ANALYSIS OF DIFFERENT TYPES OF WINTER TYRES IN REAR-END INJURY CRASHES AND FATAL LOSS-OF-CONTROL CRASHES WITH ESC

Johan Strandroth
Swedish Transport Administration and Chalmers University
Sweden

Matteo Rizzi
Folksam Research and Chalmers University
Sweden

Maria Ohlin
University of Gothenburg and Chalmers University
Sweden

Jenny Eriksson
Swedish National Road and Transport Research Institute
Sweden

Anders Lie
Swedish Transport Administration and Chalmers University
Sweden

Paper Number 15-0368

ABSTRACT

This study aimed to compare studded and non-studded winter tyres with regard to the risk of being the striking car in rear-end injury crashes with passenger cars. A further aim was to evaluate the risk for a passenger car equipped with Electronic Stability Control (ESC) to be involved in a fatal loss-of-control (LOC) crash with studded and non-studded winter tyres. This research was based on two different materials. The study on rear-end crashes used police reports from crashes in Sweden between 2008 and 2014. The study was limited to crashes occurring in the winter period, in this study defined as October through to March. Only car-to-car two vehicle crashes were included (n=4239). As tyre information was not included in the police reports, a survey form was sent to all drivers asking which type of tyres was fitted on their car at the time of the crash. In total, 717 drivers (17%) responded. The relative risk for being the striking or struck vehicle, depending on winter tyres, was calculated using an induced exposure approach. The analysis of fatal crashes in the winter period used in-depth studies of fatal crashes collected by the Swedish and Norwegian Transport Administrations in the winter period between 2003 and 2014. Cars fitted with ESC (n=44) were compared with cars without ESC (n=260). The odds ratio for being involved in a LOC-crash was calculated depending on the ESC fitment and fitment of different winter tyres. The findings showed that the risk for being the striking vehicle in a rear-end injury crash on ice or snow was at least 27% higher for non-studded winter tyres, compared to studded tyres. With regard to all road conditions, no significant difference between winter tyres with or without studs were found. As the proportion of ice and snow differs greatly in different parts of Sweden, the overall estimated effect was significant in northern Sweden but not in mid or southern Sweden. The risk of a fatal LOC-crash was 65% lower with studded tyres compared with non-studded winter tyres for cars without ESC. In ESC cars, the risk reduction, compared to cars without ESC, was 92% including all types of winter tyres, which were grouped together due to the limited size of the material. The rear-end crash analysis was based on a material with a rather limited response frequency. Hence, the representativeness of the results should be treated with caution. Regarding the fatal crashes it could be concluded that ESC is very effective in reducing LOC-crashes regardless of type of winter tyres. This is the first study that shows the effect of studded tyres related to specific crash types and to different geographical regions in Sweden. Hence, the findings in this study can contribute to the ongoing discussion on reducing the proportion of studded tyres in Sweden due to environmental and health issues.

INTRODUCTION

Injury crashes on slippery roads are a common issue during the winter period in Sweden. Of all injury crashes with passenger cars during the Swedish winter, approximately 50% occur on ice and snow (Folksam, 2015). The proportion of crashes on ice and snow in fatal crashes is similar. Amongst fatalities on ice and snow, LOC crashes account for the majority of crashes (64%) as reported by Strandroth et al., (2012). However, in many parts of Sweden the majority of winter traffic runs on dry or wet roads.

