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Does a tow-bar increase the risk of neck injury in rear-end collisions?

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ABSTRACT

Introduction: Does a tow-bar increase the risk of neck injury in the struck car in a rear-end collision? The rear part of a modern car has collision zones that are rendered nonoperational when the car is equipped with a tow-bar. Past crash tests have shown that a car's acceleration was higher in a car equipped with a tow-bar and also that a dummy placed in a car with a tow-bar had higher peak acceleration in the lower neck area. *Method:* This study aimed to investigate the association between the risk of neck injury in drivers and passengers, and the presence of a registered tow-bar on the struck car in a rear-end collision. We performed a merger of police reports, the National Hospital Discharge Registry, and the National Registry of Motor Vehicles in Denmark. We identified 9,370 drivers and passengers of whom 1,519 were diagnosed with neck injury within the first year after the collision. We found a statistically insignificant 5% decrease in the risk of neck injury in the occupants of the struck car when a tow-bar was fitted compared to when it was not fitted (hazard ratio = 0.95; 95% confidence level = 0.85–1.05; p = 0.32). The result was controlled for gender, age, and the seat of the occupant. Several other collision and car characteristics and demographic information on the drivers and passengers were evaluated as confounders but were not statistically significant. *Conclusions:* The present study may serve as valuable input for a meta-analysis on the effect of a tow-bar because negative results are necessary in order to avoid publication bias.

1. Introduction

Does a tow-bar increase the risk of neck injury in a rear-end collision? The question has become relevant because the rear part of modern vehicles is designed with a collision zone with the purpose of capturing some of the force in rear-end collisions, thereby reducing the struck car's acceleration. A collision zone will also reduce the acceleration of occupants in the struck car, thus decreasing the likelihood of neck injury. When a car has a tow-bar, this mounted construct will absorb the power of the struck car, which will never reach the collision zone, and therefore the acceleration will be larger in the cabin, implying a higher risk of neck injury including whiplash. Some tow-bars can be partly removed from the back of a car when not in use. In this situation, the hook itself is removed, but the fastener for the car is still present. Depending on the make of car, this fastening can be located within, below, or in front of the collision zone, thus inducing noise in the effect of the tow-bar.

If the tow-bar increases the risk of neck injury then it could also be associated with a higher rate of fatality. The number of deaths due to rear-end collisions in Europe was 2,000 in 2010 (The European Commission, 2012) of which some potentially could have been avoided had tow-bars been mounted in a safer way.

1.1. Previous studies on the risk due to a tow-bar

The key evidence on the effect of a tow-bar can be found in a paper by Krafft, Kullgren, Tingvall, Boström, and Fredriksson (2000). Their study addressed whether a tow-bar could change the stiffness of the car and subsequently the crash pulse. The study comprised both laboratory crash tests and data on real-life rear impacts with and without a tow-bar reported as claims to an insurance company.

The laboratory analysis of tow-bar effects was done through crash tests involving two Volvo 240s with and without a tow-bar being hit by a Volvo 240 with an impact speed of 25 km/h. The results showed that the car acceleration was higher in the tow-bar equipped car with a peak of 9.6 g compared with 8.0 g in the car without a tow-bar. The mean acceleration was similar, 3.0 g, in the two cars. The car equipped with a tow-bar recorded a higher change in velocity of 15.1 km/h compared with 14.1 km/h in the car without a tow-bar. A dummy placed in the car with a tow-bar had a 33% higher peak acceleration of 8.9 g in the lower neck region, whereas a dummy in the car without a tow-bar experienced a peak acceleration of only 6.7 g.

Next, all real-life rear-end collisions between 1990 and 1993 reported to the insurance company (Folksam, Sweden) involving three car types, Volvo 240, Volvo 700, and Saab 900, were selected (struck

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cars). A total of 75 car crashes where at least one occupant had been diagnosed with long-term neck injury as a consequence were identified. Long-term consequences were classified by a medical specialist in the insurance company as a result of a preliminary assessment after one year or after three to five years. The 75 car crashes representing long-term consequences were compared with a control group of 426 rear-end car crashes representing the general distribution of tow-bars on struck cars of the three car types. Information on tow-bars was obtained from the National Swedish Vehicle Registry. Krafft and colleagues found that there was 22% greater risk of long-term consequences in a car with a tow-bar than in one without. This result was found to be statistically significant ($p = .001$). The authors studied the short-term consequences of minor neck injuries as well, but a comparison of 233 car crashes involving at least one occupant reporting a minor neck injury and the abovementioned control group gave a statistically insignificant result.

Another study by Krafft mentioned the tow-bar as well (Krafft, 2002). However, this paper used the same data as in Krafft et al. (2000) on real-life rear impacts reported as claims to an insurance company.

