to exiting the target vehicle. Volunteer A, who underwent two rear-end impacts, reported transient, minor neck stiffness the morning following the first test. No other symptoms whatsoever were reported by any of the subjects in the one-year period following the tests. No significant differences were found between the pre and post-test MRI's, indicating no objective changes to the cervical or lumbar spines as a result of the impacts.

5. The Movement of Head and Cervical Spine During Rear-end Impact

Geigl B.C., Steffan H. Leinzinger P., Roll, Mühlbauer M., Bauer G., © Institute for Mechanics, University of Graz et al., 1994

Key words

- sled test
- based on measurements from real collisions from cars
- 49 experiments with six PMTO's(Post Mortal Test Objects)
- 37 experiments with 25 volunteers
- ΔV of 6-12 km/h
- no subjective neck

Aim of the research

- To analyze the movement of head and cervical spine during rear-end impact

Content

Due to increased traffic density the importance of rear-end impact has increased. Some studies showed that more than 50 % of all accident situations includes rear-end impacts.

Some experiments were performed for the study based on PMTO's(Post Mortal Test Objects) and Volunteers. 49 tests were performed with six PMTO's under ΔV of 6-15 km/h and 37 experiments with 25 volunteers were performed under ΔV of 6-12 km/h.

Table 27. Mean Specification of the Experiments

Experiments with:	PMTO's	Volunteers
number of objects	6	25
number of tests	49	37
gender of test objects f/m	2/4	2/23
age of test objects	50-79	20-60
ΔV [km/h]	6-15	6-12
mean acceleration [g]	1.3-8.7	1.2-4.1
initial head rotation [deg]	±45	±15
gap head-head restraint [cm]	0-16	0-8

The major target was the analysis of the movement of head and cervical spine during impact phase.

All experiments were performed on a crash sled. The change of velocity(ΔV) during the impact was varied between 6 km/h and 15 km/h. The acceleration behavior of the sled was based on measurements from real collisions from cars equipped with the accident data recorder. The mean accelerations varied between 2 and 8 g. All experiments were documented with the high speed video. For some experiments, the accelerations of head and chest were measured by three axis accelerometers. To visualize the movement of the cervical spine during the impact, two vertebra bodies of the PMTO's were marked with targets. Their movement was observed during the impact phase for various boundary conditions.

Regarding the rotation of the head the following characteristic movement could be seen for all tests. Independent of initial seating position, no head rotation could be seen during the first 60 to 100 msec. After this period the head starts to rotate backward. In this phase the shoulders are already reflected forward and the head moves with a very low translatoric movement still backward. This rotation ends after approximately 100 - 160 msec and forward rotation is initiated. The rotation angle for the backward rotation varied in a range from 10 to max. 75 degrees. The magnitude of the head rotation mainly depends on the initial distance of head and head restraint. The larger the initial distance, the bigger is the degree of rotation.

The movement of the cervical spine can be reconstructed quite well by watching the targets mounted to the vertebras. For the first period up to a time of 50 to 80 msec after impact no relative rotation between the vertebra bodies can be observed. After this period a motion starts which results in a "relative flexion" of the upper part of the cervical spine. This rotation is initiated by the fact that the shoulder starts to decelerate, but the head still moves with the original velocity. Normally this flexion can be seen up to 180 msec. The peak relative rotation of up to 45 deg. was reached for most cases between 100 and 130 msec.

Several special phenomena could also be seen during these experiments. If the head restraint cannot be adjusted at a level, which guarantees, that rather horizontal contact forces occur, additional head-rotations are created. To ensure horizontal contact forces, the contact point between head and head restraint must lay approximately at the same height as the center of gravity of the head. For certain experiments, the length of the head restraint was to short. In this cases the relative flexion between head and C3 ended after 150msec and a "extension" with a relative angle of up to 40 deg could be seen. In addition the increased inclination of the seat back enlarges the risk, that the passenger slides up along the seat back.

During tests with human subjects, all volunteers remained uninjured and no subjective neck pain were reported.

These studies have shown that improvements in the construction of seat and head restraint could reduce the risk of neck injuries during rear-end impact.

Remarks

Since 1994 when this study data was released, there have been some remarkable improvements of the seat and head restraint in their protection performance. Therefore, in the event of a rear-end collision, it can be seen that modern vehicles provide a higher level of passenger protection than past vehicles.