Testing of studded winter tyres has shown increased braking performance and increased stability on road surfaces covered with ice and snow, compared to non-studded winter tires (Auto Motor & Sport, 2008). However, the performance of studded tyres has been shown to drop substantially over time when the studs become worn, while the non-studded winter tyre has a more consistent performance (Auto Motor & Sport, 2010). The effectiveness of winter tyres in reducing real-life crashes has been studied since the early 1970´s. Also, the benefit of studded winter tyres compared to non-studded winter tyres has been evaluated. In a meta-analysis, Elvik (1999) found that use of studded tyres was associated with a reduction of crashes by 5% on roads covered with ice or snow, however the result was not statistically significant. On dry or wet roads the effect of studded tyres was 2%, also non-significant. Later studies have been done in response to the issue of air quality problems related to the use of studded tyres. Gustafsson et al. (2006) estimated the typical added safety effect of studded tyres compared to non-studded winter tyres to 0–10% reduction of passenger car crashes over a winter period and 20-25% crash reduction on roads covered with ice and snow. In a study by Strandroth et al. (2012) including cars not fitted with Electronic Stability Control (ESC), studded tyres were found to reduce fatal crashes with passenger cars on roads covered with ice or snow by 42%, compared to non-studded winter tyres. The effect on LOC crashes was 65%. ESC has been shown to have a superior effect on injury reduction on low friction roads. In a literature review by Ferguson (2007) fatal single-vehicle car crashes were found to be reduced by about 30–50% and Lie (2012) estimated a 98% reduction of fatal LOC-crashes on ice and snow. While ESC has been proven to reduce the risk for severe crashes on ice and snow, Strandroth et al (2012) could not, due to a too limited number of cases of fatal crashes with ESC equipped cars, investigate in detail how the risk of LOC crashes may be affected by different winter tyres on ESC equipped cars.

One problem associated with the use of studded tyres is the wear on roads leading to emissions of particles. In Sweden, studded tyres are estimated to account for around 80 % of the emissions of particles from roads (Johansson et al., 2004). During the last years, the issues of air quality have forced municipalities to focus on reducing the proportion of studded tyres on the urban road network (Stockholm Municipality, 2015). This change in proportion of studded tyres could have an effect on the polishing of the road surface resulting in a lower friction. Findings from a Finnish study that investigated the effect of the proportion of studded tyres in the traffic flow on the tyre-ice friction coefficient concluded that ”the stud flow could be reduced to 25-50 % without any risk of severe polishing of the icy road” (Tuononen & Sainio, 2014). Similar conclusions were drawn in a Norwegian study based on accident statistics. It was found that the number of accidents would increase if the use of studded tyres decreased below 20-25 %, compared to usage above this level (Elvik et al, 2013). In the same study, results showed an increase in the number of injury accidents when the usage of studded tyres were reduced, and also vice versa, if the usage of studded tyres increased it was associated with a reduction in the number of injury accidents. However, this analysis was performed on a macro level and did not set out to investigate what types of crashes would be affected by changes in the studded tyre usage rate.

Due to the increased grip with studded tyres shown in winter tyre tests, it could be assumed that studded tyres would reduce the risk of low friction crashes like rear-end crashes and other stability-related crashes. However, no study has yet managed to calculate the effects of studded tyres in a specific scenario in real-life crashes.

The aims of this study were to firstly compare studded and non-studded winter tyres with regard to the risk of being the striking car in rear-end injury crashes during the winter period with passenger car. A second aim was to evaluate the risk for a passenger car to be involved in a fatal loss-of-control (LOC) crash on ice and snow with different type of winter tyres and with or without Electronic Stability Control (ESC).

METHODS

This study was carried out in two separate analyses. Rear-end injury crashes were analysed to evaluate the risk of rear-end crashes in the winter period with different kind of winter tyres, also a case-by-case analysis was conducted based on in-depth studies of fatal crashes on ice and snow in order to evaluate the risk for a passenger car equipped with ESC of being involved in LOC crashes.

Both analyses were case and control studies. In the first one, an induced exposure approach was used, as the true exposure (e.g. vehicle mileage or number of registered vehicles) related to different kind of tyres was not available. With this approach, the number of crashes in which a safety measure is expected to be effective (i.e. sensitive crashes) is divided by the number of crashes where the same technology is expected to have no or limited effect (non-sensitive crashes). The basic assumption is that the non-sensitive crashes in the same way as the cases will vary with changes in vehicle miles traveled, driver characteristics, numbers of vehicles on the road, among other factors. However, these control crashes should be unaffected by the presence of the technology. Therefore, they can serve as a proxy for the true exposure (Ferguson, 2007) and the effect is given by the relative difference in crash rates between the case and control group.