A third study by Linder and colleagues also provided data on the effects of a tow-bar but touched only peripherally upon the risk of a tow-bar in rear-end collisions (Linder, Olsen, Eriksson, Svensson, & Carlsson, 2012). Their data on rear-end crashes and injury severity originated from claims to an insurance company. Only new cars less than three years old of the types Saab 9-3 and Saab 9-5 and the period from 1993 to 2007 were included. Information on tow-bar status was obtained from questionnaires sent out by the authors to the owners of the cars in cases of high impact severity. Short-term neck injury was defined as lasting for less than one week, whereas medium- to long-term injury was defined as lasting for more than one week. An analysis of 699 drivers did not show a statistically significant effect for the presence of a tow-bar on the distribution of no injuries, short-term injuries, or medium- to long-term injuries (Linder et al., 2012; from the data of Table A-II: $p = 0.30$). The authors mentioned a very slight tendency for females to have more long-term injuries with a tow-bar than without a tow-bar, but this was not statistically significant ($p = 0.56$).

Carroll et al. (2008) and Holm et al. (2008) briefly addressed the tow-bar in their best evidence synthesis and concluded that a tow-bar is a risk factor for neck injury with reference to Krafft and colleagues. A study by Hynes and Dickey (2008) concluded that vehicles with tow-bars are stiffer and have shorter times to peak acceleration, and it referred to Krafft et al. (2000). Worsfold (2014) cited Carroll et al. (who again cited Krafft et al.). Finally, the recent study by Nishimura, Simms, and Wood (2015) ended up asking for more evidence on the effect of the tow-bar on vehicle stiffness.

The idea of this study originates from several requests to the last author from lawyers who subsequently used the Swedish results as an argument for higher compensation in cases of whiplash injury because of the presence of a tow-bar.

New cars have much better collision zones than the Volvo 240. But a tow-bar mounted on a new car will still destroy the beneficial effect of the collision zones, thus increasing the risk of neck injury in the cabin. Our hypothesis is that the risk of neck injury for the driver and passengers in the struck car in a rear-end collision is greater when the struck car is fitted with a tow-bar.

1.2. Study aim

This study aimed to investigate the association between the risk of neck injury in car occupants and the presence of a registered tow-bar on the struck car in a rear-end collision.

2. Materials and methods

We conducted a registry-based study nested within the general population of Denmark (approximately 5.1 million inhabitants). We included all drivers and passengers in the struck cars of all models in rear-end collisions registered by police in the 10-year period from 2003 to 2012.

2.1. Registry data in Denmark

In Denmark, every individual has a unique civil registration number, given to all Danes at birth. This 10-digit number is used in most administrative registers, permitting the linkage of individual records – for example, hospital records – with records of police-recorded car crashes. Here, we further utilized the fact that the registration plate of a car involved in a rear-end collision could be used to link the identities of persons in the cars with technical information on the presence of a tow-bar on the struck car. We also obtained information from other public registries besides information on the tow-bar, with the aim of achieving an adjusted estimate of the risk of neck injury with and without a tow-bar.

2.2. Socio-economic information

The core of the Danish administrative registries is the Central Person Registry (CPR), which registers every demographic action (death, emigration/migration, and within-country moves) of all Danes holding a valid personal identifier, which at the same time is a social security number. From the CPR, we obtained information on sex and age (divided into categories: 0–17 years of age, 18–29, 30–39, 40–19, 50–59, 60–69, 70 and older). The police reports were linked to the National Hospital Discharge Registry, which comprises discharge dates and diagnoses from both hospitals and emergency wards. Furthermore, we linked to the socio-economic databases at Statistics Denmark, which provide the household income and the highest attained educational level per individual on a yearly basis (October 1 each year). We chose to divide the household income by quintiles by year and we used the most recent information from the year before the accident. Educational level was divided into nine categories (primary; upper secondary; vocational education; short-cycle higher education; vocational bachelors', bachelors', masters', and PhD programs; and a missing category).

2.3. Technical information on the struck car

Technical information on the struck car was obtained from police reports and the National Registry of Motor Vehicles. From the latter, we obtained information about the presence of tow-bars which were registered during the first registration of new cars, and in those cases where the owner installed and chose to register a tow-bar. The Registry of Motor Vehicles also included car weights (in five categories: 500–999, 1000–1499, 1500–1999, 2000 kg or more, missing weight), and the first registration year of the car (seven categories: 1966–1989, 1990–1994, 1995–1999, 2000–2004, 2005–2009, 2010–2015, missing). The police reports comprised information on accident type. The accident type was divided into three categories according to the Danish classification [hit directly from the back ("140"), hit from the back when turning right ("311"), or hit from the back when turning left ("321")]. We chose to include all three types of accident in our main analysis. It is unique to Denmark that the police report the accident type. Finally, the police reports could distinguish between the persons involved as either drivers or passengers. The calendar year of the accident was treated in two-year categories.

