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COMPARISON OF FRONTAL AND REAR-END IMPACTS FOR CAR OCCUPANTS WITH WHIPLASH-ASSOCIATED DISORDERS: SYMPTOMS AND CLINICAL FINDINGS

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ABSTRACT

Rear-end impacts caused worse initial symptoms and specific clinical findings, not clearly distinguished from those occurring after frontal impacts. WAD III injuries, retro-orbital pain, and isolated contra-directional pro-/retraction pain occurred more frequently after rear-end impacts, indicating the importance of shear loads and craniocervical junction vulnerability. Head inward rotation during rear-end impacts caused a more restricted mobility in the same direction at the primary examination than did outward rotation, indicating a possible influence from the shoulder part of the seat belt. The one-year outcome was mainly influenced by individual factors and less by the impact characteristics.

Key words: whiplash, rear-end impacts, frontal impacts, accident investigation, clinical findings.

WHIPLASH-ASSOCIATED DISORDERS (WAD) constitute a growing and frustrating problem in traffic safety and clinical practise. Specific injury mechanisms have been proposed for WAD caused by rear-end impacts, such as hyperextension (MacNab 1964, 1966, Panjabi et al. 2004), hyperflexion, aggravated by the diagonal part of the seat belt (von Koch et al. 1994, Walz and Muser 1995), and translational movements (Aldman 1986, Penning 1992A/B, Kaneoka et al. 1999, Deng et al. 2000). An increased sagittal segmental motion in the lower cervical spine has been shown in women with chronic WAD by Kristjansson et al. (2003). Lately, some progress has also been made for prevention of WAD in rear-end impacts by modifying the car seat (Viano and Olsen 2001, Jakobsson 2004).

Whiplash caused by frontal or side impacts has not been studied to the same extent. The pathogenesis and the mechanisms of whiplash injury are far from clear, not even in symmetric loading. There are also uncertainties regarding the risk of injury versus impact direction, change of velocity (Δv), and impact pulse characteristics such as acceleration level and pulse shape. Studies on humans, conducted to evaluate the cervical tolerance, have almost exclusively been made on healthy subjects in non-oblique rear impacts. Basic principles of mechanics indicate an increased risk of injury in structures during asymmetric loading in general. Sturzenegger et al. (1994) and Jakobsson (2004) showed an increase in WAD severity and injury rate, respectively, for occupants with rotated head during rear-end impacts. There is a growing need to analyze what influence such asymmetry would have on the injury tolerance of the cervical spine.

Neck pain and stiffness, being the most common symptoms after a whiplash trauma, are usually absent or modest the first hours after the impact, but the symptoms often become more intense and distributed during the following days. In the acute phase, it is easier for the patient to point out the focus of the pain and for the examiner to localize the anatomical structures, which may have been injured or involved in the inflammatory response. It may also be easier to provoke symptoms during movements of the injured region, indicating possible loci of injury and neurological disturbances. This is more difficult later, especially in patients who develop a myofascial pain syndrome, which may distort the primary clinical picture. Injuries caused by whiplash trauma are extremely difficult to visualize with ordinary diagnostic methods. However, injuries to the craniocervical junction have been demonstrated with magnetic resonance images (MRI) during recent years (Volle and Montazem 2001, Krakenes et al. 2002). The patients' history and the early clinical examination are fundamental for the diagnosis and treatment of most injuries of the locomotor system, and whiplash injuries are not excluded. However, as in other non-specific chronic disorders, one also must consider the psychosocial characteristics and the coping ability of the patient (Vendrig et al. 2000). Combining information on psychosocial factors, initial symptoms, findings in the early clinical examination, and crash- and vehicle-related data would make it easier to understand what might have been injured and the injury mechanisms in whiplash trauma.

The purpose of this study was to identify differences in the symptom patterns and clinical findings for car occupants with WAD in frontal and rear-end car impacts, which could indicate vulnerable anatomical structures, possible mechanisms of injury, and ways of protection.

METHODS

Adults with neck problems after a car collision were recruited, prospectively, from two emergency departments in Gothenburg during 1997-2001. All were graded WAD III or less. A standard radiological investigation was made initially on all subjects. For those injured in rear-end impacts, who negated neck problems during the year before the crash, an MRI was also made. A physiotherapist, specialised in examination of WAD-patients, made a comprehensive interview and clinical examination within 35 days after the accident (mean=16, s.d.=5, 85%≤21) and after three months and one year. For occupants injured in Volvo cars, detailed crash characteristics were also obtained. Clearance was granted from the Ethics Committee of The Göteborg University, and all participants joined the study by informed consent.

Before the first examination, the subjects answered a structured, detailed questionnaire regarding previous health problems. They defined the time interval between the accident and the start of neck, shoulder, and back symptoms, the occurrence of specified general symptoms, and the development and character of the neck, shoulder, and arm symptoms during the first days. They also described the distribution and character of pain and sensory disturbances with the aid of an anatomical picture of the body. The questionnaire included specific items regarding the existence, grade, and character of neck, shoulder, back, arm, and general problems. All clinical examinations were made with a structured protocol, elaborated for WAD-patients. Within one month, the participants also answered the following validated psychometric protocols: a) The Karolinska Scales of Personality (Schalling 1986), b) The Beck Depression Inventory (Beck et al. 1961), and c) The Impact of Event Scale (Horowitz et al. 1979).

The pain intensity was estimated on the Visual Analogue Scale, with the range 0-10 (Carlsson 1983) before the examination and during all measurements and specific tests of the cervical mobility.
The tests of the cervical mobility included the maximal voluntary active range of angular mobility at the pain limit in the two opposite directions in each of the three principal planes (sagittal, frontal, coronal) with the subject in a fixed seated erect position using a compass and inclinometer. The sum of these measurements is the total range of cervical mobility (ROM). They also included the active translational neck mobility in the sagittal plane in forward (protraction) and rearward (retraction) direction. The following provocative tests were made: a) foraminal compression {modified "Spurlings' test" (Spurling and Scoville 1944, Ellenberg et al. 1994), i.e. combined extension/lateral bending/rotation in the same direction during axial loading}, b) stretching of the cervico-brachial plexus, c) supraclavicular pressure/percussion of the cervico-brachial plexus. The distribution of pain during each active movement and isometric loading of the neck in the neutral position in the same directions were mapped anatomically as were the distribution and character of head and arm symptoms, and the location of tender points.