Rear-end injury crashes

In order to estimate the risk of being the striking vehicle in a rear-end crash, this analysis used police-reported rear-end injury crashes with passenger cars. These were acquired from the Swedish National Accident Database, STRADA. The STRADA database contains information from police records and hospital data. In STRADA no information is given on type of tyres, therefore additional information was collected from a sample of drivers involved in these accidents, using a questionnaire (see material section). The assumption was made that the positive effect of studded tyres would be relevant in a crash situation that involves braking, where the braking performance would be dependent by the friction. Being the striking part in a rear-end crash was assumed to be the sensitive event, while being the striking part in a rear-end crash was considered to be the non-sensitive event. The calculations were performed according to Equation 1 below.

$$R = \frac{striking_{studded}}{struck_{studded}} \div \frac{striking_{non-studded}}{struck_{non-studded}} \quad (1)$$

Thus, the effectiveness in reducing the risk of being the striking part in a rear-end crash with studded tyres can be expressed as:

$$E = 100 \times (1 - R)\% \quad (2)$$

The standard deviation of the effectiveness was calculated on the basis of a simplified odds ratio variance, according to Equation 3. This method gives symmetric confidence limits but the variance estimate is conservative.

$$Sd = \sqrt{\sum_{i=1}^{4} \frac{1}{n_i}} \quad (3)$$

Where n is the number of crashes of each crash type. The 95% confidence limits (CI95) are given according to:

$$\Delta E = 100 \times R \times Sd \times 1{,}96 \quad (4)$$

An important factor was to ensure that the only dissimilarities between the case and control groups were types of tyres. In Appendix 1, controls were made with regards to possible confounding factors influencing crash or injury risk.

These calculations were performed on all road conditions (ice and snow as well as dry and wet roads) and in crashes in different Swedish regions (southern, mid and northern Sweden, see Figure 2).

Fatal crashes

Data from in-depth studies of fatal crashes with passenger cars collected by the Swedish and Norwegian Transport Administrations were analysed to determine whether a crash should be classified as LOC or non-LOC and whether or not LOC had been a critical event in causing the crash. If more than one vehicle was involved in the crash (i.e. a head-on collision between the car and a heavy goods vehicle) it was determined which part initiated the chain of events (active part) leading to the crash and then whether LOC were a major contributing event or not (Figure 1). These parameters were in first hand vehicle trajectories, skid marks, impact location and direction, tyre and steering wheel angles in impact and other circumstances recorded in the in-depth studies. Only cases where a passenger car had been the active part were included.

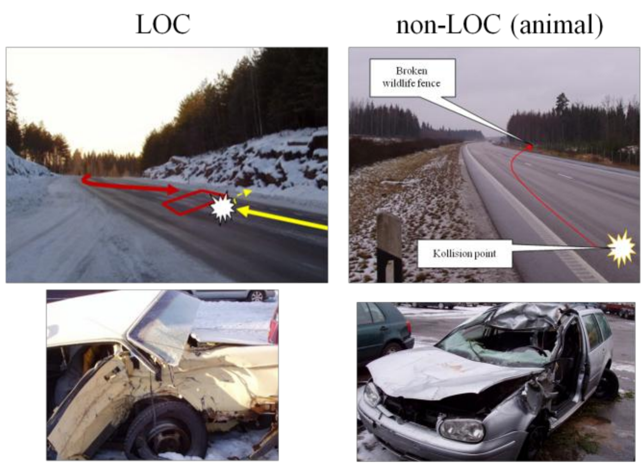

Figure 1. An example of LOC and non-LOC crashes.

Calculations were made using induced exposure, were the non-LOC crashes were considered to be non-sensitive to the effect of ESC and types of tyres. The odds-ratio (OR) for being involved in a LOC crash depending on types of tyres was calculated for both ESC and non-ESC equipped cars according to Equations 5, 6, 7 and 8.

$$OR_{non-ESC_1} = \frac{LOC_{non-studded}}{non-LOC_{non-studded}} \quad (5)$$

$$OR_{non-ESC_2} = \frac{LOC_{studded}}{non-LOC_{studded}} \quad (6)$$

$$OR_{ESC_1} = \frac{LOC_{non-studded}}{non-LOC_{non-studded}} \quad (7)$$

$$OR_{ESC_2} = \frac{LOC_{studded}}{non-LOC_{studded}} \quad (8)$$

MATERIALS

Rear-end injury crashes

Rear-end injury crashes involving passenger cars during 2008-jan 2014 were selected. The study was limited to crashes occurring in the winter period, in this study defined as October through to March. In this period studded tyres are allowed in Sweden. Only crashes involving two cars were included (n=4239).

