Assessment of the efficacy of vehicle side airbags: A matched cohort study of vehicle-vehicle side collisions using the GIDAS database

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Abstract Current literature, whilst limited, highlights inconsistencies in the efficacy of vehicle torso side airbags (tSAB). The objective of this study is to further investigate this using data from the German In-depth Accident Study (GIDAS). Collisions involving vehicle–vehicle/light-truck interaction, whereby an injured occupant is seated nearside and in the front row, was used. From this, a matched cohort study is undertaken, in which collisions with a torso side airbag (exposure) deployed are paired with similar collisions without a tSAB (non-exposure) on the basis of; occupant, vehicle and collision characteristics. This pairing process is automated by a Genetic Matching algorithm that calculates a matrix of optimal weighting values for the selected matching criteria and is capable of returning multiple non-exposure collisions per exposure collision. A conditional logistic regression then outputs the Odds Ratios for a given injury severity. Results show that for collisions with a deployed tSAB, the risk of overall thoracic injury was not reduced (MAIS1+, OR=1.08, 95%CI [0.65-1.82]), however a non-significant reduced risk for rib fracture occurred (MAIS1+, RR=0.67, 95%CI [0.29-1.54]). When stratified by change of velocity, a strong protective effect for the thoracic region occurred for dV range similar to Euro N-CAP testing (MAIS1+, RR=0.48, 95%CI [0.18-1.27]), however an increased risk of injury occurred for greater speeds (MAIS1+, RR=1.63, 95%CI [0.59-4.4]). Additionally the occupant may be more susceptible to light thoracic injury at mid-low impact speeds (MAIS1+, RR=2.48, 95%CI [0.93-6.16]).

Keywords: Odds ratio, torso side airbag, side collision, accident analysis

I. INTRODUCTION

During the 'postwar economic boom' of the 1940's and 50's occupant vehicles were becoming increasingly popular, yet it was not until 1955 that Ford appointed their first safety engineer [1]. Protection standards have since improved as all new vehicle platforms are subjected to regional-specific legal requirements and strict consumer testing prior to product release. The current trend is for vehicle manufactures to be proactive in introducing new safety technologies and these are often introduced to the market prior to any government regulation[2]. An example of this occurred when Volvo introduced their occupant side airbags (SAB) to specific vehicle models in 1994 [3]. This occurred during the period of depowering frontal passenger airbags and the ever increasing consumer awareness to improved occupant safety standards. While the purpose of a vehicle airbag is to exert a distribution of restraining forces across the occupant, they increase the energy that must be dissipated during a collision.

Vehicles were initially fitted with door-mounted SAB units but are now preferred to be embedded within the seat. These can be sewn into the side of the seat or enclosed within a compartment lateral to the seat. Units have additionally experienced a number of geometry changes to offer differing protection regions, including torso SAB (tSAB), coupled torso and shoulder/head SAB and the current trend is for a tSAB used in combination with a inflatable head curtain (IHC). All new vehicle platforms are subject to regional-specific legal requirements and strict consumer testing prior to product release. Testing includes replication of a vehicle–vehicle side collision in which a movable-deformable barrier (MDB) impacts the vehicle whilst dummy accelerations and deformations are recorded. Measurements are assessed using dummy-based injury risk functions, and aggregated results are made available to the public. The majority of new vehicles score very well during this process [4], indicating a safe environment for the occupant during a collision.

