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. Bützer, B. Zahnd*

Abstract Whiplash associated disorders (WAD) resulting from rear-end collisions continue to be a major concern. This case-control study is aimed at identifying possible predictors for WAD claims from struck car occupants using EDR (event data recorder) and insurance data. It made use of the first large-scale EDR dataset available in Switzerland. Through analysis of 168 real-world collisions, calculated crash severity metrics, such as change of velocity (delta-v) and mean acceleration, were compared to medical data. The data was separated into a WAD and a control group. It was shown that the delta-v and the mean acceleration differed significantly for the two groups. A corresponding risk curve confirmed an increase in injury risk for higher crash severity. Mean acceleration was found to be a slightly better predictor for WAD risk than delta-v. No association was found between crash severity measures and the QTF score (severity score according to Quebec Task Force). Sick leave duration did, however, correlate with impact severity, while it did not correlate with the QTF code. The study confirms previous research in the field by highlighting the link between impact severity and WAD risk. However, the QTF score seems to be of limited use for WAD claims management.

Keywords Delta-v, event data recorder, EDR, whiplash associated disorders, WAD.

I. INTRODUCTION

Whiplash associated disorders (WAD) are a major burden in Switzerland, as elsewhere. More than 10,000 cases of WAD after a rear-end collision are reported every year to the Swiss insurance industry. The yearly direct costs arising from these cases amount to several hundred million Swiss Francs [1-2]. About 10% of these cases tend towards chronification [3], putting the affected persons at a high risk of long-term sick leave, i.e. a sick leave of more than 30 consecutive days [4].

In the literature, the change of velocity of a vehicle during an impact (delta-v) is regarded as a relevant parameter to assess the WAD risk. It is a metric that describes the crash severity of an impact. As it can be estimated through classical accident reconstruction approaches (without event data recorder data), it is well established and widely used in claims management in the insurance industry, as well as in court hearings. Although there is a debate as to whether other parameters, like the mean acceleration during an impact, might be better predictors for the WAD risk, currently delta-v remains the main crash severity parameter for assessing the WAD risk. Several studies have shown a correlation between delta-v levels and the risk of sustaining neck injury [5-6]. WAD symptoms were found to last longer with higher delta-v values [5]. Injury thresholds range from 8 to 15 km/h [7]. Niederer *et al*. stated that WAD symptoms cannot be explained by biomechanics when delta-v is lower than 10 km/h [8]. In Switzerland, this delta-v threshold for the onset of WAD is widely accepted today.

More recently, event data recorders (EDR) are available and used in larger vehicle fleets. These devices allow the impact to be recorded in terms of acceleration. As a result, not only delta-v but also impact time and mean acceleration during impact can be precisely determined from EDR. Such devices allow for the investigation of different hypotheses on the basis of actual crash data. Various studies, conducted mainly in Sweden, have

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researched the correlation between EDR data and medical consequences. The impact time was found to have an effect on injury risk, and the mean acceleration to be the main factor influencing the risk of neck injuries [9]. The AXA Winterthur Insurance Company in Switzerland launched an EDR (called Crash Recorder) in 2008. This allows complementing previous works by making use of the first large-scale EDR dataset available in Switzerland. While previous studies related to WAD were often limited to a specific vehicle type or make, a larger variety of vehicles is equipped with the Crash Recorder. Today, a fleet of over 40,000 vehicles is equipped with the Crash Recorder by AXA Winterthur.

Kullgren *et al*. showed that the injury risk in rear-end collisions increases with higher delta-v. The same is true for mean acceleration [5]. The impact time also appears to be important. Linder *et al.* stated that the injury risk for a given change of velocity is increased for shorter duration of the crash pulse [9]. Based on collision analysis, the delta-v of the struck car decreases with an increasing mass ratio of the struck vs. the striking car [10]. Moreover, the automotive industry has successfully developed whiplash protection systems [11], mostly implemented in the car seats. Older cars are not fitted with whiplash protection systems, however. Finally, Kullgren *et al.* pointed out that, in a review of 13 studies, females seem to have a higher relative whiplash injury risk than males [12].

To classify the severity of WAD, the Quebec Task Force (QTF) developed a specific scheme, the so-called QTF score [7]. The QTF score ranges from QTF0 to QTF4. Krafft *et al.* found a correlation between QTF scores and crash severity measured as delta-v and mean acceleration [13]. However, Krafft *et al.* found no significant correlation between different grades of WAD and crash severity in a study conducted few years before [14].

Krafft *et al.* and Kullgren *et al.* found correlations between crash severity, measured in terms of delta-v and mean acceleration, and the duration of symptoms [5][13]. Kullgren *et al.* reported average delta-v values of 8.8 km/h for uninjured females and 9.2 km/h for uninjured males. For injured occupants with symptoms lasting less than one month, they reported mean delta-v values of 11.3 km/h for females and 12.6 km/h for males. For occupants with symptoms lasting longer than one month, they reported values of 17.8 km/h [5]. Compared to males, female occupants were found to have a double risk of symptoms lasting longer than one month [12]. Linder *et al.* found that passengers are more likely to suffer neck pain symptoms than drivers [15]. On the other hand, Jonsson *et al.* found a double relative risk for drivers compared to front-seat passengers [16]. Another study by 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 [6]. Furthermore, increasing age of struck car occupants was associated with slower recovery [17].