The radiological investigation included full and dens frontal, sagittal, and right/left oblique plain radiographs of the cervical spine. The MRI included sagittal sequences between the base of the skull and the middle part of the thorax, and transversal sequences between the second and seventh cervical vertebrae. A neuroradiologist and an orthopaedic surgeon classified the type and degree of degenerative changes without knowledge of the post-traumatic symptoms. For cases injured in Volvo cars, crash and car related data (impact direction, Δv, and character of the impact pulse), and the posture were estimated from measurements and analyses of damaged structures of the vehicle and by photographs and measurements with the person sitting in the car.

GRADING OF NECK PROBLEMS AND RADIOLOGICAL FINDINGS: The existence, history, and severity of previous neck problems were obtained from the interview data, and the grade of the previous problems was dichotomized: 0=no or minor problems, 1=more than minor problems.

The neck problems after the accident were classified according to the WAD scale (Spitzer et al. 1995). The grade of the neck-related problems - the "symptom intensity" - was also judged from the questionnaire, the interview by the physiotherapist just before the examination, and findings during the examination, as described in a previous study (Jakobsson et al. 2003). The symptom intensity was primarily coded on an ordinal scale according to table I, and dichotomized thereafter.

Table I. Grading of neck-related problems after the accident – symptom intensity

Grade	Meaning
0	No problems at all.
0+	Minimal problems, almost disappeared at the primary examination (only applicable initially).
1	Minor problems, not interfering with usual daily activities and not bothering the person.
2	Moderate problems, interfering with daily activities, bothering the person to some degree, but usually not disturbing sleep and in most cases with pain free periods.
3	Severe problems, strongly interfering with daily activities or disturbing sleep and in most cases without pain free periods.

In the analysis, the symptom intensity was judged as non-minor if it was graded 2 or 3 according to table I. This was also true for residual problems at the one-year follow-up, which were defined as "neck-related symptoms bothering to any degree".

The pathological radiological changes from all the plain radiographs and the MRI were classified using the definitions in table II. In some of the analyses, the radiological findings were dichotomized. Unless otherwise specified, pathology on radiographs means any discrepancies from a completely "normal" picture, including minor degenerative changes, sometimes not mentioned by the radiologist. This corresponds to the specification "significant" (grades 2-3) in table II.

Table II. Grading of pathological radiological changes

Grade	Specification	Meaning
0	Not significant	No changes at all.
0+	Not significant	Minimal changes, including straightening of the cervical lordosis.
1	Not significant minor	Minor changes, sometimes not mentioned by the radiologist.
2	Significant moderate	Clear degenerative disc or foraminal changes on less than three levels.
3	Significant major	Marked degenerative disc or foraminal changes on three or more levels.

SUBJECTS: Primarily, 131 subjects were included (table III). Of these, 23 were injured in frontal impacts (all Volvo) and 108 in rear-end impacts (77 Volvo). Three men (25-33 y) and two women (23 and 42 y) were lost for follow-up. One woman (45 y) sustained a neck injury in a subsequent accident before the follow-up. These six subjects were all injured in rear-end impacts; giving, in total, 125 subjects available for the analyses of crash-related problems one year after the accident.

Table III. Numbers of injured (n), age [mean (mv), min (mi), max (mx), st. dev. (sd)], type of impact, and gender

	Frontal impact										Rear-end impact									
	Males					Females					Males					Females				
	n	mv	mi	mx	sd	n	mv	mi	mx	sd	n	mv	mi	mx	sd	n	mv	mi	mx	sd
Primary included	8	34	20	54	14	15	34	15	39	9	49	36	20	75	11	59	41	22	65	12
Analysed 1 year	8	34	20	54	14	15	34	15	39	9	46	37	20	75	12	56	41	22	65	12

ANALYSIS: A multidisciplinary team consisting of car crash analysts, neurosurgical, orthopaedic and radiological experts, specialized physiotherapists, and biomechanical specialists analysed each case in detail with respect to impact characteristics, sitting posture, function of safety equipment, type and severity of pre-existing neck problems, pathological radiological findings, and type, location, and severity of the symptoms and medical findings.

The initial and residual problems were analysed with respect to Δv, the impact type (front/rear), the character of the crash pulse -"stiff" or "soft", indicating whether or not the longitudinal side members were hit/permanently deformed, according to Olsson et al. (1990), the seat position, and the weight, stature, posture (including the position of the head, torso, and arms), and previous neck problems as well as the psychological reactions indicated by the psychometric protocols.

The influence of head rotation relative the car vs the outcome was analysed separately, i.e. inward (face towards the car interior) vs outward rotation (face towards the nearest side window). The occurrence of isolated contra-directional pain (pain during movement of the head opposite the impact direction and no pain during movement in the other direction) was analysed for flexion/extension and protraction/retraction. The Pearson Chi-Square test, Fisher's exact test, the Student's two-sided T-test for data with unequal variances, and forward stepwise logistic regression were used when appropriate. Odds ratios were calculated to compare the influence of dichotomized parameters for rear-end versus frontal impacts. The standard version of SPSS 11.0.0 was used for the statistical analyses.

RESULTS

Most of the core data at the primary examination and after one year are presented in the appendices, including case reports for some of those who were injured in impacts with $\Delta v \leq 10$ km/h and with residual problems after one year. The three months examination data are omitted in this report.