Although introduced almost two decades ago, SAB are only beginning to appear in all registered vehicles [5]. Preliminary results of field data have been few in number and insufficient to draw statistical-based conclusions regarding efficacy [6]. As such, research into the efficacy of the tSAB's injury reduction potential has been

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limited and is often contradictory. Much research supports the hypothesis that the IHC system has significantly reduced occupant head injuries [4][7]. Yet, with regards to the presence of a tSAB; some studies have concluded no association in overall injury mitigation [8], no association in thoracic injury mitigation [4][10], and another had claimed an improvement to thoracic protection [12]. To date, most of the statistical publications regarding efficacy have used American data, with few using European data. One study identified employed German data, however due to the lack of case numbers, the author advised caution when considering the statistical conclusions of insufficient thoracic protective provide by tSAB [13]. Another study combined data from France, the UK and Germany and while statistical analysis showed thoracic protection, results were not significant [14]. Therefore, a new evaluation of German data may clarify these inconsistencies. This paper will assess the efficacy of tSAB during a side collision using data from the German In-Depth Accident Study (GIDAS) database. Injury severities for the occupant in the struck vehicle will be compared for accidents with and without SAB exposure. Conditional Logistic Regression [15] is combined with a Cox Hazard Regression to measure the Odds Ratio (OR) for injury association.

II. METHODS

GIDAS commenced in 1999 and investigates traffic accidents in the Dresden and Hanover regions. Criteria for inclusion in the database are for the police to report any form of traffic accident in which they deem an individual injured [16]. Around 2,000 accidents involving various traffic participants (vehicle occupants, pedestrians, cyclists, etc.) are recorded annually in a statistical random procedure representative of the national accident statistic [17]. Investigation is conducted on a technical and medical level, both at the scene and at the hospital. Each case is reconstructed and coded into the database with about 3,000 variables per case.

Data Source

A side collision was only included where; the occupant was seated near-side and in the front-row of passenger vehicle, collision with another passenger car or light-truck vehicle (<3,500 kg), the occupant is to be older than 16 years and they must sustain an injury. Each case was individually inspected to verify the presence of a deployed tSAB through the case photos. As a result, a total of 550 (102 with tSAb and 448 without) collisions were extracted from the GIDAS database.

The Abbreviated Injury Scale (AIS) [18] was used to assess the medical severity of the injured occupants. This ordinal-scale classifies occupant injuries into six categories – Minor, Moderate, Serious, Severe, Critical and Maximum. In order to obtain a set of relevant collisions with a truly injured occupant from GIDAS a minimum medical severity limit was needed. To account for this, any occupant suffering more than two AIS1+ injuries to different body regions were included in the study.

Injuries occurring between the neck and diaphragm region including the rib cage and thoracic spine were defined as thoracic region injuries. The upper extremities included those injuries to the nearside shoulder, arm, elbow or hand.

The Matching Process

Prior to commencing the statistical testing, a set of similar collisions was needed with and without a deployed tSAB. This required the exposure (deployed tSAB) collisions to be paired with similar non-exposure (non-deployed or non-fitted tSAB) collisions. The non-deployed collisions are assumed to occur near or below the deployment threshold, therefore these can be considered as non-exposure collisions where appropriate. A similar collision was defined by similar parameters based on an occupant, vehicle and collision level. This matching process was automated using a Genetic Matching algorithm [19] which is available as an add-on package to the statistical software, R [20]. The algorithm determines optimal weight values that are assigned to each of the (manually supplied) matching variables. Collisions were matched by the following criteria; ratio of Bullet Vehicle (BV) bumper height to Target Vehicle (TV) sill height, the lateral component of the TV's change of velocity (dV), impact region of TV, the presence of a far-side occupant in the TV, occupant age, the BV longitudinal stiffness, and the mass ratio of the BV and TV. These have been summarised in Table I. The automated matching process allowed for multiple non-exposure collisions to be paired to each exposure collision.

TABLE I
INDEPENDENT VARIABLES USED IN THE MATCHING MATRIX

Category	Type	No of variables
Ratio of BV bumper height to TV sill height	Binary	2
TV Lateral dV	Categorical	5
TV impact region	Binary	2
Farside occupant	Binary	2
TV Occupant Age	Binary	2
BV/TV mass ratio	Categorical	1
BV longitudinal stiffness	Continuous	1

Age was used as a binary variable, separated at 60 years. While the World Health Organization uses 65 years as the minimum for the older group, a clear definition does not exist in the biomechanical literature [21]. The binary variable allowed for flexible matching whilst still accounting for age differences. Additionally, the reader must note that occupants less than 16 years were excluded from the data. Occupants aged less than 16 years often have underdeveloped bone structures and yield differences in effective rib stiffness compared to older occupants [22].