6. Analysis of Human Test Subject Kinematic Responses to Low Velocity Rear End Impacts

Whitman E. McConnell, Richard P. Howard, Herbert M. Guzman, John B. Bomar, James H. Raddin, James V. Bendict, Harry L. Smith, Charles P. Hatsell, © Biodynamic Research Corp., 1993

Key words

- four human subjects
- 10 test runs
- ∆V of 6-8 km/h
- discomforts resolved within 3-4 days with no treatment or therapy
- whiplash due to hyperextension/hyperflextion
- discomforts due to compressive and tensile forces

Aim of the research

- To better define human and vehicle responses during low velocity collisions
- To see whether or not the time-honored description of the cervical 'whiplash' response is applicable even to the low velocity collisions

Content

Although the classic "whiplash" neck response to rear-end collisions and the widely accepted hyperextension/ hyperflexion cervical injury mechanism have been extensively written and speculated about, there have been little human experimental data available, especially for low velocity collisions. The absence of good experimental data, accurately defining real occupant kinematic response during low velocity collisions has spawned a plethora of divergent concepts, ideas and speculation about possible injury mechanisms. Low velocity collisions are defined in this report as motor vehicle collisions in which ∆V is about 12.9 km/h (8 mi/h) or less.

A series of experimental low velocity motor vehicle collisions with four human subjects were conducted and the head, neck and trunk kinematic responses have been analyzed using data obtained from multiple high speed film, video and electronic accelerometer measurements of the test subjects.

Each test subject had from 3 to 7 vehicle to vehicle test collision exposures, divided between the striking and struck roles during the 10 test collision series.

Table 28. Test Subject Driven Low Velocity Collision Test Series

Run No.	Subject No.	Struck Veh. Type	∆V [km/h]	Subject No.	Striking Veh. Type	∆V [km/h]	Day No.
1	2	Van	3.48	1	Convert	-4.81	1
2	1	Van	6.45	4	Pickup	-6.04	2
3	1	Pickup	3.04	4	Van	-3.35	2
4	4	Pickup	6.65	1	Van	-6.74	2
5	3	Convert	n/a	2	Coupe	n/a	10

6	3	Convert	8.06	2	Coupe	-7.82	10
7	2	Coupe	7.83	3	Convert	-9.24	10
8	2	Van	6.61	4	Pickup	-8.21	10
9	2	Coupe	3.93	4	Pickup	-3.28	11
10	4	Pickup	7.03	2	Van	-7.48	11

Test subject number 4 noted no symptoms at all related to his 6 test exposures. Beginning about 45 to 60 minutes after Test 2, test subject number 1 reported a "twinge" of discomfort at the posterior base of his neck which lasted about two hours. The discomfort was gone by the time of his participation in test number 3 and did not recur later. Test subject number 2 noted the onset of "achiness" in the paraspinal musculature at the base of his neck the morning of test day 12, after participating in a total of 6 test runs during the preceding two day test period. His symptoms lasted about 4-5 hours and resolved without recurrence. Test subject number 3 reported the onset of mild low and mid-neck discomfort over the area of his C6, C7 and Tl vertebra and discomfort in his trapezius musculatureon the morning following his three test runs on day 10. The pain was gone the next day, but he continued to have mild discomfort on extreme neck extension and lateral flexion until it gradually resolved during the next three days. No treatment or therapy was needed and none of the test participants had any further symptoms that related to their test exposures for greater than eighteen months following the testing.

Test subject cervical extension and flexion angles observed during this test series were always found to fall within the subject's voluntary physiological limits. Hyperextension or hyperflexion did not occur during any of the test runs.

The data from the low velocity rear-end collision test series implies that substantial Gz direction acceleration occurs and is associated with both compressive and tensile forces sequentially directed axially through the cervical spine. These push-pull forces probably represent an injury causation mechanism independent of the commonly described cervical 'whiplash" hyperextension/hyperflexion mechanism. For rear-end collisions within the velocity range included in these test series, the classic 'whiplash' injury mechanism seems unlikely since no hyperextension or hyperflexion was observed in any of the test subjects.

The reported results of this low velocity test series suggest a compression-tension injury causation mechanism which probably can cause self-limited minor cervical, thoracic and lumbar muscle strains and, possibly, connective tissue and/or vertebral joint micro-contusional injuries and that may account for the discomfort symptoms commonly reported after low velocity rear-end collisions. The very mild discomfort symptoms experienced by three test subjects of this study, after multiple test exposures, indicated that the 6 to 8 km/h struck vehicle ∆V test conditions were probably at, or near, typical human threshold for very mild, single event musculoskeletal cervical strain injury.