The aim of this study was to analyse several outcome variables with regard to WAD claimed by struck car occupants in rear-end collisions. Specifically, the following hypotheses were addressed: the delta-v and the mean acceleration of the struck car have a positive effect on the occurrence of initial WAD symptoms, on the QTF score and on the sick leave duration. The impact time of the struck car is negatively associated with the occurrence of initial WAD symptoms, while the age of the struck car is positively associated with it. Furthermore, it was expected to find that females are more likely to suffer from initial WAD symptoms and also have a longer average sick leave duration than males. The increased mass ratio of the struck vs. the striking car was assumed to reduce the risk for the struck car occupants of having initial WAD symptoms. It was also expected to find a longer sick leave duration for occupants who suffered from previous complaints and a longer sick leave duration for occupants showing initial neurological symptoms. Further, it was expected that the QTF score is positively associated with the sick leave duration.

II. METHODS

Data and selection criteria

Crash Recorder, medical, insurance claims and insurance risks data were provided by AXA Winterthur Insurances, Switzerland. To identify the relevant cases, the following selection criteria were applied: only cars and light commercial vehicles were included; the collisions had to be rear-end collisions, as defined by the Swiss federal roads office (FEDRO) [18], therefore both vehicles had to be oriented in the same direction during the collision; crashes with reversing vehicles were excluded; maximal collision angles of 30 degrees were accepted; the car-to-car overlap was limited to a minimum of 10%; in collisions with more than two vehicles, the struck car had to experience a major rear impact followed by a minor front impact; only motor liability cases were analysed, which means that the client of AXA Winterthur was in the striking car of the analysed collision. The occupants of the struck car, in contrast, can be clients of any insurance company. Hence, the sample of struck car occupants is not influenced by the Crash Recorder sales strategy of AXA Winterthur. As a consequence, the sample of struck car occupants is random and thus represents the whole car and light commercial vehicle driving population of Switzerland in a good approximation. In this study, only the data of drivers and front-seat passengers were included; rear-seat occupants were excluded. Cases of established fraud were specifically analysed and excluded in terms of sick leave duration. All cases occurred between 2008 and 2014. The WAD group was defined as follows: cases where either initial neck pain *or* a QTF score greater than 0 was reported were regarded as WAD cases; cases in which occupants did not complain about WAD symptoms built the control group.

Accident Reconstruction

The AXA Crash Recorder is an autonomous event data recorder (EDR). The key feature of the device is a linear acceleration sensor, which is able to record acceleration data in three axes up to 50 g (g = acceleration of gravity, 1 g = 9.81 m/s^2). When an internal threshold level for an incident is exceeded, the Crash Recorder saves crash data with a measurement frequency of 1,000 Hz. The internal threshold level is set at approximately 1 g, which ensures that minor impacts are also recorded. The measured acceleration data has a maximal error of 10%. Comparing to reference devices according to the SAE J211 technical standard (SAE International), the Crash Recorder differs between 3% and 5% in the acceleration signal [19]. The software Python(x,y) (Version 2.7.3.1) was used to analyse and display the Crash Recorder data. The data was filtered by the common Channel Frequency Class (CFC) 60 low-pass filter [20]. The impact time was defined as the duration of the EDR crash pulse, according to Linder *et al.* [9]. Delta-v, mean acceleration and the impact time were then calculated for every case. In most cases, however, Crash Recorder data was only available for the striking car, while in all cases the persons to analyse regarding WAD-claims sat in the struck car. Consequently, the delta-v of the struck vehicle was determined by standard means of accident reconstruction which are based on the conservation of energy and momentum. In this study, methods as described by Burg *et al.* were applied [10]. The methodology was evaluated by using the internal crash test database of AXA. 185 crash tests were selected by applying the same selection criteria as above. The selected crash tests represent the braking conditions of real-world collisions, which are statistically known from the AXA Crash Recorder database where additional data is available for striking and struck cars. For the struck vehicles, the calculated delta-v was compared to measured delta-v values for all crashes. The mean error over all crash tests was 5.9 %, the corresponding standard deviation was +/- 5.3%. The errors were also analysed for different braking conditions of the struck car. For unbraked struck cars, the mean error was 5.8% (+/- 5.1%, n = 174). For braked struck cars, the mean error was 8.6% (+/- 6.6 %, n = 11). Furthermore, no bias was detected and the distribution of the error followed a normal distribution. However, in the real-world collisions, the braking condition of the struck car was not known in many cases. In these cases, the braking condition was assessed based on expert opinions and statistical information from the AXA Crash Recorder database. The mean acceleration for the struck car was then calculated as delta-v of the struck car, divided by the impact time. Thus, all WAD analyses in this study refer to the calculated crash severity of the struck car.