OCCUPANT AND IMPACT DATA: Of the 131 subjects included primarily, 48 men and 49 women negated previous neck problems of any degree. The mean age was somewhat lower in frontal impacts cases, especially for women (34 vs 41). The neck circumference, the weight, and the Body Mass Index were somewhat greater in rear-end impacts cases, but not statistically significant.

The impact severity was greater in the frontal impacts as judged from the change of velocity and the character of the impact pulse. The mean Δv in the frontal and rear-end impacts was 13 (<5-20) and 8 (<5-30) km/h respectively. The pulse was "stiff" in 14 (61%) of the frontal and in 26 (34%) of the rear-end impacts. Of the occupants in both groups, 96% used the seat belt. The airbag was deployed in three cases in frontal impacts and one case in a combined rear and frontal impact, where the rear-end impact was judged to be the major one. The direction of head rotation relative the car, the percentage with rotated head, and the percentage that were aware of the impending collision are shown in table IV. The proportion of those who had their head rotated at impact was less in frontal (27%) than in rear-end (44%) impacts ($p=0.15$). This difference was somewhat more obvious for drivers: 20% vs 42% respectively, ($p=0.11$). More than two thirds of those injured in frontal impacts and less than one third of those injured in rear-end impacts were aware of the impending collision and able to strain their neck muscles before the impact ($p<0.000$). In rear-end impacts, the driver was aware of the impending collision twice as frequently as the front seat passenger ($p=0.14$).

Table IV. Direction of head rotation relative the car, percentages with rotated head and awareness of the impending collision versus seated position in 22 frontal and 105 rear-end impacts.

	Direction of head rotation relative the car				Rotated	Awareness
Frontal	Neutral	Inward	Outward	Total	%	%
Driver	12	1	2	15	20	73
Passenger front seat	2	1	1	4	50	75
Passenger rear seat	2	1	0	3	33	33
Total	16	3	3	22	27	70
Rear-end						
Driver	48	23	12	83	42	33
Passenger front seat	9	9	0	18	50	16
Passenger rear seat	2	1	1	4	50	50
Total	59	33	13	105	44	31

INITIAL PROBLEMS AND FINDINGS: A temporary loss of memory was reported to a greater extent (22%) after frontal than rear-end (8%) impacts. The neck symptoms started earlier after rear-end impacts than frontal impacts, within minutes in 64% and hours in 93%, compared with 27% and 68% respectively. Nine (9) subjects (3 in frontal impacts) had almost negligible initial neck problems. Somewhat more than three quarters of the subjects reported headache after the accident in both groups, also among those without previous headache. The frequency of headache was greater after rear-end impacts; daily or almost daily in 44% after rear-end and 23% after frontal impacts. Fifteen (15) subjects reported headache with retro-orbital pain after rear-end impacts, but no one did so after frontal impacts. The occurrence of other general symptoms such as vertigo or nausea, irritability, nervousness, overstrains, and restlessness was greater after rear-end impacts. Initial arm symptoms were reported by almost half of the subjects and without a clear difference between the groups. The arm symptoms disappeared more rapidly after frontal than rear-end impacts ($p=0.07$), and they remained in 38 subjects (5 after frontal and 33 after rear-end impacts) at the first examination.

At the primary examination, 14 subjects had recovered to WAD 0, including 12 without symptoms but with clinical findings (Table V). WAD III injuries were noted only after rear-end impacts. The occurrence of arm symptoms was significantly related to the WAD grade. However, 23 (60%) of those with arm symptoms were graded as WAD II. Four subjects with disturbances of the central nervous system without arm symptoms were graded as WAD III. The sensitivity of arm symptoms, indicating WAD III, was 79% and the specificity was 39%. Encroachment of the intervertebral foramina (foraminal stenosis) was significantly related to WAD III. Women reported higher pain intensities at the initial examination as compared to men. This difference remained when regard was taken to the type of impact, but was not statistically significant for "worst" pain. The mean pain intensity was greater after rear-end impacts in both genders, most obviously for women. The cervical range of mobility in each of the three principal planes and the protraction and retraction distances were negatively and significantly correlated to the pain intensity.

Table V. The grade of the primary neck problems at the first examination after frontal and rear-end impacts

Impact type	**WAD-grade (according to Québec Task Force)**				**Total**
	0	I	II	III	
Front	3	2	18	0	23
Rear	11	5	73	19	108
Total	14	7	91	19	131
	Grade of primary neck-related problems (defined in Table I)				
	0	1	2	3	
Front	4	12	5	2	23
Rear	11	48	42	7	108
Total	15	60	47	9	131

Head rotation at impact: If no regard was taken to the type of impact, 29 (56%) of those with rotated head position and 25 (33%) of those with neutral head position had non-minor initial neck problems (p=0.01). The influence of head rotation on the grade of the initial problems was most obvious in frontal impacts (p=0.05) and less in rear-end impacts (p=0.08). The odds ratio for non-minor problems with rotated vs neutral head position was 8.7 in frontal and 2.0 in rear-end impacts.

A difference was noted in rear-end impacts for those who had their head rotated with regard to the direction of rotation relative the car. Inward rotation caused a more restricted mobility in the same direction than did outward rotation. The mean value of the difference between the inward and the outward rotation range in 33 occupants with inward rotated head at the impact was –5 degrees (S.D. 11). The mean value of the difference between the outward and the inward rotation range in 13 occupants with outward rotated head was +3 degrees (S.D. 9) (p=0.013). No such difference was noted for inward versus outward inclination (side bending) of the neck.

Severity and type of impact: The severity of the primary symptoms, the medical findings, and the WAD grade did not correlate in a consistent way with the impact severity, expressed as Δv or engagement of the longitudinal side members. On the contrary, in many cases, there were reversed relationships. In 100 cases where Δv could be estimated, about one third were judged to have neck problems of more than minor grade at the primary examination (Table VI). This proportion was about the same or even greater at a low Δv, and there was no difference between frontal and rear-end impacts.