The mechanical collision severity is another parameter that must be accounted for. This can be measured by the dV of the target vehicle experiences during the collision. To account for the primary direction of force (PDOF) imposed by the bullet vehicle, the lateral component of the change in velocity can be calculated. The PDOF has been identified as a factor affecting occupant injury in a side collision [23]. Additionally the lateral dV can be compared to those used during Euro-NCAP testing procedure. This variable was categorized into 10 km/h speed ranges.

The intruding door is a leading cause of injury during a side collision [24]. It is also the position where the movable deformable barrier strikes the vehicle in the Euro N-CAP testing procedure. Therefore one must include the impact location when searching for a similar collision. This is controlled by a binary variable of whether primary contact to the target vehicle was between the A- and B- pillar.

With changes in vehicle design in order to meet the frontal impact regulatory test procedure, cars have become heavier and hence the average mass of the vehicle fleet is increasing [25]. The use of vehicle crash mass (ratio) in the matching process aims to account for newer vehicle as well as different vehicle types.

Vehicles have become significantly stiffer in recent years [26]. Therefore assuming a constant value prior to 1980, stiffness was linearly increased by 144% until 2010. This was applied to the year vehicle models were first introduced to the market. Target vehicles produced prior to 1998 were not removed from the dataset as this would have limited the available collisions. Instead the introduction of the stiffness variable would aim to pair similar model year vehicles.

Using a ratio for the BV bumper height and the TV sill height would aim to differentiate between different vehicle types. A value near one would allow the greater likelihood of floor sill engagement of the BV. When struck and deformed, this allows for larger energy dissipation during a collision. This was used as a binary variable, separated at 1.5. This value represents the striking bumper height is 50% higher than the struck sill.

Lee et al. [27] showed that the presence of passengers is correlated with lower prevalence of risky behavior that reduces crash potential, but did not investigate the influence on injury potential. Research identified that having a far-side occupant during a side collision increases the risk of injury to the near-side occupant [28]. Therefore the number of front row occupants is a requirement for the matching criteria.

Matching according to recorded seatbelt use was initially conducted, yet results did not differ when compared to non-belt compliance. It was hypothesised to not play an influential role in the association of injury severity during a side collision, a result also in agreement with literature [29]. Ultimately it was not considered for the matching criteria.

The Statistical Analysis:

Conditional logistic modeling was applied after the (1 exposure + k non- exposure collisions) matching process was completed. This is combines a Cox Proportional Hazard regression and does not introduce bias due to the unequal number of exposure and non- exposure collisions. The regression was further stratified by pair identities which allowed for differing baseline functions. The outputs of the regression gave the Odds Ratio for a given injury severity.

III. RESULTS

The quantity of tSAB exposure collisions obtained and verified from GIDAS is depicted in the Venn diagram below. Formatting in such a manner allows the reader to assess where cases are lost. Figure 1 shows that 102 collisions occurred for the collision conditions with a tSAB deployment and 448 collisions occurred without tSAB deployment.