Medical outcome

Except for sick leave, all information about the occupants and the medical conditions were extracted from the "documentary file for the first consultation after a cranio-cervical acceleration trauma" [21]. This medical form was introduced in Switzerland in 2003, by the Swiss Insurance Association, with the goal of standardising medical reporting for WAD cases. Only medical doctors are allowed to fill in this questionnaire. In this standardised form, based on the first physical examination after the collision, the doctor reports the medical findings of the WAD patient and provides also the QTF score according to the QTF definitions [21]. In a standard claims management process, the file should be available to the insurance company within one month after the collision. If no such file was available, as much information as possible was extracted from other medical reports written by medical doctors. If no medical report was available, only initial complaints, such as neck pain or headache, reported by the struck car occupant were considered. Sick leave was not directly extracted from the "documentary file for the first consultation after a cranio-cervical acceleration trauma", but from other medical documents that confirmed the sick leave duration. In this study, sick leave duration is defined as the time span in which a person is absent from paid work due to medical problems. Furthermore, sick leave had to be caused by WAD symptoms. According to this, it was assumed that the WAD symptoms were present at least until the sick leave duration ended. Hence the sick leave duration can be compared to duration of symptoms from other studies. Sick leave was split into two durations: 100% sick leave duration and total sick leave duration. 100% sick leave duration describes for the length of time during which the occupant could not work at all. Total sick leave duration was composed out of the 100% sick leave duration plus the sick leave duration when the occupant could work, but could not fulfil the total workload. Struck car occupants who had a workload of 0% before the collision were excluded in terms of sick leave. The quality of the medical forms was checked. Medical reports were accepted in this study and regarded as valid as long as no other information available in the insurance file disproved this validity. Every report in this study was verified in this sense.

Statistics

The data was analysed by means of the statistics software R Studio (Version 0.98.1102) and Microsoft Excel (2010). Assumptions for parametric and non-parametric statistical tests were verified. T-test (t), Mann-Whitney (W) and Chi-squared (X^2) tests were used to compare groups with a 5% significance level. Thereby, 95% confidence intervals (CI) and standard errors (SE) were calculated for the estimated parameters. Mean (M), standard deviation (SD) and median (Mdn) were calculated. Risk, such as the WAD risk and the risk of sick leave, was calculated as the proportion of number of suffering from WAD over the total number of occupants in the corresponding delta-v group. This procedure was adapted from Kullgren *et al.* [5] and therefore intervals with less than three observations were excluded and no mathematical function was used, simply a scatterplot with interpolated lines in Microsoft Excel [5].

III. RESULTS

Description of the sample

In this study, a total of 168 real-world rear-end collisions were analysed. From 62 of these collisions, a total of 66 persons reported initial WAD symptoms, which formed the WAD group. In 106 collisions, no WAD symptoms were reported. These cases formed the control group.

The mean age of the striking cars was 8.3 years (SD=5.7, N=168) and the mean of the struck cars was 7.1 years (SD=5.2, N=162). Mean masses were 1231.7 kg (SD=244.5, N=168) for the striking cars and 1430.4 kg (SD=313.1, N=168) for the struck cars.

Table I summarises the vehicle makes of the sample. Seven light commercial vehicles are among the struck vehicles, while all other vehicles were passenger cars.

On average, the striking cars experienced a delta-v of 12.8 km/h (SD=6.7, N=160) and a mean acceleration of 3.08 g (SD=1.97, N=160), whereas the struck cars experienced smaller delta-v of 9.8 km/h (SD=5.3, N=168) and smaller mean acceleration of 2.34 g (SD=1.53, N=168). On average, the age of the struck car was greater in WAD group (M=7.83 years, CI=1.41, SE=0.71, N=63) compared to control group (M=6.7 years, CI=0.96, SE=0.49, N=99). However, this difference was not statistically significant: t(118.15) = 1.32, p (one-tailed) = 0.095. On average, the mass ratio of the struck vs. the striking car was greater in the control group (M=1.24, CI=0.07, SE=0.03, N=106) than in the WAD group (M=1.15, CI=0.08, SE=0.04, N=65). However, this difference was not statistically significant: t(145.98) = -1.53, p (one-tailed) = 0.065.

The mean age of the struck car occupants of the WAD group was 35.1 years (SD=13.6, N=66), of the control group 37.9 years (SD=13.7, N=44) and the mean age of both groups together was 36.2 years (SD=13.6, N=110). Sick leave was observed in 34 occupants of the WAD group. Nineteen occupants resumed work without any absence, four were unknown and nine were excluded because they were unemployed at the time of the collision.

TABLE I
DISTRIBUTION OF MAKES: ABSOLUTE AND RELATIVE NUMBERS OF STRIKING AND STRUCK CARS

Striking car			**Struck car**		
Make	**Number of cars**		**Make**	**Number of cars**	
VW	27	16%	VW	31	18%
Peugeot	15	9%	Audi	13	8%
Ford	12	7%	Opel	13	8%
Opel	12	7%	Ford	13	8%
Fiat	11	7%	BMW	10	6%
Renault	11	7%	Toyota	11	7%
Audi	10	6%	Mercedes-Benz	10	6%
Mazda	7	4%	Renault	9	5%
Seat	8	5%	Citroën	7	4%
Citroën	6	4%	Mazda	7	4%
Volvo	5	3%	Volvo	6	4%
Kia	4	2%	Skoda	5	3%
Nissan	4	2%	Nissan	4	2%
Subaru	4	2%	Peugeot	4	2%
Toyota	4	2%	Mitsubishi	3	2%
Honda	3	2%	Saab	3	2%
Hyundai	3	2%	Seat	3	2%
Mitsubishi	3	2%			
Suzuki	3	2%			
Other	16	10%	Other	16	10%
Total	*168*	*100%*	*Total*	*168*	*100%*