In the accident database STRADA no information is given on type of tyres, therefore additional information was collected from a sample of drivers involved in rear-end crashes during the winter period, using a questionnaire. The questionnaire was designed as a postcard (A5-size) with four questions (Appendix 2). The first dispatch included the postcard and a missive, which were both put in an envelope. Two weeks later a reminder was sent out on a postcard and the respondents were informed about the option to answer a web-based questionnaire. The survey data collection period was May– June 2014.

In total, 4239 car drivers were identified to have been involved in winter period rear-end crashes, but the addresses were only available for 3945 of them, due to incomplete personal identification in the register or people living abroad, being deceased or having unknown/confidential address. A number of 31 questionnaires were returned to the sender, which indicated that the driver had moved from the address. Three of the respondents actively refused to answer the questionnaire. In all, 23 of the crashes appeared not to be rear-end collisions according to the accident descriptions given by the respondents. The overall response rate was 17 % (Table 1).

Table 1.
Response rate and number of survey non-respondents.

Total sample	**No. of cases**
Total sample from STRADA	4239
Total posted questionnaires	3945
Respondents	
Total answers	728
Non response	
Refusals	3
Address known, but no response	316
Personal ID incomplete	211
Respondent living abroad, deceased or unknown	83
Return to sender	31
Over coverage	
Not a rear-end collision	23
The response rate	17%

Out of the 728 respondents, eleven cases were not possible to include in the analysis due to incomplete data. In total, 717 cases were further investigated. Table 2 shows the number and proportion of striking and struck cases.

Table 2.
Proportion of striking and struck vehicles in the respondent group.

	No. of cases	**Proportion**
Striking	265	37%
Struck	452	63%
Total	717	100%

In Table 3, type of tyre is illustrated. As the purpose of this study was to examine the difference between studded (n=379) and non-studded (n=207) winter tyres, only these types of tyres were included in the final dataset and used in the induced exposure calculations.

Table 3.
Type of tyre in the respondent group.

Type of tyre	No. of cases	Proportion
Studded	379	53%
Non-studded	207	29%
Summer	111	15%
Unknown	20	3%
Total	717	100%

Fatal crashes

The Swedish Transport Administration (STA) has been carrying out in-depth studies for each fatal road crash since 1997. At STA, crash investigators systematically collect information from the crash site as well as inspect the vehicles involved in fatal crashes and record direction of impact, vehicular intrusion, seat belt use, airbag deployment, tyre properties, etc. Information collected from the crash site is for example road characteristics, collision objects, etc. Information about injuries is provided by forensic examinations and emergency services. Also questioning and witness statements from the police are included in the in-depth studies. The Norwegian Public Roads Administration (NPRA) has been conducted in-depth investigations based on a similar process.

The analysis of fatal crashes used in-depth studies of fatal crashes collected by STA and NPRA in all winter period (Nov-March) between 2003 and March 2014. Crashes on dry or wet roads were excluded from the analysis since these crashes were assumed to be non-sensitive to studded tyres. Cases in which the cars were not fitted with approved winter tyres (i.e. thread depth below legal requirement of a minimum 3 mm or majority of studs missing) were excluded from the analysis. Also cases with documented suicide or death of natural causes. Two datasets were acquired. One including cars fitted with ESC (n=44) and one with cars not fitted with ESC (n=260). All crashes were analysed with regard to crash characteristics and type of winter tyres.

RESULTS

Rear-end injury crashes

In Table 5, the result from the odds ratio calculations for striking/struck cars in rear-end injury crashes are shown for all road conditions, ice and snow as well as dry conditions. Overall, on all road conditions, no significant difference was found between studded and non-studded winter tyres. In the specific case with braking applied by the striking car no significant difference was found on dry roads. However, on ice or snow, a 51% risk reduction for being the striking car was observed on cars fitted with studded tyres (CI95, 51%±24%).

Table 4.
Number of striking/struck cars in rear-end injury crashes with studded and non-studded winter tyres.

	Striking	Struck	Odds ratio
All road conditions			
Studded	142	237	0.6
Non-studded	85	122	0.7
Ice and snow			
Studded	81	163	0.5
Non-studded	47	46	1.02
Dry			
Studded	40	57	0.7
Non-studded	33	58	0.6

Table 5.
The effect of studded tyres in reducing the risk of being the striking car in a rear-end injury crash.