7. Comparative Analysis of Low Speed Live Occupant Crash Test Results to Current Literature

D. Mills, G. Carty, © TSI Solutions Inc., 2004

Key words

- literature reviews of 767 human subject crash test exposures
- rear-end vehicle-to-vehicle collisions
- rear-end bumper car-to-bumper car collisions
- neck rotation angle

Aim of the research

- To validate the results of previously published live occupant crash tests
- To document the kinematic response of the occupants to the low speed collisions

Content

Reviewing literature for human crash exposures during crash testing, it cumulatively reports 767 human subject crash test exposures. All of the crash tests presented by the authors resulted in a ΔV of less of than 12 km/h for the target vehicle. Of these 767 exposures the vast majority of volunteers reported no injury as a result of the testing. A much smaller portion (approximately 25) reported transient soft tissue tenderness for less than 1 day. Even less (2) occupants reported minor soft tissue injuries that were gone in under 2 weeks. Since most of the human subject exposures resulted in transient to no injuries, the true threshold was not found in these tests. The only way to derive a threshold, above which there is a high probability of injury and below which there is little, would be to have many tests that resulted in subject injury.

Aside from the literature research, live-occupant crash tests were conducted in 2003 which were grouped into testing #1 and testing #2.

VEHICLES

- Crash Testing #1:
  - V1-1 – 1997 Honda Accord ER, 4-door sedan, curb weight – 1,485 kg
  - V2-1 – 1997 Ford Escort LX, 4-door wagon, curb weight – 1,145 kg
- Crash Testing #2:
  - V1-2 – unknown model year, Gruppo 3B Madrid bumper-car, curb weight – 340 kg
  - V2-2 – unknown model year, Gruppo 3B Madrid bumper-car, curb weight – 340 kg

The 4 rear-end vehicle-to-vehicle collisions in Crash Testing #1 were completed with a male occupant(subject #1). The medical examination of the subject by a doctor at 24 and 72 hours after the completion of 4 rear-end crash tests found no reduction in joint mobility or tenderness.

Table 29. Vehicle-to-vehicle tests parameters

Test #	Bullet Vehicle	VCBullet (km/h)	∆VBullet (km/h)	Target Vehicle	∆VTarget (km/h)	+Y∠rotation (degrees)
RE1-1	V1-1	5.0	2.9	V2-1	3.7	6.4
RE2-1	V1-1	10.0	5.3	V2-1	6.9	7.2
RE3-1	V1-1	15.0	7.7	V2-1	9.8	8.0
RE4-1	V2-1	22.0	6.0	V1-1	7.8	7.2

The 10 rear-end bumper car-to-bumper car collisions in Crash Testing #2 were completed with a male and a female occupant (subject #2 and #3, ∆V : 6.2-6.3 km/h). Both occupants were interviewed 24 hours after the crash testing regarding their perception of any injuries that they may have sustained and they had no symptoms.

Table 30. Bumper car-to-bumper car tests parameters

Test #	VCBullet (km/h)	∆VBullet (km/h)	∆VTarget (km/h)	+Y∠rotation (degrees)
RE1-2	10.9	6.2	6.2	44.8
RE2-2	10.9	6.2	6.2	42.5
RE3-2	11.0	6.2	6.3	48.3
RE4-2	11.0	6.2	6.2	45.6
RE5-2	11.0	6.3	6.3	46.2
RE6-2	11.0	6.3	6.3	36.7
RE7-2	11.0	6.3	6.3	37.3
RE8-2	10.9	6.2	6.2	39.0
RE9-2	10.9	6.2	6.2	35.6
RE10-2	11.0	6.3	6.3	36.7

Bumper cars were used for Crash Test#2 because of their similarity to vehicle-to-vehicle collisions. This was supported by the crash pulses recoded during the tests. Video was reviewed for Crash Test RE2-2 to observe the movement of subject #3 during the collision and to verify that it matched the movement of an occupant in a vehicle-to-vehicle crash test. While the collision forces were quite similar, the occupant movements were quite different. In all of the completed vehicle-to-vehicle crash tests, none of the neck rotations even exceeded 10 degrees. The majority of the bumper-car tests yielded even greater neck rotations, the maximum being 48.3 degrees rotation from pre-impact head orientation. This is solely due to absence of any head support for bumper-car riders, whereas all of the vehicles used in the tests had adequate head support for the front occupants. The absence of repeated injury reports from bumper-car riders indicates that while the rotation and extension of the subject's neck appears excessive in the video, the risk for injury to an otherwise healthy person is minimal for bumper-car riders.