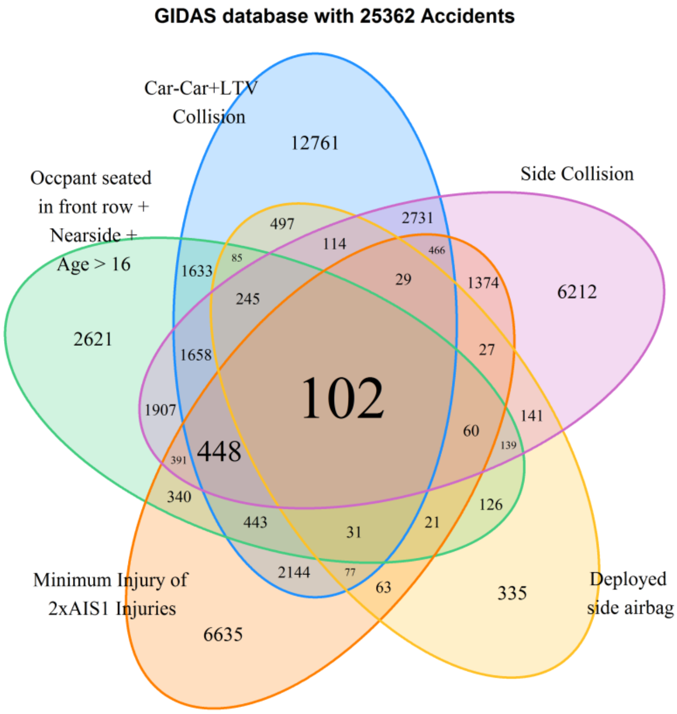

Fig. 1. Quantity of GIDAS Accidents for the specified collision-criteria. Shown in largest font are exposure and non-exposure accidents, respectively. Additionally one can easily identify that 245 collisions occurred with a deployed airbag however the occupant was not injured or missing this information.

Only 100 of the 102 tSAB collisions were able to be successfully paired with 143 non-tSAB cases. Referring to the Appendix, the Q-Q plots for the continuous data and the sunflower-scatter plots for the categorical data can be seen. The distribution of collision characteristics is compared between the exposed and non-exposed cases. χ^2- and t-tests were conducted on the categorical and continuous variables to highlight any differences between the pairs. Results are shown in Table II.

TABLE II
DEMOGRAPHICS OF MATCHED DATA SET FOR TSAB CASE AND CONTROL COLLISIONS.
NOTE: THE UNDERLINED VARIABLES ARE THOSE USED IN THE MATCHING CRITERIA.

Symbol	Exposure Collisions (n=100)	Non-Exposure Collisions (n=143)	p value
Occupant Demographics	*Mean*	*Mean*	
Male, %	45	48.3	0.603
Age, <60 years, %	81	86.5	0.246
Farside occupant, %	42.9	57.1	0.753
Vehicle			
TV Sill height, cm	30.0	30.5	0.369
TV longitudinal height, cm	53.5	53.4	0.950
TV Crash Mass, kg	1380.4	1273.4	<0.001
BV longitudinal height, cm	53.5	53.4	0.950
BV Crash Mass, kg	1481.6	1458	0.640
Year BV was first introduced %			0.610
<1995	48	54.7	
1996-2000	26	29.1	
2001-2005	16	21.3	
2006+	10	8.51	
Initial impact to door, %	67	65.2	0.777
Collision			
TV Lateral dV Orientation			0.151
< 10km/h, %	20	13.5	
10≤x<20 km/h, %	37	51.7	
20≤x<30 km/h, %	28	24.8	
30≤x<50 km/h, %	15	9.9	
BV:TV Masst Ratio			0.621
< 0.8, %	12	9.2	
0.8≤x<1.2, %	58	60.8	
1.2+, %	30	27	
Driver's Side Collision	80	85.1	0.3

As expected, the matched pairs had similar demographics for the variable used in the matching process. This indicates that collisions had successfully been paired on an occupant, collision and environmental level. Occupants with SAB exposure were seated in heavier vehicles ($p<0.001$), however the BV:TV mass ratio used in the pairing process ensures optimal pairing ($p=0.621$).