The neck pain started within minutes after frontal impacts in all cases if the side members were engaged, and later if they were not. The neck pain started within minutes after rear-end impacts in almost two thirds of the cases, irrespective of side member engagement. The time elapse before the start of neck pain did not correlate with Δv. Δv had no influence on the mean pain intensity or the total range of cervical mobility.

Pain increase during active extension of the neck was more frequently noted after rear-end than frontal impacts (p=0.04). The mean value of the extension range was about 10% lower after rear-end than frontal impacts (59 vs 65 degrees, p=0.057). The ranges of movement during active flexion and extension, protraction and retraction and the corresponding pain increase during these tests after frontal and rear-end impacts are shown in figure 1.

Isolated contra-directional pain was noted more frequently during flexion after frontal impacts than during extension after rear-end impacts (p=0.08). Retraction and protraction were associated with increased pain in 58% and 49% respectively if no regard was taken to the impact direction (p<0.001).

Two (2) of 6 occupants injured in frontal impacts had isolated protraction pain and 23 of 30 occupants injured in rear-end impacts had isolated retraction pain (p=0.057).

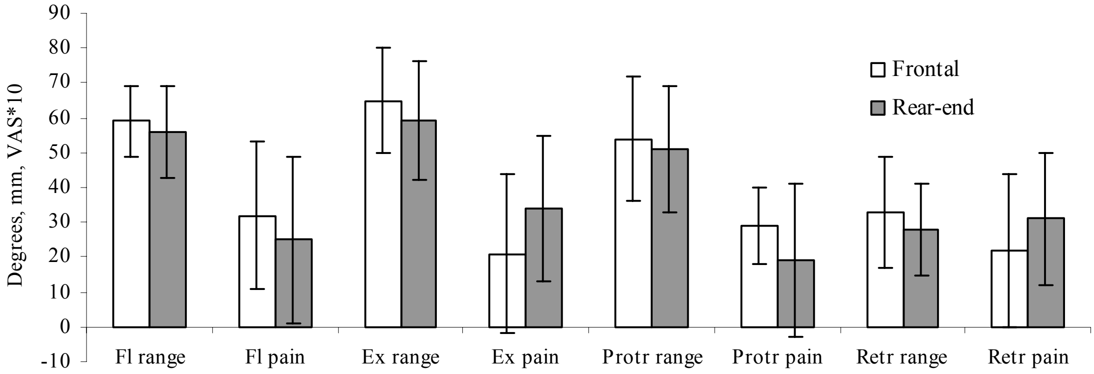

Figure 1. Mean values +/-1 sd for the range of movement during flexion (Fl) and extension (Ex) (degrees), protraction (Protr) and retraction (Retr) (mm), and the corresponding pain increase (VAS*10) for frontal and rear-end impacts.

RESIDUAL PROBLEMS: One year after the accident, 56 of 125 subjects (45%) had no residual problems at all; 18 had deteriorated, 15 (14 after rear-end impacts) because of the accident. In 109 of the subjects, no other factor than the accident could be identified which might have any influence on the status at that time. In the other 16 cases, there were difficulties of varying degree in making conclusions about the influence of competing factors. However, in 11 of these 16 cases, there was a reasonable causative relationship with the accident. Thus, a total of 120 cases were available, for which there was a reasonable possibility to estimate the influence of the primary crash and individual-related factors on the outcome. Three groups are labelled according to the causation strength in appendix 2 ("no", "reasonable", or "clear"). In most of the following analyses, reasonable causation is valid.

Influence of individual factors: Women had residual problems more frequently than men. Problems of any grade and non-minor grade were noted for women in 62% and 34% respectively and for men in 42% and 17% respectively. Even in those without any previous neck problems, women were judged to have residual problems more frequently, not depending on the impact type (33% vs 15%). Age, stature and weight did not influence the outcome; neither did prior neck problems.

Degenerative changes of the cervical spine were significantly related to the occurrence of residual problems of non-minor grade. Such changes were noted in 35% of those with residual problems and in 17% of those without problems, giving the odds ratio of 2.5 (p=0.04). Pronounced degenerative changes were over-represented in those 14 with residual pain of continuous bothering character (50% vs 11% in the other). Foraminal stenosis at the primary radiographs was significantly related to severe residual problems, giving an odds ratio for stenosis versus no stenosis of 5.0 (p=0.004).

Influence of initial findings: Initial arm symptoms were significantly related to residual problems (p<0.001). A reduced range of the total cervical mobility, adjusted for gender and age, was significantly related to residual problems for women (p=0.003) but not for men (p=0.2). The probability of residual problems after one year versus the deviation from the normal ROM for women is shown in fig. 2. In the 108 cases for which the WAD-grades were possible to estimate at the follow-up, 2 (2%) were graded WAD I, 47 (44%) as WAD II, and 11 (10%) as WAD III. The WAD grade at the primary examination was significantly related to the occurrence of residual problems (p<0.001).

Influence of psychological factors: According to KSP, the muscular tension tendency was related to residual problems in women (p<0.02), but not in men. A high BDI score, indicating depression, was related to residual problems in women (p<0.001), but not in men. A high IES score, indicating post-traumatic stress, was significantly related to residual problems in both genders (p<0.01 for each).

Influence of rotated head at impact: A rotated head at impact significantly influenced the outcome if no regard was taken to the impact direction. Of 45 subjects with rotated head, 16 (36%) had non-minor problems after one year compared with 13 (18%) of 71 who did not have the head rotated, giving an odds ratio of 2.5 (p=0.037). This difference was quite obvious in frontal impacts, where 3 of the 6 subjects with rotated head were judged to have non-minor problems at the follow-up, but only one of those 14 who did not have the head rotated, giving an odds ratio of 13 (p=0.06). The influence was less obvious in rear-end impacts, where 13 of 39 subjects (33%) who had the head rotated were judged to have non-minor problems after one year compared with 12 (21%) of 57 who had not, giving an odds ratio of 1.9 (p=0.18). In rear-end impacts, there was a somewhat stronger relationship for head rotation and major problems (grade 3 in table II), but not significant. Of 39 subjects with rotated head 7 (18%) were judged to have major problems after one year compared with 4 (7%) of 57 who did not have so, giving an odds ratio of 3.1 (p=0.08).