2.4. Definition of neck injury and whiplash

We obtained diagnoses from the Hospital Discharge Registry with information on whether the drivers and passengers had been in the emergency ward, admitted to hospital, or both. We identified all persons in the study population with a neck injury (International Classification of Disease version 2010: ICD-10) code DS13.4*. DS13.4* could be further subdivided, and code DS13.4C denoted whiplash syndrome in the Danish version of ICD-10. This definition of neck injury (and whiplash) was chosen following Joud et al. (2013). We used the term “neck injury” [or whiplash (syndrome)] throughout. The diagnosis was done by a medical doctor.

2.5. Count of cars with tow-bars

We supplemented the registry study with counts of cars in typical Danish parking lots. We wanted to estimate the frequency of tow-bars on Danish cars along with the frequency of cars with a tow-bar where the hook had been taken off.

2.6. Statistical model

Each study participant was followed-up until the occurrence of a neck injury, emigration, death, or study end (one year after the accident), whichever came first. For the multivariate analysis, we applied the Cox proportional hazard regression model, with the time since the accident as the underlying continuous time scale (Klein & Moeschberger, 1997).

Missing values were multiply imputed using chained equations, basing predictions of missing values on observations of variables with no missing values (Harrell, 2001).

The outcome measure of Cox regression is the hazard rate ratio. The hazard rate ratio can be interpreted as the incidence rate ratio, which we utilized throughout this paper. The data were analyzed in STATA 14 (StataCorp, 2015).

2.7. Assumptions of the Cox model

The Cox Proportional Hazards model rests on two assumptions: first, the assumption of so-called proportional hazards (PH), which was checked by diagnostic plots for each variable in the model (Klein & Moeschberger, 1997), and second, the assumption of so-called non-informative censoring should be met. We conditioned our analysis on participants being alive just after the collision and assumed that the occurrence of deaths and emigrations in the following year did not contribute information on having a diagnosis of neck injury.

2.8. Adjustment for clustering of persons in cars

Some of the passengers and drivers analyzed here were seated in the same cars and were not independent samples of injured people. To correct for this clustering, we re-estimated the standard errors of the regression coefficients with the Huber-White sandwich estimator. This procedure typically increases the standard errors of the hazard rate estimates because we do not have the same volume of information when some of the persons were in the same cars.

2.9. Power calculation

We supplemented the Cox regression analysis with computations of statistical power and type 2 error for detecting an array of effect sizes (20%, 15%, 10%, 7% and 5%).

3. Results

We found 13,201 rear-end collisions in police reports for the period from 2003 to 2012. In the struck cars (only private cars and taxis) of all models, we detected 10,533 occupants (91% drivers). Of these, 39 were involved in two collisions, of which we only included the first. Two hundred and six did not have a social security number and were probably foreigners; furthermore 46 were in the police reports but not in the CPR, which could be due to errors – all had to be excluded. Then we also excluded those occupants who had been hit by a “light” transport type such as a bike, scooter, moped, motorcycle, or unknown road user type (764 occupants). Three drivers who were not present when the police arrived and two born before 1914 were excluded. Finally, we chose to exclude 103 occupants who were registered as emigrants (in the CPR) on the date of accident because being registered as emigrants can complicate follow-up in other administrative registries. Summing up, 9370 people could be followed-up from the day of their accident. Of those, 1,519 were registered as having neck injuries occurring within the first year after the collision (accumulated risk of 16.2%). A total of 60 died (34 died on the day after neck injury diagnosis), while 57 emigrated within the first year after the collision.

We found no association between the incidence rate of neck injury in occupants and the presence of a registered tow-bar on the struck car in a rear-end collision. The rate of neck injury within the first year after the collision was estimated to be 5% lower with a registered tow-bar than without but was statistically insignificant at the 5% level ($p = 0.32$).

Based on the registry data in this study, we estimated the frequency of cars with a tow-bar as 60% (4,521 of 7,492; 95% CI: 59–61%), when disregarding cars with unknown tow-bar status (901 of 8393 identified registration plates). A count of 1,280 cars in typical Danish parking lots gave an estimate of 48% (95% CI: 45–51%) with a tow-bar - of which 90% (95% CI: 88–92%) actually carried the hook while 10% (95% CI: 8–13%) had had the hook taken off while the fastening was still intact.

Table 1 shows the results of univariate descriptive analyses without mutual adjustment for other risk factors to the left. Mutual adjustment for all variables is presented to the right of Table 1. Table 1 provides incidence rates of neck injury within the first year after the accident in drivers and passengers exposed to a rear-end collision to the left; we found an incidence rate of 194 registered neck injuries per 1,000 person-years. Overall, the standard errors due to clustering of occupants in the same cars were of the same size when adjusting for clustering and without. We chose to present the unadjusted standard errors to keep things simple.

From the descriptive analyses to the left of Table 1, we can also see that females had a much higher rate of neck injury than males. A passenger seat was associated with a higher injury rate than the driver's seat. The age pattern was characterized by high rates among young people aged 15 to 29 years with rates decreasing thereafter.