A conditional logistic regression was then applied to the paired dataset to obtain the association between airbag deployment in a car collision and occupant injury. Results are listed in Table III. The presence of a deployed tSAB is associated with an insignificant increased risk for overall injury severity of the occupant (Greater than 2x AIS1+ injuries, 1.09[0.76-1.58] and MAIS3+, 1.13[0.55-2.35]). No association of injury reduction occurred for any thoracic injury (MAIS1+, 1.08[0.65-1.82]), however a positive trend was established when the minor injuries were excluded (MAIS2+, 0.86[0.36-2.01]). A reduced risk of rib fracture was associated with the presence of a tSAB (MAIS1+, 0.67[0.29-1.54]). No association of reduced nearside upper extremity injury was found (MAIS1+, 0.97[0.56-1.64]). Occupant hip and pelvis region appeared to be at a greater risk of injury with the presence of a deployed tSAB (MAIS1+, 1.33[0.52-3.42]). Also the abdomen region demonstrated no association of injury reduction (MAIS2+, 1.04[0.37-2.97]).

TABLE III
MEASURE OF INJURY RISK ASSOCIATION BETWEEN TSAB EXPOSURE CASES FOR OVERALL OCCUPANT INJURY AND SPECIFIC BODY REGION. N=243 COLLISIONS.

Injury Severity	OR	95% CI
Overall		
Greater than 2x AIS1+ injuries	1.09	0.76-1.58
MAIS3+	1.13	0.55-2.35
Thorax		
MAIS1+	1.08	0.65-1.82
MAIS2+	0.86	0.36-2.01
Rib fracture		
MAIS1+	0.67	0.29-1.54
MAIS2+	0.85	0.34-1.54
Abdome*n*		
MAIS1+	0.79	0.38-1.67
MAIS2+	1.04	0.37-2.97
Nearside Upper Extremities		
MAIS1+	0.97	0.56-1.64
MAIS2+	0.68	0.22-2.12
Hip or Pelvis		
MAIS1+	1.33	0.52-3.42
MAIS2+	1.33	0.52-3.42

The data was then investigated as a function of the target vehicle's dV with results shown in Table IV. For the Euro-NCAP test, a MDB of mass 950kg collides with new vehicle platforms at 50km/h. This results in a latereral dV of the target vehicle within the range of 20-35km/h [30]. The risk of overall thoracic injury shows a clear reduction for collisions within this range (20≤dV<30km/h MAIS1+, 0.48[0.18-1.27]). The risk associated with thoracic injury at speeds greater than the Euro N-CAP range indicates the occupant is at an increased risk of injury (30≤dV<50km/h MAIS1+, 1.63[0.59-4.47]). Additionally at low-mid vehicle collision severities the occupant the occupant is at an increased risk of injury (10≤dV<20km/h MAIS1+, 2.48[0.93-6.16]), however very few MAIS2+ injuries occur.

IV. DISCUSSION

SABs are primarily designed to provide protection to the occupant's head and thoracic region. A common acceptance is the improved ability to reduce head injuries, although the efficacy of torso injury prevention has been contradictory and remains the scope of this paper.

When assessing the overall occupant injury risk, the presence of a tSAB is not associated with a reduction of injury. The non-association of risk reduction with a deployed tSAB is parallel to results found in [9].

When analysing the thoracic region the presence of a tSAB does not indicate a clear reduction of injury. Results show an equal risk for light injuries and only a slight reduction is established for the greater severity injuries. This is in parallel to results that showed no evidence of injury reduction [11][10][13] or where an airbag was associated with a reduced risk of injury [7][12][14]. A positive relationship was established when only rib fracture injuries were considered. The magnitude of the injury reduction value is similar to those in [7][14]. While a positive relationship was seen for the rib fractures, the equal risk of overall thoracic injury needs to be investigated further, in particular the frequency of visceral (soft tissue) trauma. In his study into side airbag out-of-position (OOP) deployment, [31] stated visceral trauma risk may be more sensitive to OOP torso SAB deployment than skeletal (hard tissue) trauma. This is a further research point.

TABLE IV
MEASURE OF INJURY RISK ASSOCIATION BETWEEN tSAB EXPOSURE CASES BY TARGET VEHICLE LATERAL dV CATEGORY.