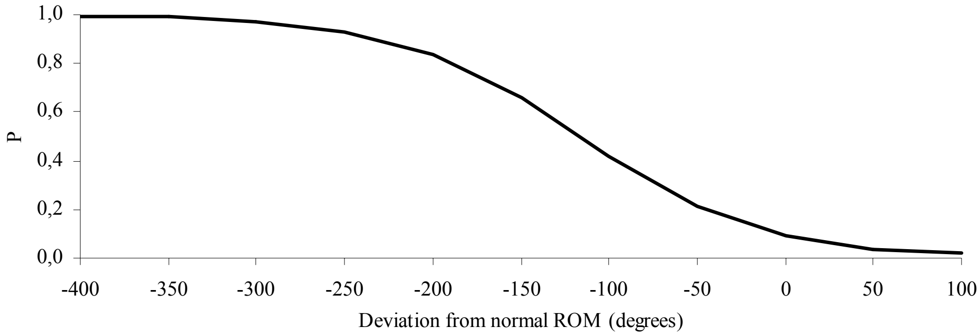

Figure 2. Probability of residual neck problems related to an accident of more than negligible grade, one year after frontal or rear impacts in 57 women as a function of the deviation from the normal cervical range of motion, according to Dvorak et al. (1992), at the primary examination.

Influence of impact characteristics: The only difference that could be clearly seen between frontal and rear-end impacts, with regard to residual problems, was an almost twice as high rate for problems of any grade in rear-end impacts as compared to frontal impacts, giving an odds ratio of about 3. One fourth of those without any previous neck problems had residual problems, equal in frontal and rear-end impacts. Residual problems of more than minor grade were noted in 32 subjects (27%): 4 (19%; 1 man and 3 women) after frontal and 28 (28%; 8 men and 20 women) after rear-end impacts, which might also indicate a worse prognosis for non-minor problems after rear-end impacts, but not statistically significant. Of these 32 occupants, 18 were primarily graded as WAD II and 14 as WAD III.

Δv, as an estimate of the impact severity, was not related to residual problems, neither after frontal (p=0.4), nor rear-end impacts (p=0.5), not even in subjects without any previous neck problems. In fact, 10 of 61 subjects (9 in rear-end impacts) were judged to have non-minor problems one year after impact with $\Delta v \leq 10$ km/h (Table VI). Of these, 8 (7 in rear-end impacts) negated any previous neck problems. A "stiff" impact pulse caused residual problems of non-minor grade in 20% of the subjects, without any difference between frontal and rear-end impacts.

Table VI. Initial and residual neck problems after one year of more than minor grade versus Δv.

	Problems at the primary examination				Problems after one year			
Δv (km/h)	No	Yes	Total	% w prbl	No	Yes	Total	% w prbl
<=05	22	20	42	48	31	8	39	21
06-10	17	6	23	26	20	2	22	9
11-15	11	6	17	35	13	4	17	24
16-20	8	3	11	27	9	2	11	18
21-25	4	1	5	20	5	0	5	0
26-30	2	0	2	0	1	1	2	50
Total	64	36	100	36	79	17	96	18

DISCUSSION

This study was made on selected individuals, who accepted quite a large number of examinations during one year, some of them rather extensive. Maybe, a bias exists because of the inclusion criteria - enrolling injured subjects only. The number of occupants injured in frontal impacts was much smaller than those injured in rear-end impacts, which limited the possibility of conclusions on the differences between frontal and rear-end impacts. The lower number of frontal cases might be explained by a lower expectancy of long-term WAD for these subjects. Fifteen percent (15%) of the occupants were examined later than three weeks after the injury, a period sufficient to mask many of the localised initial symptoms. The best would be to collect data within only a few days after the accident. For practical reasons this was not possible. Some of the data collection relied on the occupant's own recollection. The impact severity could be checked against an on-board crash pulse recorder in only one (frontal) impact (showing a good correlation). However, because of the detailed information in each case, the study makes a contribution to the understanding of WAD for different impact situations. Even though there are limitations in the data, for the purpose of this study (mainly comparing frontal and rear-end impacts) the reliability of the data can be considered good, and there are no obvious reasons for systematic differences between the data from the frontal and the rear-end impacts.

A general trend of more severe initial problems after rear-end impacts was found, despite a greater occurrence of potential risk factors in the frontal impact cases: greater Δv, more often stiff impact, and degenerative changes of the cervical spine. The reason for this is not obvious and it might be because of different injury mechanisms. The airbag was deployed in some cases in the frontal impacts, possibly reducing the risk of injury. Subjects in frontal impacts also had a better possibility to prepare themselves, as they were more often aware of the impending collision and able to strain their neck muscles. This study also shows a worse long-term prognosis for neck problems of any grade after rear-end impacts - the odds being three times that for frontal impacts. A similar but not so obvious difference was noted for more severe problems. Non-minor problems were noted after one year in 4 of 23 (17%) occupants after frontal impacts and in 28 of 102 (27%) after rear-end impacts, giving an odds ratio for non-minor, long-term problems of 1.8 for rear-end versus frontal impacts.

Retro-orbital pain was noted only after rear-end impacts. Persistent headache occurred more frequently after rear-end impacts, as did pain increase during minimal sagittal and coronal movements (which almost exclusively take place in the craniocervical junction). These findings indicate a possible locus of injury in the uppermost cervical segment or the adjacent musculature, as its pain reference zones include the temporal and orbital areas (Feinstein et al. 1954). The tolerance and the mechanisms of injury of the upper cervical spine and the cranio-cervical junction should be further investigated, and existing MRI-protocols, developed for exploration of this region, should be applied (Volle and Montazem 2001, Krakenes et al. 2002).