8. Do “whiplash injuries” occur in low-speed rear impacts?

W.H.M. Castro, M. Schilgen, S.Meyer, M. Weber, C. Peuker, K. Wortler, European Spine Society, 1997,
© Springer-Verlag

Key words

- automobile rear-end collisions
- bumper car rear-end collisions
- experimental, biomechanical, kinematic and clinical analysis
- fourteen male volunteers and five female volunteers
- electromyography(EGM)
- no hyperextension of the cervical spine at ΔVs up to 15 km/h

Aim of the study

- To find out whether in rear-impact motor vehicle accident, velocity changes in the impact vehicle of between 10 and 15 km/h can cause so-called ‘whiplash injuries‘.
- To compare vehicle rear-end collisions with amusement park bumper car collisions

Contents

A study was conducted to find out whether in a rear-impact motor vehicle accident, ΔVs in the impact vehicle of between 10 and 15 km/h can cause so called "whiplash injuries". An assessment of the actual injury mechanism of such whiplash injuries and comparison of vehicle rear-end collisions with amusement park bumper car collisions was also carried out. The study was based on experimental biomechanical, kinematic, and clinical analysis with volunteers.

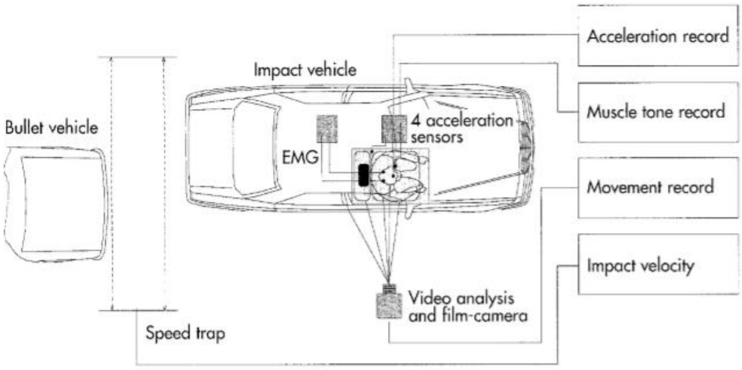

Fig. 29 Design of the experiment

Fourteen male volunteers (aged 28-47 years; average 33.2 years) and five female volunteers (aged 26-37 years; average 32.8 years) participated in 17 vehicle rear-end collisions and 3 bumper car collisions.

All cars were fitted with normal European bumper systems. Before, 1 day after and 4-5 weeks after each vehicle crash test and in two of the three bumper car crash tests a clinical examination, a computerized motion analysis, and an MRI examination with Gd-DTPA of the cervical spine of the test persons were performed. During each crash test, in which the test persons were completely screened-off visually and acoustically, the muscle tension of various neck muscles was recorded by surface electromyography (EMG). The kinematic responses of the test persons and the forces occurring were measured by accelerometers. The kinematic analyses were performed with movement markers and a screening frequency of 700 Hz. To record the acceleration effects of the target vehicle and the bullet vehicle, vehicle accident data recorders were installed in both. The contact phase of the vehicle structures and the kinematics of the test persons were also recorded using high-speed cameras.

The results showed that the range of ΔV (vehicle collisions) was 8.7-14.2 km/h (average 11.4 km/h) and the range of mean acceleration of the target vehicle was 2.1-3.6 g (average 2.7 g). The range of ΔV (bumper car collisions) was 8.3- 10.6 km/h (average 9.9 km/h) and the range of mean acceleration of the target bumper car was 1.8-2.6 g (average 2.2 g). No injury signs were found at the physical examinations, computerized motion analyses, or at the MRI examinations. One female and three subjects reported symptoms like sensation of muscle soreness in the cervical spine which disappeared within 3 days or less. The other male subject suffered a reduction of rotation of the cervical spine to the left of 10 ° for 10 weeks. The kinematic analysis very clearly showed that the whiplash mechanism consists of translation/extension (high energy) of the cervical spine with consecutive flexion (low energy) of the cervical spine: hyperextension of the cervical spine during the vehicle crashes was not observed. All the tests showed that the EMG signal of the neck muscles starts before the head movement takes place. The stresses recorded in the vehicle collisions were in the same range as those recorded in the bumper car crashes.

The study concluded as below.

1. The biomechanical "limit of harmlessness" in two- car rear-end collisions lies at ΔV of between 10 and 15 km/h. Morphologic and anatomic signs of injury to the cervical spine cannot be demonstrated up to this speed range. At present, it is difficult to ascertain the extent to which psychological stresses are present or occur that can lead to persistent symptoms in victims of accidents involving ΔV below this limit.