Household income was subdivided into categories by quintiles, and the incidence rate was lower for the occupants below the first quintile and lower in the richest category above the fourth quintile.

The highest attained educational level was associated with a lower risk of neck injury. There was a decreasing trend in rates from “bachelors' programs” to “PhD programs.” Otherwise, the rates were similar except for a marginally statistically significant drop for “vocational bachelors' programs.” The fact that the highest rate was obtained for “qualifying education” was a result of the scarcity of data.

The study included collisions where the car was hit in the back when turning either left or right along with cars hit directly from the back. As can be seen in Table 1, the risk of neck injury was lower when hit while turning right. Being hit while turning left, which presumably happens on rural roads with higher speeds, had similar rates to rear-end collisions directly from the back.

Next, there was, roughly speaking, a negative trend in incidence rates (with several deviations) regarding calendar time without any mutual adjustment for all variables.

Now, we focus on the struck car. The weight of the car showed a clearly decreasing pattern in the sense that sitting in a non-heavy car was associated with higher risk, whereas a heavy car offered the most protection. When it came to the first registration year of the struck car, the newest cars were related to the lowest neck injury rate. There was a clear-cut negative trend from the 1990–1994 category to 2010–2015.

All variables from Table 1 were entered into the Cox regression model and the result of this analysis is shown to the right of Table 1. Here, we obtained an estimated 7% reduction in the neck injury rate

Table 1
To the left numbers, person-years and neck injury rates by variables mentioned in the literature or else considered important. To the right hazard ratios from the Cox regression model including all the variables of Table 1. Missing values were multiply imputed.
Public registry data from Denmark 2003–2012

	N	N	p-years in 1000s	IR per 1000	Hazard ratio	SE[a]	95% CI		P-value	Variable significance[b]
	Persons	Events								
All	9370	1519	7.810	194.5						
Tow-bar on struck car										
Yes	5019	827	4.168	198.4	0.925	0.057	0.827	1.034	0.168	p = 0.168
No	3244	575	2.652	216.8	1.000					
Unknown	1112	117	0.990	118.2						
Sex										
Male	5612	713	4.872	146.4	1.000					p < 0.0001
Female	3763	806	2.938	274.3	1.604	0.055	1.439	1.787	0.000	
Age										
0–17	209	30	0.173	173.2	0.523	0.207	0.349	0.785	0.002	p < 0.0001
18–29	2302	445	1.844	241.4	1.029	0.075	0.889	1.191	0.699	
30–39	2313	430	1.880	228.7	1.000					
40–49	1975	333	1.641	202.9	0.906	0.074	0.784	1.046	0.178	
50–59	1426	183	1.242	147.3	0.686	0.089	0.576	0.817	0.000	
60–69	787	78	0.702	111.1	0.549	0.124	0.431	0.700	0.000	
70 +	363	20	0.328	61.0	0.287	0.231	0.182	0.451	0.000	
Seat in struck car										
Driver	8550	1325	7.189	184.3	1.000					p < 0.0001
Passenger	825	194	0.621	312.3	1.497	0.085	1.267	1.770	0.000	
Household income										
<1st quintile	1799	297	1.471	201.9	0.847	0.088	0.712	1.007	0.059	p = 0.120
1st–2nd quintiles	1794	336	1.455	230.9	0.986	0.079	0.844	1.151	0.858	
2nd–3rd	1793	335	1.456	230.2	1.000					
3rd–4th	1795	310	1.482	209.2	0.974	0.081	0.831	1.141	0.740	
>4th	1790	236	1.554	151.9	0.848	0.092	0.709	1.015	0.072	
Unknown	404	5	0.393	12.7						
Highest level of education										
Primary education	2813	496	2.300	215.7	1.018	0.138	0.777	1.334	0.899	p = 0.539
Upper secondary education	689	128	0.556	230.3	0.967	0.158	0.710	1.317	0.831	
Vocational education and training (VET)	3008	475	2.532	187.6	0.942	0.134	0.724	1.226	0.657	
Qualifying educational programme	5	2	0.003	665.3	2.448	0.726	0.590	10.155	0.218	
Short cycle higher education	361	63	0.296	213.0	1.000					
Vocational bachelors programmes	1210	228	0.978	233.1	1.092	0.143	0.826	1.445	0.535	
Bachelors programmes	101	17	0.083	205.6	0.918	0.274	0.536	1.573	0.757	
Masters programmes	457	59	0.397	148.6	0.863	0.183	0.602	1.236	0.421	
PhD programmes	25	2	0.023	86.9	0.615	0.709	0.153	2.465	0.492	
Missing	706	49	0.643	76.2						
Accident type										
Hit from the back when driving straight ahead	7444	1217	6.192	196.6	1.000					p = 0.084
Hit from the back when turning right	394	47	0.346	135.9	0.729	0.149	0.544	0.976	0.034	
Hit from the back when turning left	1537	255	1.273	200.4	0.943	0.070	0.822	1.081	0.398	
Calendar year										
2003–4	2181	394	1.770	222.6	1.000					p = 0.317
2005–6	1945	332	1.606	206.8	0.952	0.075	0.822	1.102	0.508	
2007–8	2009	300	1.698	176.7	0.858	0.079	0.735	1.001	0.052	
2009–10	1660	265	1.388	190.9	0.942	0.084	0.800	1.110	0.477	
2011–12	1580	228	1.349	169.1	0.868	0.093	0.724	1.041	0.126	
Weight of struck car in kg										
500–1000	2174	380	1.776	214.0	1.002	0.067	0.879	1.143	0.971	p = 0.964
1000–1500	4890	793	4.083	194.2	1.000					
1500–2000	781	108	0.673	160.5	0.983	0.101	0.807	1.198	0.868	
2000 +	107	12	0.093	128.8	0.866	0.288	0.493	1.524	0.619	
Unknown	1418	226	1.185	190.7						
First registration year of struck car										
1966–1989	726	125	0.593	210.8	0.973	0.106	0.791	1.198	0.799	p = 0.373
1990–1994	1225	223	0.994	224.3	1.043	0.087	0.879	1.236	0.631	
1995–1999	2313	387	1.923	201.2	0.967	0.075	0.834	1.119	0.649	
2000–2004	1989	327	1.649	198.3	1.000					
2005–2009	1470	200	1.266	158.0	0.843	0.094	0.700	1.014	0.070	
2010–2015	245	33	0.214	154.5	0.799	0.194	0.546	1.169	0.247	
Unknown	1402	224	1.171	191.2						