WAD III injuries were noted only after rear-end impacts, and significantly related to foraminal stenosis. A stenosis may cause a temporal entrapment of the nerve root or traction of the cervical plexus during the extremes of the whiplash motion. A rotated head will, by itself, diminish the dimensions of the ipsilateral intervertebral foramina, making the nerve tissue more vulnerable during this phase, as has been described by Cailliet in 1964. The higher occurrence of "isolated contra-directional" pain during retraction in those injured in rear-end impacts is in accordance with this finding, as retraction, being the initial part of the whiplash movement in rear-end impacts, also diminishes the dimensions of the foramina. Injuries of the craniocervical junction should be suspected in subjects with cranial pain referred to the temporal and retro-orbital areas, as such symptoms are over-represented in subjects injured in rear-end impacts. Shear loads in motion segments, including the cranio-cervical junction, may be critical in rear-end impacts, as they act during a very short time in the initial phase of the whiplash motion and are difficult to reduce with conventional neck protection devices. This finding is also in accordance with some of those made by Kristjansson et al. (2003), who noted an abnormal increased motion of the C3-C4 and C5-C6 segments in women with WAD.

A rotated head at impact is clearly unfavourable, as has been shown in the present study similar to other studies, both with respect to initial injury rate as well as long-term problems (Sturzenegger et al. 1994 and 1995, Jakobsson 2004). In this study, there were no obvious differences regarding the impact direction and the rate of long-term problems for those who had their head rotated at the moment of impact. One may speculate about the reason why there was a difference between the inward and outward rotation capability in those who had their head rotated in the rear-end impacts, depending on the direction of the rotation at impact. One reason may be the diagonal part of the seat belt, which could impose an asymmetric load on the cervical spine during the retardation. This might have occurred in frontal impacts as well, but such a difference could not be seen. However, the number of frontal impacts was much less. The same findings were noted in a previous study on rear-end impacts at the Traffic Injury Register.

The injury mechanisms and the risk of injury in physical trauma, where there are no obvious patho-anatomical signs, are difficult to understand and estimate. WAD like other disorders without clarified pathophysilogy are also influenced by psychosocial factors, and there are studies indicating the importance of them (Schrader et al. 1996, Ferrari et al. 2003). Some authors even deny the possibility of sustaining a neck sprain in impacts with Δv less than a specified limit (Castro et al. 1997). There are also controversies regarding the natural history of WAD and the variance of the symptom intensity during the first period after the injury. In this study, 18 subjects deteriorated during the first year and for 15 of them no other cause could be identified than the accident. Opinions about causation may have great importance in medico-legal contexts, and there are individuals injured in car crashes that suffer from difficulties in compensation for their sequelae, because “the damage to the car was so small”, or “the symptoms developed too late after the crash”. The present study was not intended to clarify these circumstances, but the impact severity may be low (Krafft et al. 2002) and it leads us to conclude that we cannot specify a Δv below which it is impossible to sustain a neck sprain with long-term consequences. Because of the importance of occupant-related factors and the complexity of pain physiology, the tolerance limit for different individuals varies. For several of the previously healthy occupants in this study, the Δv was low; the details in some of these cases are found in appendix 3.

The general conclusion is that there are no differences between the symptoms and clinical findings which may clearly indicate different mechanisms of injury in frontal and rear-end impacts. However, some findings deserve further investigation, such as symptoms indicating possible injuries in the craniocervical junction caused by rear-end impacts; the pattern of isolated contra-directional retraction/protraction pain indicating the importance of shear loads; and the influence of the diagonal part of the seat belt, that may cause an asymmetric load. There are several individual and medical factors at the primary examination, which influence the long-term outcome, but only a few which may discriminate frontal and rear-end impacts. Individual factors, including psychological ones, seem to be much more important for the long-term prognosis than crash related factors, as has also been shown by other authors (Richter et al. 2004). The variance between individuals of the healing process after spinal trauma may be critical. As this process also includes psychological and stress-related mechanisms involving the central nervous system and the neuro-endocrine system, this is not unexpected. There are several psychometric instruments, which have been used in attempts to identify individuals at risk after a traumatic event. One component of the Karolinska Scales of Personality - “muscular tension tendency” - showed higher scores in females with an unfavourable one-year outcome. This is an interesting finding with relevance for chronic pain development in general, also in work-related myalgia in modern societies, which recently has been extensively investigated by Johansson et al. (2003). Individual factors should not be neglected in future studies of WAD, as they can disturb subtle influences of various impact characteristics. In fact, it should be fundamental to combine individual data and crash-related data. The individual data should also be obtained much earlier than in some cases in this study, preferably within the first few days, and psychological reactions, indicating bad prognoses should be handled properly, which is in agreement with well-known recommendations in rehabilitation medicine. Even if most patients will recover completely after a whiplash trauma, there is a need to identify those who are at risk to develop long-term problems. This can only be done if, right at the outset, all factors which may influence the prognosis, are considered.

CONCLUSIONS

There are a few differences between frontal and rear-end impacts with regard to medical consequences of whiplash trauma, but they are disturbed by individual factors to a great extent.

In this study, the car and crash-related factors were found to influence the outcome of whiplash trauma only to some extent. The early symptoms and medical findings are those that may disclose the locus and mechanisms of injury and they should be used to improve protection in cars. The long-term effects are almost exclusively influenced by individual factors, including psychosocial ones.

The retraction during the initial phase of the whiplash motion and the influence of the diagonal part of the belt in rear-end impacts are two possible injury mechanisms indicated in this study, that should be further investigated. So should also injuries to the craniocervical junction.

An early detailed medical examination, including psychological reactions and monitoring of the long-term consequences of whiplash trauma are of fundamental importance for understanding the natural history of WAD, for the treatment, and for the judgement in a medico-legal context.