2. The extent of damage to the cars involved is crucial to determining ΔV due to collision.

3. From preliminary results of the on-going motion analysis it can already be concluded that hyperextension of the cervical spine does not occur in rear-end automobile collisions involving ΔVs of up to 15 km/h if head restraints are installed.

4. From a biomechanical perspective, automobile rear- end collisions are comparable to bumper car rear-end collisions.

9. Rear Impact Tests with Bumper Cars [2]

Heckaufprallversuche mit Autoscootern

Im Auftrag des Gesamtverbandes der deutschen Versicherungswirtschaft GDV
In Zusammenarbeit mit dem Institut für Rechtsmedizin der
Ludwig-Maximilians-Universität (LMU), München
und der Universitätsklinik Ulm, Abteilung für Unfallchirurgie, Germany, 2009

Key words

- bumper car test
- 16 volunteers
- electromyographic examination(EMG)
- 900,000 bumper car rides at Munich Oktoberfest
- no clinical findings at below ΔV = 10km/h
- high protection potential of head restraint in passenger cars compared to bumper cars

Aim of the study

- to confirm comparability of loads between bumper car and passenger car
- to evaluate whiplash injury risk at low ΔV by bumper car tests with human subjects

Contents

Biomechanical limit values for strains of the cervical spine in minor accidents are still being discussed. A pragmatic approach to approximating limit values is therefore to do a statistical study of the real loading that occurs in daily life without injury. This situation exists in the case of bumper cars. A study was done to determine the loads on occupants of bumper cars in rear impact collisions.

A survey of bumper car use during Oktoberfest in Munich was initially carried out, combined with an analysis of medical archives of the emergency department and nearby hospitals during Oktoberfest in 2006 and 2007. Among 900,000 bumper car rides, the archives mentioned two cases of Whiplash Associated Disorders (WAD), one for each year. Neither patient presented with objectified symptoms, but one patient suffered from asthenia and the other had previously been in a rear impact accident.

In addition, bumper car riders at three different street fairs or festivals were asked for their subjective condition three days after their visit to the site. This survey showed seven cases of discomfort but none of the affected people was planning to consult a physician. Relevant injuries were not reported.

In a second step, rear impact tests with bumper cars were conducted under realistic conditions on the crash track of AZT Automotive GmbH using a BioRID II rear impact dummy and volunteers. These tests provided data about loading of occupants (dummy or people) during bumper car collisions. In 20 tests with ten volunteers, an electromyographic examination (EMG) of muscular activity was done before, during, and after the test. A total of 23 tests with the dummy and 32 tests with volunteers were performed. Dummy tests were conducted with velocity changes from 6.9 km/h to 11 km/h, while volunteer tests were done with velocity changes of 6.9 km/h and 8.8 km/h. None of the volunteers reported any discomfort after the tests.

Fig. 30 BioRID II with measurement harness

Fig. 31 Volunteer with probes in bumper car

Test data were compared with data from rear impact tests on cars to check for the comparability of bumper car and passenger car behavior in terms of neck loading. This showed that both cases are comparable in terms of kinematics, but occupants experienced higher neck loads in bumper cars in all cases. Automobile seats provide far better protection against excessive head movement than bumper car seats.

The results of the study are as follows:

- Out of almost 900,000 bumper car rides at Oktoberfest in 2007 and 2008, only one clinically relevant case was found for each year; both cases had a history of impairment.
- Bumper car riders were surveyed to record any potential impairment over a longer period. None of the 291 respondents had consulted a physician or planned to do so, although seven cases(2.4%) of the respondents stated that they had experienced pain.
- None of the respondents had relevant injuries that would lead them to consult a physician.
- The pattern of motion in bumper cars in a rear impact is comparable with passenger cars.
- Thanks to the high potential protection offered by the head restraints and seats in (modern) passenger cars, the intensity of motion is less and the loading values are lower in passenger cars than in bumper cars during comparable impacts.
- Even under the unfavorable conditions in bumper cars, there were no clinically relevant findings during the tests below ΔV = 10km/h.
- The ΔV and the potential protection offered by the seat are the decisive factors for occupant loading.
- Bumper cars have existed for some 90 years. Over those decades, a speed limit has been established that can lead to discomfort in individual cases but normally does not cause any relevant injuries. The potential protection for the cervical spine which is offered by passenger car seats is greater than that of bumper cars.

The study discloses that healthy bumper car riders themselves do not take seriously, and even accept any discomfort that occurs in isolated cases, at least up to the studied ΔVs of 10 km/h.