Table II shows details of the sample regarding gender. A statistically significant relation between gender and whether occupants suffered from initial WAD symptoms or not was found ($X^2(1) = 8.52$, $p = 0.0035$*). Calculating the odds ratio shows that the odds of suffering from initial WAD symptoms were 2.87 times higher for females than for males. Female occupants suffered statistically significantly longer from 100% sick leave duration (Mdn=0 days, M=14.4, SE=5.2, N=52) than male occupants (Mdn=0 days, M=6.0, SE=5.5, N=61), W = 1924, p (one-tailed) = 0.0062*. On average, female struck car occupants also suffered longer from total sick leave duration (M=25.0 days, CI=16.3, SE=8.1, N=56) compared to males (M=8.6 days, CI=6.9, SE=3.4, N=63). This difference was statistically significant: $t(67.65) = 1.86$, $p = 0.034$*.

TABLE II
CONTINGENCY TABLE REPRESENTING ABSOLUTE NUMBERS OF FEMALES AND MALES SEPARATED IN WAD AND CONTROL GROUP

	Female	Male	Total	*unknown*
WAD	40	26	66	*0*
Control	22	41	63	*43*
Total	62	67	129	*43*

Table III shows the distribution of the QTF scores within the WAD group, separated by gender. In the study sample, all affected persons had a QTF score lower than QTF3. The two variables are statistically independent ($X^2(2) = 2.37$, $p = 0.3058$).

In Table IV the initial symptoms of the struck car occupants of the WAD group are listed. Unsurprisingly, headache and neck pain were the most commonly reported symptoms. Tenderness on palpation was reported in 55% of all cases.

TABLE III
CONTINGENCY TABLE REPRESENTING ABSOLUTE NUMBERS OF QTF SCORES WITHIN THE WAD GROUP, SEPARATED BY GENDER

	QTF0	QTF1	QTF2	QTF3	QTF4	*unknown*
Female	0	9	13	0	0	*18*
Male	2	9	10	0	0	*5*
Total	2	18	23	0	0	*23*

TABLE IV
ABSOLUTE AND RELATIVE NUMBERS OF INITIAL WAD SYMPTOMS (WAD GROUP, N=66)

Initial symptoms	**Yes**		**No**		**unknown**	
Headache	38	58%	16	24%	12	18%
Neck pain	58	88%	2	3%	6	9%
Dizziness	21	32%	27	41%	18	27%
Nausea	11	17%	36	55%	19	29%
Vomiting	1	2%	46	70%	19	29%
Hearing defect	3	5%	43	65%	20	30%
Vision defect	2	3%	45	68%	19	29%
Tenderness on palpation	36	55%	10	15%	20	30%
Neurological symptoms	7	11%	40	61%	19	29%

For occupants who suffered from neurological initial symptoms after the collision, a longer 100% sick leave duration was found (Mdn=129, M=97.2, SE=35.0, N=5) than for occupants who had no initial neurological symptoms (Mdn=8, M=18.3, SE=5.5, N=31). This difference was statistically significant: W = 23.5, p (one-tailed) = 0.0065*. The same was true for total sick leave duration. For occupants who suffered from neurological initial symptoms, a longer total sick leave duration was found (Mdn=186.5, M=152, SE=48.8, N=4) than for occupants who had no initial neurological symptoms (Mdn=11, M=36.4, SE=9.6, N=31). This difference was statistically significant as well: W = 16.5, p (one-tailed) = 0.0091*.

Table V shows detailed previous complaints of the WAD group before the collision occurred. Due to small numbers, all previous complaints were treated as one factor in the following statistical calculations. Occupants with previous complaints suffered longer from 100% sick leave duration (Mdn=13 days, M=48, SE=20.3, N=9) than occupants without previous complaints (Mdn=7.5 days, M=20.6, SE=7.7, N=20), but this difference was statistically not significant: W = 57.5, p (one-tailed) = 0.063. Similar results were found with total sick leave duration: occupants with previous complaints suffered longer from total sick leave duration (Mdn=20, M=68.9, SE=28.9, N=8) than occupants without previous complaints (Mdn=15.5, M=45.0, SE=13.6, N=20). This difference was not statistically significant either: W = 63.5, p (one-tailed) = 0.20.