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Appendix 1

Data at the primary examination			Frontal		Rear		p	Odds R
	Number and percentage of all cases with the characteristic		n	%	n	%		R vs F
General	Gender	Female	15	65	59	55	0,35	
		Male	8	35	49	45		
	Previous problems	Neck problems; Any grade	10	44	24	22	0,035	
		Neck problems; Grade 1	8	35	10	9	0,004	
		Headache	10	46	41	38	0,6	
	Radiol pathology	Any significance (PatSig0)	15	71	60	58	0,3	
		Higher significance (PatSig1)	4	19	18	18	1,00	
	Behaviour at the accident	Used seat belt	22	96	104	96	1,00	
		Head rotated at impact	6	27	46	44	0,15	
		Aware of impending collision	16	70	33	31	0,000	0,19
		Strained the neck muscles	16	73	27	26	0,000	0,13
	Primary symptoms	Temporary loss of memory	5	22	9	8	0,060	0,33
		Neck pain within minutes	6	27	65	64	0,002	4,7
		Feeling of neck instability at prim exam	1	10	15	48	0,03	8,4
		Increased neck pain when straining	2	9	33	33	0,02	5,0
		Upper back pain	9	39	71	66	0,02	3,0
		Headache after the accident	17	77	85	79	0,9	
		Headache almost daily after the accident	5	23	48	44	0,06	2,7
		Co-incidental headache and neck pain	4	24	45	48	0,06	3,0
		Retro-orbital pain	0	0	15	14	0,06	-
		Any other general symptom (11 specified)	20	87	97	90	0,7	
		Arm symptoms according to interview	12	52	47	44	0,5	
		Arm symptoms at the primary examination	5	22	33	31	0,4	
	WAD	Grade >=II	17	74	93	86	0,20	2,4
		Grade III	0	0	19	18	0,03	-
	Non-minor neck problems	With no regard to head rotation	7	30	49	45	0,19	1,9
		Head rotated at the impatc	4	67	25	54	0,7	
		Head not rotated at the impact	3	19	22	37	0,16	2,6
Impact data	"Stiff" impact pulse		14	61	26	34	0,02	0,33
Cervical spine	Pain increase during	Craniocervical minor sagital movements	3	13	32	30	0,10	2,8
		Craniocervical minor coronal movements	3	13	29	27	0,16	2,1
		Flexion, active	14	61	61	56	0,7	0,8
		Flexion, isometric	9	39	48	44	0,6	1,2
		Extension, active	9	39	67	62	0,04	2,5
		Extension, isometric	6	26	46	43	0,14	2,1
		Protraction	7	30	39	36	0,6	1,3
		Retraction	9	39	55	51	0,3	1,6
	Isolated contra-directional pain during	Flexion-extension, active	5	100	19	59	0,08	0,0
		Flexion-extension, isometric	4	80	9	45	0,16	0,2
		Protraction-retraction	2	33	23	77	0,06	6,6
	Isolated cranial pain during	Flexion, active	0	0	10	17	0,19	-
		Extension active	1	11	15	23	0,7	
		Protraction	2	29	11	29	1,0	
		Retraction	1	11	18	34	0,25	4,1

Data at the primary examination			Frontal			Rear			p
	Number of cases, mean value, standard deviation		n	mean	SD	n	mean	SD	
Individual data	Length (cm)		23	172	7	108	174	9	0,5
	Sitting height (cm)		23	90	7	103	91	6	0,5
	Head circumference (cm)		23	57	2	107	57	3	0,8
	Neck circumference (cm)		23	36	3	107	38	4	0,07
	Weight (kg)		23	71	13	108	77	15	0,08
	Body Mass Index (kg/m^2)		23	24	4	108	25	5	0,11
	Age	All	23	34	10,7	108	39	11,7	0,07
		Female	15	34	9,2	59	41	11,7	0,03
		Male	8	34	13,8	49	36	11,4	0,68
Pain	Pain intensity	VAS best	22	0,5	0,9	108	1,2	1,5	0,005
		VAS actual	22	1,5	1,9	107	2,4	2,0	0,054
		VAS worst	22	3,3	2,6	108	4,1	2,6	0,19
Psycholgy	Psychometric tests	BDI (sum)	14	2,5	3,3	93	5,5	6,7	0,01
		IES (sum)	16	17	12,6	95	16	16,0	0,8
		KSP (Muscular tension, sum)	17	16,5	4,7	97	14,7	3,5	0,13
Impact	Delta V		23	13,0	6,0	77	7,6	6,0	0,000
Cervical spine	ROM (degrees)		22	341	46	108	319	60	0,07
	Flexion (degrees)		22	59	10	108	56	13	0,30
	Extension (degrees)		23	65	15	108	59	17	0,057
	Protraction (cm)		23	5,4	1,8	107	5,1	1,8	0,5
	Retraction (cm)		23	3,3	1,6	107	2,8	1,3	0,2
	Flexion pain level	Only those with pain increase	14	3,2	2,1	67	2,5	2,4	0,3
	Extension pain level	Only those with pain increase	14	2,1	2,3	67	3,4	2,1	0,07
	Protraction pain level	Only those with pain increase	7	2,9	1,1	55	1,9	2,2	0,07
	Retraction pain level	Only those with pain increase	7	2,2	2,2	55	3,1	1,9	0,4

Appendix 2

Data at the one year examination

	Number and percentage of all cases with the characteristic		Frontal n	Frontal %	Rear n	Rear %	p	Odds R R vs F
Residual problems	No regard to causation	Any problems	8	34	61	60	0,03	2,8
		More than minor problems	4	17	28	28	0,3	
		More than moderate problems	2	9	12	12	0,7	
	Reasonable causation	Any problems	6	29	58	59	0,01	3,5
		More than minor problems	4	19	28	28	0,4	
		More than moderate problems	2	10	12	12	1	
	Clear causation	Any problems	6	29	47	53	0,04	2,9
		More than minor problems	4	19	24	27	0,4	
		More than moderate problems	2	10	10	11	1	
WAD	No regard to causation	Grade >=II	9	43	50	57	0,3	
		Grade III	0	0	11	12	0,1	
	Reasonable causation	Grade >=II	8	40	50	57	0,2	
		Grade III	0	0	11	13	0,2	-
	Clear causation	Grade >=II	8	40	42	54	0,3	
		Grade III	0	0	8	10	0,2	-
Strained n muscles at impact	Yes	More than minor problems	1	6	6	22	0,2	
	No	More than minor problems	2	33	21	29	0,8	
Head posture at imapct	Rotated	More than minor problems	3	50	13	33	0,7	
	Not rotated	More than minor problems	1	7	12	21	0,4	