[a] i.e. SE(ln(hazard ratio)).
[b] Wald's test.

when a tow-bar was mounted on the struck car compared to a car without one ($p = 0.17$). With regard to sex, women had a 60% increased rate of neck injury ($p < 0.0001$), and with regard to age, the younger age groups experienced a higher rate. The rate ratio declined steadily from 50 years ($p < 0.0001$). The passenger seat was associated with a 50% increase in rate compared with the driver's seat ($p < 0.0001$). The rate ratios regarding income were close to the referent category ($p = 0.12$) [below the 1st and above the 4th quintile was associated with a marginally statistically lower risk ($p = 0.06$ and $p = 0.07$ respectively)]. Concerning the highest educational level attained, no rate

Table 2
Estimated hazard ratios in multivariate Cox proportional hazard regression using multiple imputations of missing values. Reduced model including statistically significant variables in Table 1.
Public registry data from Denmark 2003–2012

Variable	Hazard ratio	SE[a]	95% CI		P-value	Variable significance[b]
Tow-bar on struck car						
Yes	0.948	0.054	0.852	1.054	0.322	p = 0.322
No	1.000					
Sex						
Male	1.000					p < 0.0001
Female	1.641	0.052	1.481	1.818	0.000	
Age						
0–17	0.494	0.203	0.332	0.734	0.000	p < 0.0001
18–29	1.025	0.068	0.897	1.171	0.721	
30–39	1.000					
40–49	0.892	0.073	0.773	1.030	0.119	
50–59	0.677	0.088	0.569	0.805	0.000	
60–69	0.541	0.123	0.425	0.688	0.000	
70+	0.281	0.229	0.179	0.440	0.000	
Seat in struck car						
Driver	1.000					p < 0.0001
Passenger	1.527	0.084	1.296	1.801	0.000	

[a] i.e. SE(ln(hazard ratio)).
[b] Wald's test.

ratios were statistically significantly different from the referent category ($p = 0.54$).

The incidence rate ratios related to accident type reflected the results of the univariate rates in to the left of Table 1; being hit when turning right reduced the rate ratio compared with accident types 140 and 321 ($p < 0.03$). But the common Wald's test of no significance of the variable showed only marginal statistical significance ($p = 0.08$).

The effect of calendar time vanished after mutual adjustment for all variables ($p = 0.32$). The weight of the car did not reach statistical significance either ($p = 0.96$). Finally, regarding the first registration year of the car, the rate ratios were similar before 2005, whereas a registration year from 2005 to 2009 was related to a reduction in the rate of neck injury of 16% ($p = 0.07$). This reduction remained at 20% for first registrations from 2010 to 2015 but the variable did not reach statistical significance ($p = 0.37$).

In Table 2, we present a reduced Cox regression model only including those confounder variables from Table 1 which were statistically significant at the 5% level; when controlling the tow-bar status for sex, age, and seat we ended up with a statistically insignificant 5% reduction of neck injury related to a tow-bar ($p = 0.32$). The hazard rate ratio estimates of the other variables were hardly changed.

We verified the PH assumption for all variables as mentioned in Section 2.7 (in Cox regression without multiple imputations).