TABLE V
ABSOLUTE AND RELATIVE NUMBERS OF PREVIOUS COMPLAINTS. OCCUPANTS MAY SHOW MULTIPLE PREVIOUS COMPLAINTS

Previous complaints	**Yes**		**No**		**unknown**	
Head	6	9%	32	48%	28	42%
Neck	6	9%	32	48%	28	42%
Back	3	5%	34	52%	29	44%
Mental	2	3%	35	53%	29	44%
Pectoral girdle	2	3%	35	53%	29	44%
Total	*13*	*20%*	*25*	*38%*	*28*	*42%*

Initial WAD Symptoms

Figure 1 shows the absolute numbers of struck car occupants sorted by increasing delta-v groups and by WAD versus control group. Figure 2 illustrates the risk of suffering from WAD initial symptoms in relation to delta-v of the struck car. On average, occupants who suffered from WAD initial symptoms experienced greater delta-v (M=11.1 km/h, CI=1.4, SE=0.7, N=66) than non-injured occupants (M=8.9 km/h, CI=0.9, SE=0.5, N=106). This difference was statistically significant: t(117.63) = 2.47, p (one-tailed) = 0.0074*. Corresponding box- and bar-plots can be found in Fig. 3.

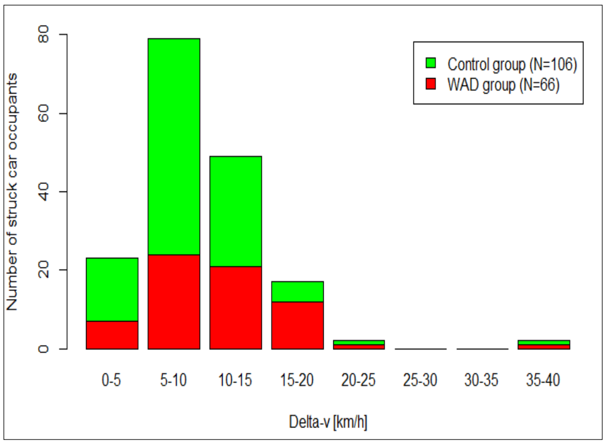

Fig. 1. Numbers of occupants suffering from initial WAD symptoms and uninjured occupants in intervals of delta-v.

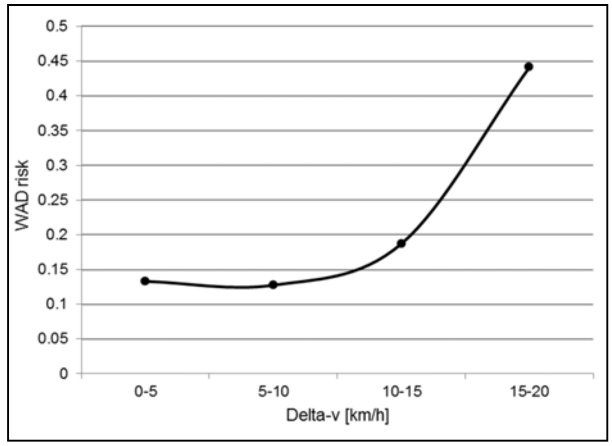

Fig. 2. Risk curve for initial WAD symptoms in intervals of delta-v (N=168).

On average, occupants who suffered from initial WAD symptoms experienced greater mean acceleration (M=2.87 g, CI=0.44, SE=0.22, N=66) than non-injured occupants (M=2.02 g, CI=0.24, SE=0.12, N=106). This difference was statistically significant: t(103.2) = 3.38, p (one-tailed) = 0.00051*. Corresponding box- and bar-plots can be found in Fig. 4.

Triggered by the findings of the descriptive analysis, the influence of impact time was tested. Occupants who suffered from WAD initial symptoms experienced statistically significant shorter impact times (Mdn=114 ms, M=113.1, SE=2.4, N=66) than non-injured occupants (Mdn=131.5 ms, M=133.8, SE=3.0, N=106): W = 2138.5, p (one-tailed) < 0.0001*. Four cases of the control group had impact times of more than 200 ms. While this is uncommon in rear-end bumper-to-bumper collisions, it can happen when the striking car under-rides the struck car or in small overlap collisions.

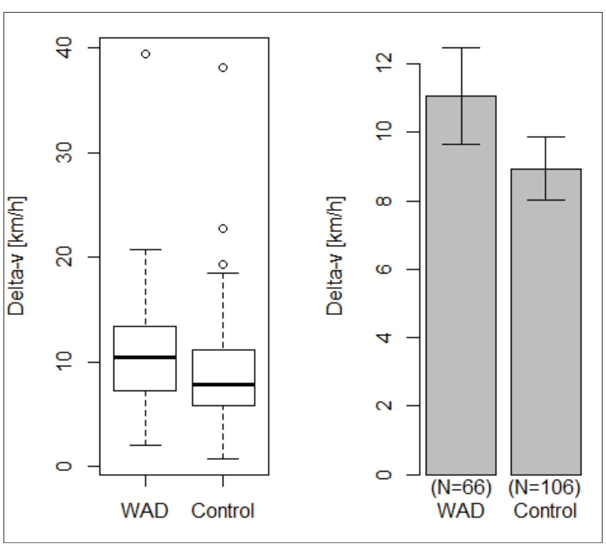

Fig. 3. Delta-v of struck car compared between WAD and control group. The error bars denote the 95% confidence intervals.