Injury	OR	95% CI
Delta V < 10km/h (n=18)		
Thorax		
MAIS1+	2 injuries in exposure collisions, 5 in non-exposure	
MAIS2+	0 injuries in both	
10 ≤ Delta V ≤ 20km/h (n=76)		
Thorax		
MAIS1+	2.48	0.93-6.16
MAIS2+	2 injuries in exposure, 0 in non-exposure	
20 ≤ Delta V ≤ 30km/h (n=87)		
Thorax		
MAIS1+	0.48	0.18-1.27
MAIS2+	0.17	0.02-1.42
30 ≤ Delta V ≤ 50km/h (n=54)		
Thorax		
MAIS1+	1.63	0.59-4.47
MAIS2+	2.46	0.59-10.33

When stratified by change of velocity categories, the highest range of dV resulted in greater risk of thoracic injury. Results also indicate the increase risk of light injuries at low-mid impact severities. Whilst within the EURO N-CAP ranges, the risk of thoracic skeletal injury was reduced. Research has suggested to further reduce non-senior fatalities in near-side crashes, future side airbags should be designed for protection at higher delta-v [32] and while occupant age was not within the scope of the paper, the results indicate improved protection is needed for the higher dV ranges.

The nearside upper extremity of the occupant was at equal risk of injury with and without a deployed airbag. This is in contradiction to the significantly increased risk obtained in another study [33]. That study focused on moderate-severity (MAIS2+, 3+) upper extremity injuries and did not differentiate between the nearside and far-side arm. Early research indicated the deployment of the airbag would not cause humerus fracture and results presented here do not violate those studies [34][35].

Although not designed to provide primary protection, the abdomen region was not associated with a reduced injury risk MAIS2+, parallel to results found in [4]. The hip and pelvis region appear to be at an increased risk of injury. Results must be interpreted with caution due to the limited number of injuries as indicated by the bounds of the confidence intervals.

A strength of the study was the use of collisions from the detailed GIDAS database. All cases had their photos cross-examined to ensure correct exposure coding and in addition all subsequent medical analysis was conducted by a trained physician. Reference [11] stated a limitation to their study was the inability to confirm the availability of tSAB.

The major limitation of this study was the manner in which collisions were paired, as accuracy and quantity of the pairs directly influenced the logistic output. Reference [36] identified that vehicle safety articles need to adequately report the steps of model construction. This provides the reader with greater confidence to assess whether the conclusions reported are likely due to the manner in which the model was constructed, or to the actual utility of the model to predict injury mitigation outcomes in the real world. For this reason, the methodology is similar to that employed in [10], although greater care has been taken to explain the matching process, which directly influences the final outcomes. Another limitation is the number of cases used within the study. The Venn diagram in Fig. 1 depicts how a database of over 25,000 collisions severely reduces once a collision-criterion is specified. Additionally it is possible that vehicle collisions may have occurred whereby the airbag is fired and the occupant remains uninjured, thus these collisions are not recorded in GIDAS.

Already discussed as a strength, the source of data is also a limitation of the work presented. Although detailed in manner, the requirement for a collision to be recorded in GIDAS is for the police to deem an occupant injured. They often have little to no training in medical examinations. As such, the method to assess the efficacy of tSAB protection may outline the minimum values due to a significant number of collisions not recorded in the database. However, given that the study identified 69 different models of vehicle with a deployed tSAB, spanning manufacturing from 1997 to 2012, it is likely that that the results are representative of the current collision environment. Similar results have been found in other literature with differing vehicle populations.

The next step is to further optimize the matching process to confirm the results and to investigate the frequency of soft tissue injuries and see if they are a cause of potential OOP.

V. Conclusions

The results of the paper conclude that;

- Sufficient matching of collision-pairs with and without airbag exposure was conducted. No significance difference occurred between the variables used in the matching criteria.
- Overall thoracic injury yielded no net reduction of injury severity with a deployed tSAB, however a positive relationship was established for rib fractures
- When stratified by change of velocity categories, the occupant was at greatest risk of thoracic injury at higher severity crashes. For velocity changes within the Euro N-CAP test range, good protection standards were provided.