Furthermore, we aimed at evaluating the type 2 error of the study [the power is calculated as one minus the type 2 error]. We found 9370 subjects who experienced a rear-end collision, and of those 16.2% reported a neck injury within the first year after the accident. These numbers were entered into a power calculation presented in Table 3.

Table 3
Power calculation in Cox regression with 9370 subjects and an event probability of 16%.

Effect size	Power
5%	0.16
7%	0.27
10%	0.49
15%	0.83
20%	0.97

As it can be seen in Table 3, the power was computed for an array of different effect sizes. A hypothesized effect size of 5% was associated with a type 2 error of 84%. The present study would be able to detect an effect size of 15% with a type 2 error less than 20%.

4. Discussion

This study found no association between the risk of neck injury and presence of a tow-bar on the struck car in a rear-end collision. The reduction of the neck injury rate within one year after the collision was estimated to be 5% (95% CI: (−5% to 15%)) with a registered tow-bar compared to no tow-bar, thus indicating that the tow-bar was not responsible for increased neck injury rates ($p = 0.32$).

We identified as many as 9370 occupants of hit cars, of whom 1519 were diagnosed with neck injuries, but the power of a study like this would only be able to detect an effect as large as 15%. The study would, however, be valuable input for a meta-analysis on the impact of a tow-bar in a rear-end collision, because negative results are necessary in order to avoid publication bias.

4.1. A negative finding in light of the literature

The key evidence on the impact of a tow-bar was found in the work by Krafft et al. (2000). Two crash tests involving Volvo 240s with and without tow-bars hit by a Volvo 240 at a speed of 25 km/h clearly demonstrated that the acceleration and the velocity were increased with a tow-bar and the lower neck of the dummy inside the cars was hit with 33% greater acceleration with a tow-bar than without one. Also, the epidemiologic study of Krafft and colleagues of real-life car collisions indicated an increased risk of neck injury when seated in a Volvo 240, Volvo 700, or Saab 900 in the period 1990–1993. We expected a high risk of neck injury including whiplash syndrome in those car types, and we found it highly unlikely that newer cars were not affected by a tow-bar in the same sense as the old cars. How can our unexpected result be explained?

First, we suggest that errors in the information about the tow-bar could have biased the findings regarding an increased risk of the tow-bar towards the null hypothesis. The registration of a tow-bar could be misleading, because some car owners chose not to register their recently mounted tow-bars except when the tow-bars had been installed on new cars. When this error is independent of the information of the neck injury outcome, bias against the null hypothesis can be expected. Nowadays, tow-bars can be demounted easily and it might be unclear whether that removes or reduces the risk of neck injury. We performed a count of cars with tow-bars in typical Danish parking lots. The frequency of cars with installed tow-bars where the hook had been taken off was found to be only 10%, telling us that a tow-bar and its hook were likely to be present on the car, thus indicating a more precise measure of tow-bar status. Furthermore, we will mention the possibility of the presence of measurement errors in the outcome as well. Some involved in rear-end collisions might "falsely" claim to be injured in the neck for insurance reasons. But this error is considered to be unrelated to the tow-bar exposure, because it is not commonly known in Denmark that tow-bars constitute a risk for neck injury. This measurement error will cause bias towards the null hypothesis. However, we expect this bias to be minimal in Denmark compared to, for example, the United States, because insurance payouts are much smaller.

Secondly, even though the laws of physics tell us that the installed tow-bar will hamper the collision zones, drivers and passengers in struck cars might still be more protected against neck injury and whiplash in newer cars. The crash tests by Krafft and colleagues were performed with Volvo 240s with no modern collision zones (and no other technical advances), which could have increased the damaging impact of the tow-bar compared with a modern car. The speed of the striking Volvo was 25 km/h, which is very similar to the low collision speeds in most rear-end collisions that take place at crossings in urban areas, and therefore the speed is not likely to explain our negative finding.

Thirdly, confounding factors such as psychosocial behavior and imprecise measures of socio-economic class could be a problem (Holm et al., 2008). The previously mentioned factors seem to be moderate to strong confounders, and inclusion might affect the regression results and hypothetically turn the effect of the tow-bar into a harmful one. Some parts of the medical literature suggested that occupants with poor self-rated health and high-frequency use of medical services before the injury had an increased post-injury risk of neck injury and specifically whiplash (Joud et al., 2013; Myrtveit et al., 2014; Myrtveit, Carstensen, Kasch, Ørnbøl, & Frostholm, 2015). This implies that information on pre-injury use of medical service could explain much of the statistical variation in neck injury occurrence if entered into our regression analysis. Inclusion of such registry material would be possible with Danish data but was beyond the scope of this study.

Fourthly, our negative finding was in concordance with the result of the study by Linder et al. (2012). Their study used only new cars with whiplash protection systems, whose occupants should be less vulnerable to collisions. Their study did however only collect information on tow-bars as a by-product, and measurement error could possibly explain their results. Otherwise, the sum of evidence of our study and Linder's study points in the direction of a tow-bar having no impact.