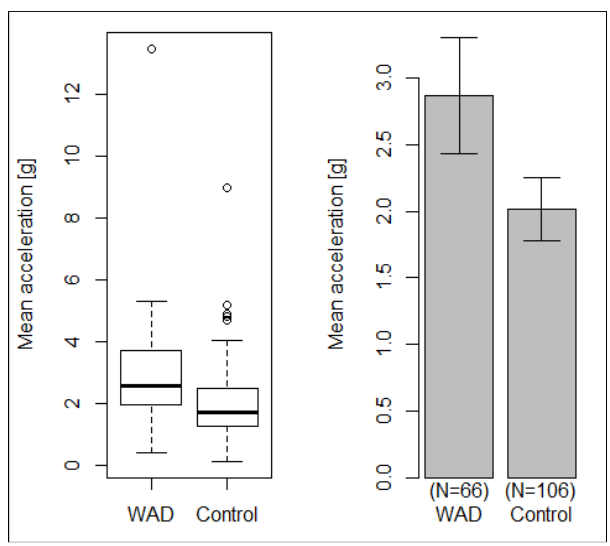

Fig. 4. Mean acceleration of struck car compared between WAD and control group. The error bars denote the 95% confidence intervals.

QTF Score

No positive relationship was found between delta-v and QTF scores within the WAD group (N=43, unknown=23): QTF0 (M=25.4 km/h, SD=19.8, SE=14.0, N=2), QTF1 (M=10.5 km/h, SD=5.0, SE=1.2, N=18), QTF2 (M=10.1 km/h, SD=5.2, SE=1.1, N=23). Also, no positive relationship was found between mean acceleration and QTF scores within the WAD group (N=43, unknown=23): QTF0 (M=8.59 g, SD=6.89, SE=4.9, N=2), QTF1 (M=2.49 g, SD=1.15, SE=0.3, N=18), QTF2 (M=2.53 g, SD=1.26, SE=0.3, N=23). Figures 5 and 6 visualise these results. The difference in mean acceleration between QTF1 and QTF2 is statistically not significant: t(37.968) = -0.121, p (one-tailed) = 0.4519.

No positive relationship could be found between QTF scores and 100% sick leave duration within the WAD group (N=43, unknown=23): QTF0 (M=50.0, SD=na N=1), QTF1 (M=30.7, SD=42.1, SE=11.7, N=13), QTF2 (M=25.1, SD=50.3, SE=11.5, N=19). Likewise, no relationship could be found between QTF scores and total sick leave duration within the WAD group (N=43, unknown=23): QTF0 (M=50.0, SD=na, N=1), QTF1 (M=51.3, SD=65.6, SE=18.2, N=13), QTF2 (M=53.7, SD=76.1, SE=17.5, N=19). Figures 7 and 8 show the corresponding box-plots. The difference in total sick leave between QTF1 and QTF2 is statistically not significant: t(28.281) = -0.0942, p (one-tailed) = 0.4682.

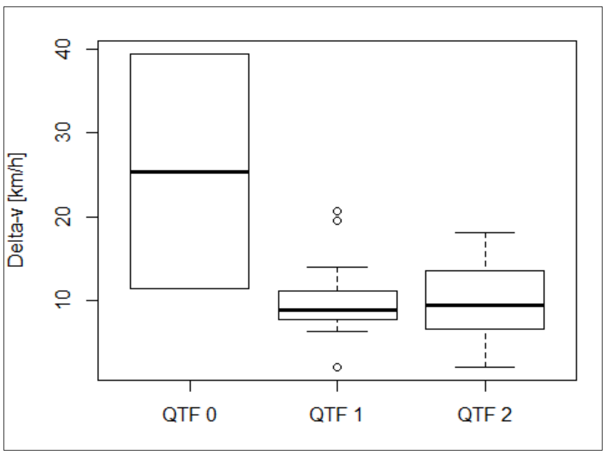

Fig. 5: Relationship between delta-v of struck car and QTF scores within the WAD group.

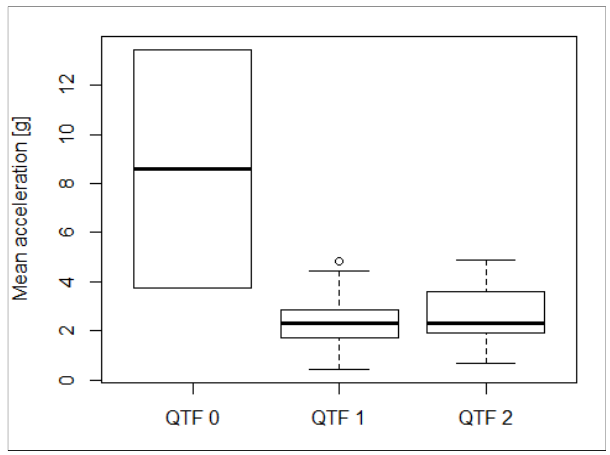

Fig. 6. Relationship between mean acceleration of struck car and QTF scores within the WAD group.