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VII. References

[1] Eastman, G. Styling Vs. Safety: The American Automobile Industry and the Development of Automotive Safety 1900-1966, pp. 209–10), *University Press of America*, USA, 1984.

[2] O'Neill, B. Airbags – Yesterday, Today and Tomorrow. *Proceedings of Airbag Conference*, 2006, Karlsruhe (Germany).

[3] Pilhall, S., Korner, J., Ouchterlony, B. SIPSBAG – A New, Seat-Mounted Side Impact Airbag System. *Proceedings of Enhanced Safety of Vehicles Conference*, 1994, Munich (Germany).

[4] Malczyk, A. Occupant protection by side airbags in vehicle-to-vehicle collisions. *Proceedings from Airbag Conference*, 2014, Karlsruhe (Germany).

[5] IIHS Status Report. New safety features take 3 decades on average to spread through the vehicle fleet, a HLDI report says. *IIHS Status Report*, 2012, Vol. 47(1):1–5.

[6] Yoganandan, N., Pintar, F., Gennarelli, T. Evaluation of side impact injuries in vehicles equipped with side airbags. *Proceedings of IRCOBI Conference*, 2005, Prague (Czech Republic).

[7] Braver, E. R, Kyrychenko, S. Y. Efficacy of side air bags in reducing driver deaths in driver-side collisions. *American Journal of Epidemiology*, 2004, 59:556–64.

[8] Jakobsson, L. Real World Data Driven Evolution of Volvo Cars' Side Impact Protection Systems and their Effectiveness. *Proccedings of AAAM Conference*, 2010, Las Vegas, Nevada (USA).

[9] McGwin, G. Jr, Metzger, J., Porterfield, J. R., Moran, S. G., Rue III, L. W. Association between side air bags and risk of injury in motor vehicle collisions with near-side impact. *J Trauma*. 2003, 55:430–34, discussion 434–6.

[10] Griffin, R. Association between side-impact airbag deployment and risk of injury: A matched cohort study using the CIREN and the NASS-CDS. *Journal of Trauma and Acute Care Surgery*, 2012, Volume 73(4):914–18.

[11] D'Elia, A., Newstead, S., Scully, J. Evaluation of vehicle side airbag effectiveness in Victoria, Australia. *Accident Analysis & Prevention*, 2013, 54:67–72.

[12] McGwin, G. Jr, Metzger, J., Rue III, L. W. The influence of side airbags on the risk of head and thoracic injury after motor vehicle collisions. *J Trauma*, 2004, 56:512–16, discussion 516–17.

[13] Otte, D., Hüfner, T. Effectiveness of Side-Airbags for Front Struckside Belted Car Occupants in Lateral Impact Conditions – An In-Depth-Analysis by GIDAS. SAE Technical Paper, 2007, 01-1157.

[14] Page, Y., Thomas, P., Herve, V. The Effectiveness of Side Airbags in Preventing Thoracic Injuries in Europe. *Proceedings from ESAR Conference*, 2006, Hanover (Germany).

[15] Gail, M, Lubin, J, Rubinstein, L. Likelihood Calculations for matched case-control studies and survival studies with tied death time. Biometrika. 1981;68;703-707

[16] Otte, D., Krettek, C., Brunner, H., Zwipp, H. Scientific approach and methodology of a new in-depth-investigation study in Germany so called GIDAS. *Proceedings of Enhanced Safety of Vehicles Conference*, 2003, Nagoya (Japan).

[17] Pfeiffer, M., Schmidt, J. Statistical and Methodological Foundations of the GIDAS Accident Survey System. *Proceedings of ESAR Conference*, 2006, Hanover (Germany).

[18] The Abbreviated Injury Scale - 2005 Revision, Update 2008. *AAAM*, Barrington, IL, USA, 2008.