Fifthly, selection bias due to drop-out seemed negligible. The sample was complete and population-based, and included all police-reported rear-end collisions and all accident registrations in Danish emergency rooms and hospitals. The initial drop-out of 11% described in the Results section was limited. One may argue that the 7% of persons who did not have a social security number could induce problems; a large number of them, however, were probably foreigners who were not eligible for inclusion in a Danish study.

Finally, the evidence in the literature was sparse and could be confounded by other risk factors that were controlled for in our multivariate analysis (Carroll et al., 2008). Furthermore, cars in 2017 could be more protective against neck injury, which might be an important factor as argued above. We will stress that more crash tests of new cars, including measurements of acceleration in the lower neck of a dummy are highly warranted in order to corroborate our findings based on registry data.

As mentioned in the Introduction section, the idea of the study originated from the use of the Swedish evidence in insurance cases. The available evidence greatly suggested that being exposed to a tow-bar in a rear-end collision was associated with a higher risk of neck injury. Our result weakens this evidence. If our study had confirmed the Swedish result, we would have recommended that deformation zones were changed in order to compensate for the impact of a tow-bar, or advised against the use of a tow-bar, or recommended the use of tow-bars with hooks that can be taken off. However, in the case of a negative result we cannot give any practical recommendations other than to ask for more evidence in the line of Nishimura et al. (2015).

As a clarifying remark, we were puzzled as to why 60% of the cars in our study, but only 48% in parking lots, were equipped with tow-bars. During the study period of 2003–2012, the frequency of tow-bars in the registry dropped by almost 10% to 54% in 2012. From 2012 to 2017, the numbers of small cars and second cars in households – which are less likely to have a tow-bar – have steadily grown in Denmark. To illustrate this point, we checked the percentages of cars for sale fitted with tow-bars with registration years 2012 and 2016, respectively (Bilbasen [Database of cars for sale], 2017). We found that 22% of cars with a registration year of 2012 were fitted with tow-bars, whereas the proportion was only 6% for the registration year 2016. Following this argument, the abovementioned gap between 54% and 48% was likely to have further diminished since 2012. The remaining gap between 54% and 48% could be explained if accidents involving cars with tow-bars had a larger likelihood of being registered by the police because of more material damage to the hitting car in the presence of a tow-bar.

4.2. Other risk factors

Our study suggested an increased rate of neck injury in women. In their best evidence synthesis, Carroll and colleagues found that in 7 out of 11 studied cohorts of occupants of struck cars, females had modest and at most a two-fold increased risk (Carroll et al., 2008); the evidence on sex was however conflicting according to Carroll et al., who mentioned psychological factors as the explanation for the slight sex difference. These factors included differences in seeking medical help. In the extreme, the sex difference could be explained if female occupants visit emergency rooms 50% more frequently than male occupants. Regarding age, the evidence for an increased rate of neck injury in younger age groups was clearer, but again these findings could be explained by a higher rate of seeking help among younger age groups (Carroll et al., 2008). The literature was sparse and rather conflicting on the importance of educational level and no studies seemed to have investigated the effect of household income as we did. At first, the tendency that the poorest and richest groups had reductions in the neck injury rate seemed to be mystery. Differing explanations for the different income groups seemed most likely. Perhaps the poorest people travelled in cars or sought medical help less frequently, while the richest travelled in the most expensive and safest cars.

According to Holm et al. (2008), preliminary evidence suggested that headrests and car seats, constructed to limit the head extension during rear-end collision, had a preventive effect on neck injury, especially in women. Judged from a technical angle, the seats of the driver and the front passenger are usually the safest seats with the best headrests, whereas the rear seats tend to be the least safe. In our study, however, we could only detect a combined effect of the front passenger seat and the rear seats and it was impossible to distinguish the effect in the rear seats alone.

The year of manufacture showed no association with risk of neck injury ($p = 0.44$), which could be attributed to safer cars and a more recent study period (2003–2012) compared to the period of the 1980s and 1990s considered by Krafft (2002).

4.3. Sensitivity analysis

In order to check the validity of our results, we ran a couple of sensitivity analyses. Firstly, we wanted to restrict the neck injury outcome to specifically "whiplash syndrome," coded as DS13.4C. But, we found only 52 cases, which was too few for an analysis. We found 1306 drivers and passengers (86%) diagnosed with "DS13.4," which probably include more whiplash syndromes. However, we cannot be sure. Next, we included only rear-end collisions directly from the back (79% of occupants), thus excluding those who were hit when turning left or right. This analysis did not affect the effect of a tow-bar (hazard ratio = 0.93; 95% CI = 0.82–1.04; $p = 0.191$).