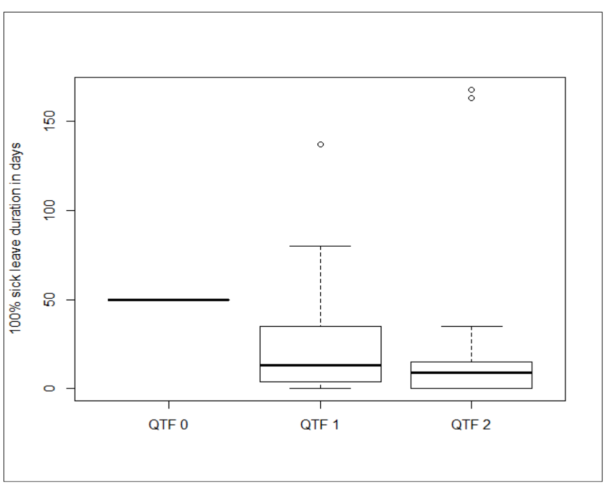

Fig. 7. Relationship between QTF scores and 100% sick leave duration within the WAD group.

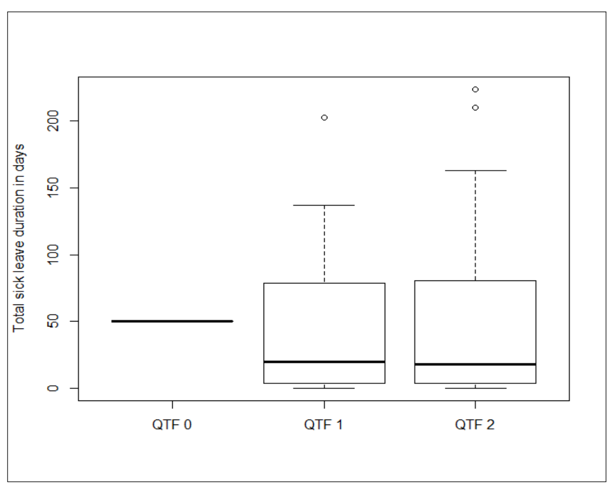

Fig. 8. Relationship between QTF scores and total sick leave duration within the WAD group.

Sick leave

Figure 9 shows a positive relationship between delta-v and 100% sick leave duration. Displayed are the means of 100% sick leave duration in days grouped into 5 km/h delta-v groups for the whole sample. The corresponding means are: delta-v 0-5 km/h (M=1.8, SD=4.9, SE=1.0, N=22), delta-v 5-10 km/h (M=2.6, SD=10.6, SE=1.3, N=69), delta-v 10-15 km/h (M=9.2, SD=31.3, SE=4.6, N=47), delta-v 15-20 km/h (M=22.2, SD=44.2, SE=11.4, N=15) and delta-v >20 km/h (M=45.7, SD=79.1, SE=45.7, N=3). Figure 11 shows the same for the total sick leave duration. The means are: delta-v 0-5 km/h (M=2.5, SD=7.4, SE=1.6, N=22), delta-v 5-10 km/h (M=11.1, SD=40.8, SE=4.9, N=69), delta-v 10-15 km/h (M=10.3, SD=38.1, SE=5.6, N=46), delta-v 15-20 km/h (M=24.6, SD=44.4, SE=11.5, N=15) and delta-v >20 km/h (M=45.7, SD=97.1, N=3). Figures 10 and 12 show the corresponding risk curves for the WAD-groups. It has to be noted that in one case, although knowing that after a 100% sick leave a partial sick leave was prescribed by the medical doctor, it was not possible to obtain the exact total sick leave duration.

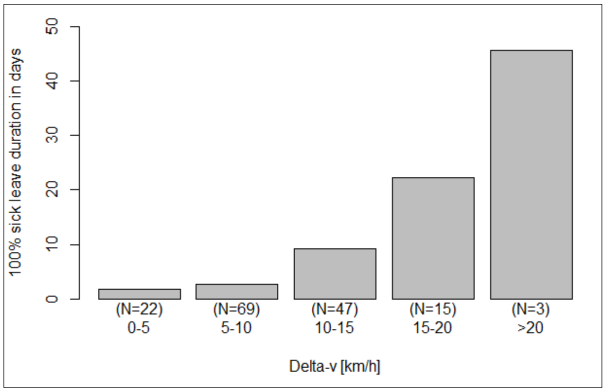

Fig. 9. Relationship between delta-v and 100% sick leave displayed as the mean of 100% sick leave duration in intervals of delta-v of the whole sample.

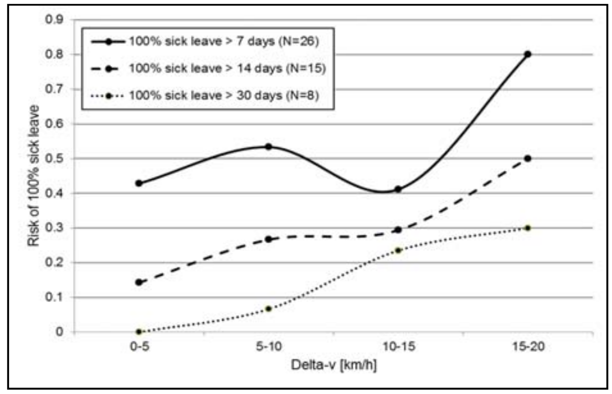

Fig. 10. Risk curves of the WAD group for different 100% sick leave time spans as a function of delta-v intervals (N=49).