The results of the tests on the crash track show that the transmission of loading into the body of the occupant proceeds in comparable fashion in bumper cars and passenger cars. The kinematic freedom of the head in passenger cars is, however, very limited compared with bumper cars thanks to the superior head restraints. That is why, at comparable ΔVs of up to 10 km/h, the loading on occupants of passenger cars is generally lower than in bumper cars.

We can say that riding bumper cars is safe, but riding passenger cars is safer.

10. A Study of Impact on Head and Neck Using Human Volunteer Low-Speed Impact Tests

Sung-Ji Park, Kyungmoo Yang, Hong-Seok Lee, Nam-Kyu Park, Seong-Woo Hong, Jae-Ho Yoo, Hansung Kim, National Forensic Service et al., South Korea, 2013, © Korean Journal of Legal Medicine

Key words

- 50 dynamic sled tests
- 50 human subjects
- medical supervision
- no cervical injury at ΔV of less than 8 km/h

Aim of the study

- To examine the influence of low-speed vehicular rear-end impacts on middle-aged men, and to analyze the head and neck injury criteria for the symptomatic human volunteers

Contents

Data was examined from the results of 50 dynamic sled tests, originally performed by Hong et al. (2012). In the tests, 50 men aged 30-50 years were exposed to an impulse equivalent to a bumper-to-bumper rear collision under medical supervision, and no resulting whiplash injury was identified.

Fig. 32 Movement of a human volunteer at 7.9 ㎞/h of ΔV

Although there were no changes in MRI findings in all subjects at the pre-/post-test orthopedic examination, 6 subjects revealed mild aches around the shoulder, back, or lumbar area, and their symptoms disappeared within 2 days.

Table 31. Description of Cervical Spine Status of the Symptomatic Individuals

Subject	Age (year)	MRI (pre-test)	MRI (post-test)	Symptom (duration)
No. 25	50	- Mild degeneration of intervertebral disc with posterolateral protrusion, C5−6	No change	Lumbar dull ache (< 1 days)
No. 29	46	- Multiple level disc degeneration, C3−6 - Protrusion of soft and hard disc, C5−6 with effacement of cerabrospinal fluid space - Hypertrophy of ligamentum flavum, C5−6	No change	Lumbar dull ache (< 0.5 days)
No. 30	49	- Protrusion of soft and hard disc, C5, 6 with effacement of cerebrospinal fluid space - Hypertrophy of ligamentum flavum, C4−6 - Hernation of C5−6 intervertebral disc and hypertrophy of posterior rim of end plate (hard disc) with entrapment of spinal canal, central to left	No change	Shoulder dull ache (< 2 days)
No. 39	47	- Multiple level disc degeneration, C3−6 - Mild degeneration of intervertebral disc with posterolateral protrusion, C5−6	No change	Lumbar dull ache (< 2 days)
No. 44	32	- Multiple level disc degeneration, C4−7 - Mild degenerated of intervertebral disc with posterolateral protrusion, C5−6	No change	Shoulder dull ache (< 2 days)
No. 46	46	- Protrusion of disc C3−4 - Herniation of C5−6, C6−7 intervertebral disc and protrusion to central spinal canal	No change	Back dull ache (< 2 days)

Since 50 subjects did not show any pain or neurological abnormalities that interfere with life, it is judged that there is a high possibility that cervical injury does not occur at a speed change of less than 8 km/h. It is expected that there will also be an effect by the sitting posture and muscle tension, but considering the overseas research cases of various conditions such as head support, seat angle, and sitting posture, these conditions would not significantly affect the test results at an effective impact speed of less than 8 km/h.

11. Occupant's Injury Risk in Rear-end Minor Collision

Namhyung Kim, Guanhee Kim, KIDI/KART, South Korea, 2021, © KIDI/KART

Key words

- vehicle-to-vehicle rear-end collision tests
- 24 human subjects
- medical monitoring
- ΔV of 1.5-9.4 km/h

Aim of the study

- To evaluate the risk of whiplash injury in a low-speed rear-end collision accident by the vehicle-to-vehicle collision tests with human subjects

Contents

The following 3 limit-condition tests were conducted so that they could represent various accidents with various combinations of the weight ratio, the collision angle(α) and the overlap amount.