	Number of cases, mean value, standard deviation		Frontal n	Frontal mean	Frontal SD	Rear n	Rear mean	Rear SD	p
Cervical spine	ROM (degrees)		20	356	42	76	329	62	0,03
	Flexion (degrees)		20	59	13	77	55	12	0,3
	Extension (degrees)		20	66	13	77	62	15	0,16
General	Pain intensity	VAS best	20	0,4	1,3	77	0,6	1,3	0,6
		VAS actual	20	0,7	1,9	78	1,2	1,8	0,4
		VAS worst	20	1,5	2,8	78	2,5	2,9	0,18

Appendix 3. Some subjects injured in rear-end impacts at Δv≤10 km/h with non-minor problems after one year. (Max. IES=75)

Case 46: Man, 28, pipe-layer. No previous neck problems. X-ray showed minor reduction of the disc height and bone spurs on C4-5. Driver, head not rotated. Δv<5. Neck stiffness after 45 min. Night mares and co-ordination problems left hand before the 1st ex. 13 days: IES=45. Daily global headache. Symmetric neck findings except right-sided pain dominance during head rotation and pain/less power in the right shoulder and arm. Ex 3 m: Somewhat improved, but still headache. Symmetrical symptoms and findings. Ex 12m: Quite severe headache, neck stiffness and pain radiating to the shoulders and numbness in fingers.

Case 64: Man, 40, printmaker. No previous neck problems, but 5 years earlier collided with another car. X-ray: minor bone spurs on ventral part of C1 near the atlanto-dental junction, bilateral arthritis of the zygapophyseal joints C7-Th1, and possibly a small stenosis of the right C3-4 intervertebral foramen. Driver, first rear impact, Δv=5, then frontal impact Δv<5. Head turned to the left. Immediately "burning" pain in the left part of the neck. Following morning; stiffness and tenderness in the shoulders. 1st ex. 18 days: IES=17. Deep pain C1-2 left side and left levator scapulae. Clear tenderness on the left side of the neck and shoulder. Ex 3 m: Left-sided neck symptoms and deep pain left arm. Increased pain during minimal movements in the sagittal and coronal planes, flexion, left side-bending and right rotation. Radiation to the left 8th segment during cervical plexus test. Left sided neck compression pain. Tenderness in the neck-shoulder region, most obvious to the left. Ex 12m: Somewhat more severe problems, including cervical vertigo and throbbing neck pain during rapid neck movements.

Case 93: Man, 43, printing worker. Negated earlier neck-shoulder-back problems but referred to hospital due to "tension headache" 1 y earlier. X-ray: Moderate degenerative disc changes C4-5, C5-6 and bilateral uncovertebral arthritis with minimal foraminal stenosis C4-5. Driver, oblique rear impact turning the car counter-clockwise, Δv=6. Head neutral or left turned. Neck- and lower back pain within minutes preventing sleep 1st night. Headache and right retro-orbital pain following days. 1st ex. 21 days: IES not answered. Never pain-free. Increased pain during all cervical movements, incl minimal movements in the sagittal and coronal planes. Positive cervical plexus test right side. Disturbed sensibility right side of face-neck. Marked tenderness in neck-shoulder region, most to the right. Ex 3 m: Worse, had been on sick leave 6 weeks, but now working. Continuous sleeping problems, depressed, neck pain and headache right side. Very reduced cervical mobility, increased pain also during minimal movements in the sagittal and coronal planes and reduced shoulder mobility. Disturbed sensibility right side of face-neck like before. Ex 12m: Continuous, even worse problems of similar nature, however has worked all the time. Findings almost similar as at 3 m, but also sensory disturbances right arm.

Case 120: Woman, 41, travel bureau agent. Previous healthy, but sometimes frontal headache. X-ray: Moderate degenerative disc changes C6-7. Impacted from behind at Δv<5 when stopped for cyclist, head and body somewhat right turned. Shocked, neck pain within a short time, exaggerating first day. Pain and bruise over left shoulder due to the safety belt. Occipital headache getting worse and tender point in upper neck. 1st ex. 21 days: IES=40. Symmetrical signs with left dominance. Ex 3 m: Worse, never pain free, on sick leave 50%. Temporo-mandibular joint problems (TMJD) right side. Ex 12m: almost the same problems, on sick leave 25%. Never pain free. Obvious tenderness sub-occipitally and right sternocleidomastoid+shoulder.

Case 136: Woman, 61, seller. Hypothyroid, knee+hip problems, frontal headache <1hr, <1/week before accident, but no neck-shoulder problems. X-ray: Minimal degenerative changes C5-6. MRI: Medial disc protrusions with left sided dominance C4-5, C5-6, slightly encroaching left part of medulla and left root at C5-6. Driver impacted from behind at Δv<5, when stopped before right turn, head turned to the left. Immediate neck pain, headache, nausea, tinnitus, TMJD within days. 1st ex. 21 days: IES=16. Sleeping disturbances, vertigo, never pain free VAS_{worst}=6.2. Increased pain during all cervical movements, incl minimal movements in the sagittal and coronal planes. Widespread tenderness in neck-shoulder region, mostly left side. Ex 3 m: Almost the same grade and type of problems, on sick leave. Ex 12m: Sleeping problems with neck pain and numbness in the hands every day and night, however, sometimes pain free.

Back