5. Conclusions

Our large registry study of 9,370 drivers and passengers in struck cars in rear-end collisions suggested that there was no increased risk of neck injury related to a tow-bar. Within one year of an accident, however, 16% of the 9,370 occupants reported neck injuries that were diagnosed by a medical doctor in emergency rooms and/or hospitals. Most of them reported the injury shortly after the crash (96%). The internal validity of the study could be questioned because of the expected measurement error in tow-bar exposure, but counts of cars in parking lots showed that an estimated 90% of cars with tow-bars actually carried the hook, thus suggesting a less imprecise measure. The study may serve as valuable input for a meta-analysis on the effect of a tow-bar on neck injury risk in a rear-end collision – a meta-analysis that is highly relevant because tow-bars could be involved in the 2,000 rear-end collision fatalities per year alone in Europe. Negative findings are necessary in a meta-analysis in order to avoid publication bias.

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References

Bilbasen [Database of cars for sale] (2017). URL: www.bilbasen.dk (accessed 2.1.17).

Carroll, L. J., Holm, L. W., Hogg-Johnson, S., Côté, P., Cassidy, J. D., Haldeman, S., ... Guzman, J. (2008). Course and prognostic factors for neck pain in whiplash-associated disorders (WAD). *European Spine Journal*, *17*, 83–92. https://doi.org/10.1007/s00586-008-0628-7.

Harrell, F. E. (2001). *Regression modeling strategies*. New York: Springer Science+Business Media, Inc.

Holm, L. W., Carroll, L. J., Cassidy, J. D., Hogg-Johnson, S., Côté, P., Guzman, J., ... Haldeman, S. (2008). The burden and determinants of neck pain in whiplash-associated disorders after traffic collisions. *European Spine Journal*, *17*, 52–59. https://doi.org/10.1007/s00586-008-0625-x.

Hynes, L. M., & Dickey, J. P. (2008). The rate of change in acceleration: Implications to head kinematics during rear-end impacts. *Accident Analysis and Prevention*, *40*, 1063–1068. https://doi.org/10.1016/j.aap.2007.11.012.

Joud, A., Stjerna, J., Malmstrom, E., Westergren, H., Petersson, I. F., & Englund, M. (2013). Healthcare consultation and sick leave before and after neck injury: A cohort study with matched population-based references. *BMJ Open*, *3*, e003172. https://doi.org/10.1136/bmjopen-2013-003172.

Klein, J. P., & Moeschberger, M. L. (1997). *Survival analysis* (1st ed.). New York: Springer-Verlag Inc.

Krafft, M. (2002). When do AIS 1 neck injuries result in long-term consequences? Vehicle and human factors. *Traffic Injury Prevention*, *3*, 89–97. https://doi.org/10.1080/15389580211998.

Krafft, M., Kullgren, A., Tingvall, C., Boström, O., & Fredriksson, R. (2000). How crash severity in rear impacts influences short- and long-term consequences to the neck. *Accident Analysis and Prevention*, *32*, 187–195. https://doi.org/10.1016/S0001-4575(99)00083-4.

Linder, A., Olsen, S., Eriksson, J., Svensson, M. Y., & Carlsson, A. (2012). Influence of gender, height, weight, age, seated position and collision site related to neck pain symptoms in rear end impacts. *Proceedings: IRCOBI Conference; September 12–14, 2012*. Dublin, Ireland: Trinity College DOI: http://www.ircobi.org/wordpress/downloads/irc12/pdf_files/31.pdf.

Myrtveit, S. M., Carstensen, T., Kasch, H., Ørnbøl, E., & Frostholm, L. (2015). Initial healthcare and coping preferences. *BMJ Open*, *5*, e007239. https://doi.org/10.1136/bmjopen-2014-007239.

Myrtveit, S. M., Skogen, J. C., Petrie, K. J., Wilhelmsen, I., Wenzel, H. G., & Sivertsen, B. (2014). Factors related to non-recovery from whiplash. The Nord-Trøndelag Health Study (HUNT). *International Journal of Behavioral Medicine*, *21*, 430–438. https://doi.org/10.1007/s12529-013-9338-6.

Nishimura, N., Simms, C. K., & Wood, D. P. (2015). Impact characteristics of a vehicle population in low speed front to rear collisions. *Accident Analysis and Prevention*, *79*, 1–12. https://doi.org/10.1016/j.aap.2015.02.001.

StataCorp (2015). *STATA statistical software: Release 14*. College Station, Texas: Stata-Corp LP.

The European Commission (2012). Answer to parliamentary question based on The European Accident Database CARE. URL: http://www.europarl.europa.eu/sides/getAllAnswers.do?reference=E-2011-011477&language=EN (accessed 11.11.17).

Worsfold, C. (2014). When range of motion is not enough: Towards an evidence-based approach to medico-legal reporting in whiplash injury. *Journal of Forensic and Legal Medicine*, *25*, 95–98. https://doi.org/10.1016/j.jflm.2014.04.013.

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