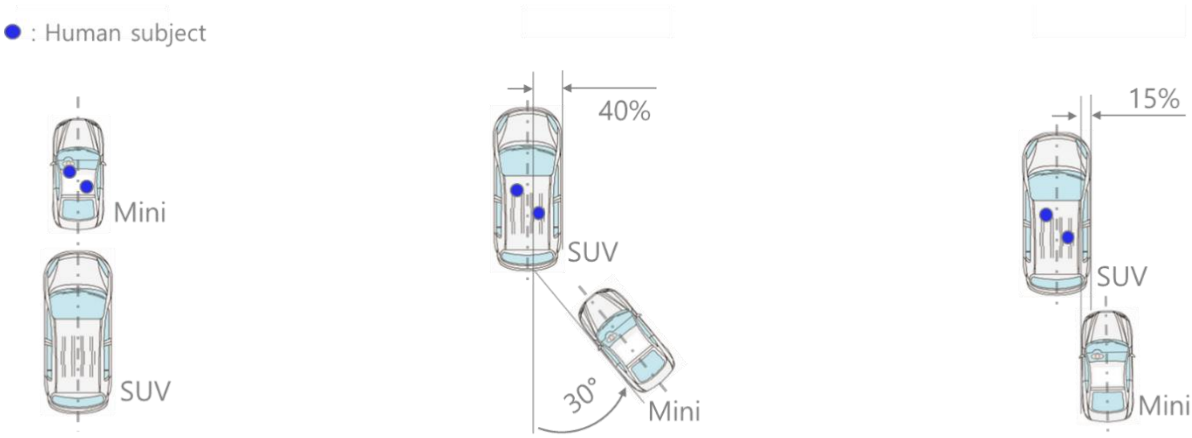

Fig. 33 Three limit-condition tests

And also, some additional tests with conditions of 100% overlap, 0 degree of angle and some combinations of vehicle sizes were performed in order to interpolate data of limit-condition tests above.

24 volunteers of 16 males and 8 females were subjected to vehicle-to-vehicle rear-end collision tests. The selected human subjects were those who can do daily life activities such as walking alone without any other help and getting on/off and driving a vehicle without physical discomfort.

In all of 16 human-subject tests, ΔV, mean acceleration and maximum acceleration are shown as the following under striking velocities.

- ΔV : 1.5-9.4 km/h, a_mean : 0.2-1.7 g, a_peak : 0.4-4.1 g

In the Table 32, the following abbreviations are used.

- V : Striking velocity
- ΔV : Change of velocity of struck vehicle
- a_mean : Mean acceleration of struck vehicle
- a_peak : Maximum acceleration of struck vehicle
- Fr_Le : Front left seat
- Rr_Ri : Rear right seat

Table 32. Data set of vehicle test result with human subjects

No	Struck vehicle	Striking vehicle	Overlap [%]	α [°]	V [km/h]	ΔV [km/h]	a_mean [g]	a_peak [g]	Occupant	
									Fr_Le	Rr_Ri
1	Compact	SUV	100	0	8.6	6.6	0.8	1.4	Male	-
2	Midsize	SUV	100	0	8.2	5.5	1.0	2.0	Male	-
3	Large size	SUV	100	0	8.3	6.7	1.7	2.7	Male	-
4	Compact	Midsize	100	0	7.8	6.1	1.2	2.1	Male	-
5	Midsize	Midsize	100	0	8.1	6.1	1.4	2.3	Male	-
6	Large size	Midsize	100	0	7.8	6.4	1.1	2.1	Male	-
7	Midsize	SUV	100	0	11.7	8.0	1.3	2.1	Male	-
8	Large size	SUV	100	0	11.7	9.4	1.5	3.6	Male	-
9	Mini	SUV	100	0	8.6	7.5	1.6	3.0	Male*	Female*
10	Mini	SUV	100	0	8.6	7.3	1.7	3.0	Male*	Female*
11	SUV	Mini	40	30	8.9	3.5	0.8	3.5	Male*	Female*
12	SUV	Mini	40	30	8.9	3.6	0.8	4.1	Female*	Male
13	SUV	Mini	15	0	9.6	1.7	0.3	0.5	Male	Female*
14	SUV	Mini	15	0	9.6	1.5	0.2	0.4	Female	Male
15	Mini	SUV	5	30	8.8	3.3	0.5	1.6	Male	Female
16	Mini	SUV	5	30	8.8	3.4	0.5	1.7	Female	Male

Note) The superscript of * denotes the subject who had the initial symptom.

Medical monitoring showed that 8 subjects felt slight pain or stiffness on their necks or waists after the tests. The pains disappeared within 7-10 days after the tests without any medical treatment. However, the pain did not affect their daily activities. And also, no abnormal medical signs were found by MRI, electromyography and electroneurography.

Although the number of samples is small, we need to pay attention to the vehicle test results showing that there is no whiplash injury even at ΔV of 9.4 km/h. Several overseas studies show that the risk increases rapidly from around 10 km/h of ΔV.