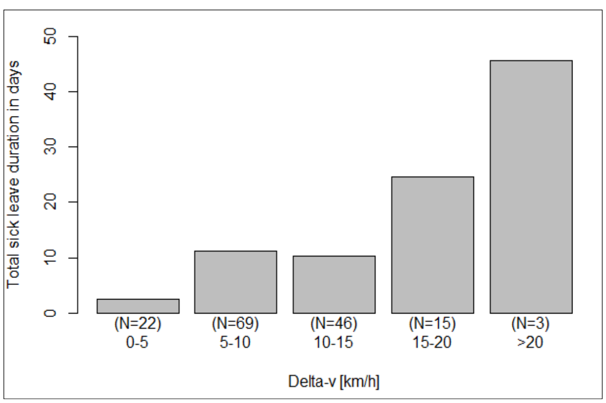

Fig. 11. Relationship between delta-v and total sick leave displayed as the mean of total sick leave duration in intervals of delta-v of the whole sample.

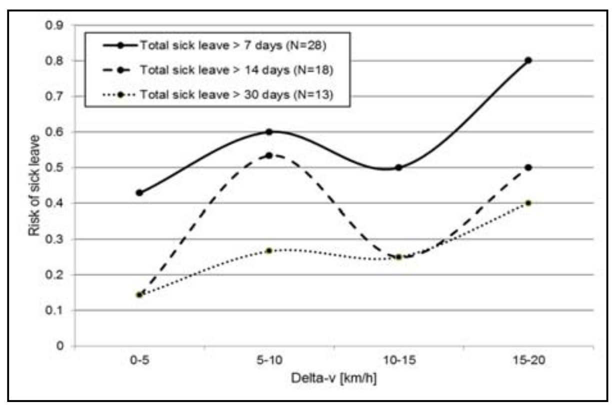

Fig. 12. Risk curves of the WAD group for different total sick leave time spans as a function of delta-v intervals (N=48).

IV. DISCUSSION

In this study, the first large-scale EDR dataset available in Switzerland was analysed regarding relevant WAD outcome variables. Crash pulse data of the striking car was used to reconstruct the crash severity of the struck vehicle. This approach resulted in relevant crash severity metrics for the struck car such as the delta-v with an estimated mean error of 5.9 % (SD: +/- 5.3%) compared to corresponding crash test data. The validity of this approach was assessed by comparing different variables such as the car type, the breaking condition of struck car and the delta-v range of the striking car. As anticipated, delta-v has an effect on the onset of initial WAD symptoms. Kullgren *et al.* stated that the WAD risk increases with higher delta-v values [5]. In this study, from delta-v values between approximately 9 and 12 km/h, the risk of complaining about initial WAD symptoms starts to increase strongly with the delta-v. According to Krafft *et al.* and Kullgren *et al.*, longer sick leave durations were expected for higher delta-v values [5][13]. This is true for 100% sick leave as well as total sick leave duration; 100% sick leave duration rises strongly for delta-v values higher than 10 km/h. This finding is in line with a threshold value as suggested by Niederer *et al.* [8]. 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. 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 delta-v 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, as highlighted by the findings of this sample. Thus, a biomechanical, rather than a purely technical, assessment of the event is mandatory.

Similarly to delta-v, mean acceleration can be seen as a risk factor for WAD [5]. However, in contrast to the delta-v, the 95% confidence intervals for mean acceleration did not overlap and the p-value was smaller. This indicates that the mean acceleration is a better predictor for WAD initial symptoms than the delta-v. According to Linder *et al*., mean acceleration has been found to be the main factor influencing the risk of AIS1 neck injuries [9]. Furthermore, Krafft *et al.* stated that the mean acceleration is a better predictor for duration of symptoms [22]. Though mean acceleration seems to be a better predictor, delta-v nonetheless remains important.

According to Linder *et al*., the injury risk for a given change of velocity increased with a shorter duration of the crash pulse [9]. The findings of this study support this. Consequently it can be hypothesized that under-riding 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 [11]. 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 [12]. 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 [12]. 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 [6]. 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.

Despite the fact that the number of occupants who suffered from neurological initial symptoms was small, the results were statistically significant. Suissa *et al.* already concluded that whiplash patients presenting with neurological signs and symptoms will have a longer recovery period [17]. The results of this study support this statement.

Krafft *et al.* found a correlation between QTF scores and delta-v [13]. However, in a different study conducted previously Krafft *et al.* found no significant correlation between different grades of WAD and crash severity [14]. In this study no relationship was found between delta-v 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 [6][23].

V. CONCLUSION

The large-scale introduction of EDRs in Switzerland allows detailed analysis of WAD claims. Using calculated EDR data can improve the quality of the corresponding accident reconstruction. This study confirms previous research in the field by highlighting the link between impact severity and WAD risk of struck car occupants in rear-end collisions. Both the short-term occurrence of initial WAD symptoms and the long-term sick leave consequences are positively associated with the crash severity measures delta-v and mean acceleration. Furthermore, evidence was found that the mean acceleration describes the WAD risk better than the delta-v. However, the data also revealed that starting from a delta-v of 10 km/h, a WAD claim is more frequent. Other factors, like the mass ratio of the involved vehicles, the age of the struck vehicle, the impact time, gender and previous medical complaints of the occupants and the presence of neurological initial symptoms, also play an important role in the WAD risk assessment. However, the QTF score seems to be of limited use for WAD claims management.

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