[19] Sekhon, J. Multivariate and Propensity Score Matching Software with Automated Balance Optimization: The Matching package for R. *Journal of Statistical Software*, 2011, 42(7):1–52.

[20] R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing, 2014, Vienna, Austria. Internet: <http://www.R-project.org/> Version 3.1.2 (2014-10-31)

[21] Yoganandan, N., Pintar, F., Stemper, B., Gennarelli, T., Weigelt, J. Biomechanics of side impact: Injury criteria, aging occupants, and airbag technology. *Journal of Biomechanics*, 2007, 40:227–43.

[22] Agnew, A., Kang, S., Moorhouse, K., Herriott, R., Bolte, J. Age-Related Changes in Stiffness in Human Ribs. *Proceedings of IRCOBI Conference*, 2013, Gothenburg (Sweden).

[23] Dakin, G. J., Arbelaez, R. A., Nolan, J. M., Lund, A. K. Insurance Institute for Highway Safety Side Impact Crashworthiness Evaluation Program: Impact Configuration and Rationale. *Proceedings of Enhanced Safety of Vehicles Conference*, 2003, Nagoya (Japan).

[24] Gierczycka, D., Cronin, D. S. Investigation of Injury Metric Sensitivity to Thorax Impact Loading Using a Human Body Model. *Proceedings of IRCOBI Conference*, 2014, Berlin (Germany)

[25] Welsh, R., Morris, A., Thomas, P., Lenard, J., Barnes, J., Otte, D. Car to car struck side impacts – A comparison between European accident data and directive 96/27/EC. *Proceedings of IRCOBI Conference*, 2009, York (UK).

[26] Sahraei, M. High strength steels, stiffness of vehicle front-end structure, and risk of injury to rear seat occupants. *Accident Analysis & Prevention*, 2014, 66:43–54.

[27] Lee, C., Abdel-Aty, M. Presence of passengers: Does it increase or reduce driver's crash potential? *Accident Analysis & Prevention*, 2008, 40:1703–12.

[28] Stigson, H. Kullgren A. Effect of side impact protection in reducing injuries. *Proceedings of Enhanced Safety of Vehicles Conference*, 2011, Washington DC (USA)

[29] Campbell, B. M., Cronin, D. S. Coupled human body and side impact model to predict thoracic response. *International Journal for Crashworthiness*, 2014, 19(4):394–413.

[30] Tingvall, C., Krafft, M., Lie, A., Kullgren, A. The Role of Impact Velocity and Change of Velocity in Side Impacts. *Proceedings of Enhanced Safety of Vehicles Conference*, 2003, Nagoya (Japan).

[31] Hallman, J J. Yoganandan, N. Pintar, F. Side airbag out-of-position deployments: Thoracic injury to stationary and dynamic occupants. *Proceedings of IRCOBI Conference*, 2009, York (UK).

[32] Sunnevang, C. Rosen, E. Bostrom, O. Real-Life Fatal Outcome in Car-to-Car Near-Side Impacts—Implications for Improved Protection Considering Age and Crash Severity. Traffic Injury Prevention, 2009, 10:2, 194-203.

[33] McGwin, G., Modjarrad, K., Duma, S., Rue, L. W. Association between upper extremity injuries and side airbag availability. *Journal of Trauma*, 2008, 64:1297–301

[34] Kallieris, D., Rizzetti, A., Mattern, R., Jost, S., Priemer, P., Unger, M. Response and Vulnerability of the upper arm through side airbag deployment. SAE Technical Paper, 1997, 973323.

[35] Sokol Jaffredo, A., Potier, P., Robin, S., Le Coz J., Lassau, J. Upper Extremity interaction with side impact airbag. *Proceedings of IRCOBI Conference*, 1998, Prague (Göteburg).

[36] Hoggarth, P. Prediction of driving ability: Are we building valid models? *Accident Analysis & Prevention*, 2015, 77:29–34.

VIII. APPENDIX