Therefore, we can say that the risk of whiplash injury is close to zero at the low-speed rear-end collision of a struck vehicle up to 9 km/h of ΔV.

Appendix C. Cases of damage patterns

Damage patterns of the struck and striking cars can be various in the rear-end minor collision even under the same ΔV condition. Damage patterns depend on many factors such as the sort of the car, under or over-riding and so on.

Some cases of damage patterns can be referred to by visiting the websites below.

- CTS(crashtest-service.com)
- IIHS TechData(techdata.iihs.org)
- AGU(crashdb.agu.ch)

Appendix D. Publications on Evaluation methods for whiplash associated disorders

1. Bemessung der Verletzungsschwelle der HWS bei Heckkollisionen [28]

Prof. Dr. med. F. Walz Facharzt für Rechtsmedizin Spez. Forensische Biomechanik D r. sc. techn. M. Muser dipl. Ing. ETH, AGU Zuerich, http://agu.ch/1.0/pdf/HWS-2007.pdf (website as of 4 August 2022)

Key words

- vehicle-to-vehicle rear-end collision,
- understanding of parameters
- limitations of evaluated studies Necessity of collaboration of disciplines for evaluation of WAD probability

Aim of the study

- To discuss the feasibility of an injury threshold for whiplash associated disorders after rear-end accidents
- Critical view on research and in particular some exemplary studies

Contents

The paper critically analyzes some studies on “injury thresholds”, pointing out fails in either the study’s scientific design or in the interpretation of results. The authors decline global statements found in some studies. Furthermore the individual’s health status is mentioned as one descriptive parameter for the evaluation of the individual risk. Another such factor is the circumstances of the accident under discussion. The paper concludes that the complete evaluation shall comprise an accident analysis in order to get best information about the occupant’s loading, a medical diagnosis of the individual’s health status regards the spine and muscular system and eventually a biomechanical evaluation of the so far gathered information. Only this process is considered appropriate to give evidence for the causal relationship between accident and complaint. The study also points out the authors’ opinion, that under normal conditions a WAD is not likely underneath a change of velocity (ΔV)>10 km/h - 15 km/h based on numerous other studies.

Remarks

The paper is a relatively short version, considering former publications of F. Walz which have been more detailed.

2. Begutachtung von HWS-Distorsionen – technische, biomechanische, medizinische und rechtliche Aspekte, Teile 1 & 2 [31]

(Assessment of cervical spine distortions - technical, biomechanical, medical and le gal aspects, parts 1 & 2)
Jiri Adamec, H. Bäumler, Norman Doukoff, M. Graw; 2017
https://www.researchgate.net/publication/316330072_Medizinische_und_rechtliche_Aspekte_bei_der_Begutachtung_von_Halswirbelsaulendistorsionen#fullTextFileContent (web site as of 5 August 2022)

http://agu.ch/1.0/pdf/HWS-2007.pdf

Key words

- cervical spine distortion
- definitions, causality
- legal background in Germany
- basic technical background on and the purpose of accident analysis
- basic requirements for and purpose of medical and biomechanical examination
- modus operandi for collaboration of disciplines for evaluation of WAD probability

Aim of the study

- a comprehensive overview of the complex topic of neck pain and cervical spine distortion after accidents
- This paper serves as training document for physicians in Germany (for mandatory continous training and certification)

Contents

The authors of this paper represent the involved disciplines according to a proposal initially made by Prof. (ETH) Felix Walz. Walz found that no isolated discipline will be able to evaluate the causality of a distortion of the cervical spine after an accident, hence the involved disciplines would have to collaborate in such an evaluation. Norman Doukoff as a former Presiding Judge at the Munich Higher Regional Court adds the legal aspects for German law, which might be interesting for legal systems with comparable basic foundations.

In the first part of this article the technical reconstruction of vehicle collisions and the biomechani cal aspects of the expertise are presented, i. e. the areas of the interdisciplinary approach that d eal with the parameters of the external mechanical forces on the body. The second part presents the medical and the legal aspects of the forensic expertise of whiplash-associated disorders.

Remarks

This paper is noticeable insofar, as a judge (Norman Doukoff, former Presiding Judge at the Munich Higher Regional Court), two professors for forensic medicine (Matthias Graw, director of the faculty of legal medicine of the Ludwig-Maximiiians-Unviersitaet Munich and Jiri Adamec) and a former professor for accident analysis (Hans Baeumler, University of applied sciences Munich) describe the aspects of neck distortion claims after accidents from their respective professional perspective.

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