	Effect	CI95
All road conditions	14%	± 30%
Ice and snow	51%	± 24%
Dry	-23%	± 73%

The overall non-significant result for all road conditions was based on a proportion of 60% ice and snow and 40% dry or wet roads. Naturally, this proportion varies in different parts of Sweden. The overall results for northern, mid and southern parts of Sweden were therefore calculated (Table 6). In the northern part of Sweden, cars with studded tyres had a significantly lower risk for being the striking vehicle in a rear-end injury crash. No significant results was found in the mid or southern regions.

Table 6.
The effect of studded tyres in northern, mid and southern Sweden.

	Striking	Struck	Effect	CI95
Northern Sweden			55%	± 50%
Studded	32	62		
Non-studded	8	7		
Mid Sweden			-1%	± 45%
Studded	93	145		
Non-studded	47	74		
Southern Sweden			10%	± 68%
Studded	18	29		
Non-studded	29	42		

Fatal crashes

Regarding fatal crashes, the relative risk of being involved in a LOC crash depending on studded on non-studded tyres in non-ESC cars are shown in Table 8. Based on these results, it was calculated that the risk reduction with studded tyres on non-ESC cars was 65%. As the proportion of LOC crashes on ice and snow was 64%, the total risk reduction with studded tyres on non-ESC cars was 42% (CI95, 42%±16%). The total number of LOC crashes with ESC cars was only 10 cases. For that reason, all ESC cars were grouped together, regardless of type of winter tyres. Out of the 44 ESC cars, 30 were fitted with studded tyres and 14 were fitted with non-studded tyres. The LOC/non-LOC odds ratio for all ESC cars was 0.29, compared to 3.5 for non-studded non-ESC cars and 1.22 for studded non-ESC cars (1.78 for all non-ESC cars).

Table 7.
Relative risk for loss-of-control in ESC and non-ESC cars with studded and non-studded tyres.

	LOC	Non-LOC	Odds ratio	Risk index
Non-ESC cars (n=260)				
Non-studded	42	12	3.5	1
Studded	113	93	1.22	0.35
ESC cars (n=44)	10	34	0.29	0.08

In non-ESC cars the risk reduction of LOC for studded tyres compared to non-studded was 65%. In ESC cars, the risk reduction, compared with non-ESC cars, was 92% including all types of winter tyres. In a similar way as for rear-end crashes, the effect of studded tyres depends on the proportion of traffic on ice and snow, which differs greatly between the different regions in Sweden. With non-ESC cars fitted with non-studded tyres, the risk for a fatal crash during the winter period increases in Southern Sweden by 9% compared to non-ESC cars with studded tyres. In the Middle and Northern part the same risk increase was 16 and 32%, respectively.

Figure 2. Fatal crash risk increase with non-studded tyres on non-ESC cars compared to studded tyres.

DISCUSSION

Rear-end injury crashes

In the first part of this study, studded winter tyres were found to reduce the risk of being the striking car in a rear-end injury crash on ice and snow by at least 27% (CI95, 51%±24%). Since the proportion of crashes on ice and snow differs greatly between different geographical regions, the overall effect of studded tyres in rear-end crashes also varies. On a national level, and in the mid and southern regions, no significant benefits were found. On the other hand, the effect on all road conditions was at least 5% in the northern regions (CI95, 55%±50%).

This was the first study to evaluate the benefit of studded tyres on a specific crash type such as rear-end injury crashes. This is a crash type in which better braking performance may play an important role. While the effects were large and significant, it should be noted that this particular crash type accounts for a small proportion of the total crashes during a winter period. Therefore, it is not surprising that earlier studies (Elvik 1999; Elvik 2013) only found small benefits on a macro level. As an example, rear-end crashes on ice and snow accounted for 4% of all injury crashes in the Stockholm region during 2010-2013. Under the assumption that 50% of the cars in that region are fitted with studded tyres, the overall effect of changing those tyres to non-studded winter tyres would be 1% increased risk of injury crashes (50%*50%*4%=1%), given that no other changes in the road environment occur (i.e. improved road maintenance).

One limitation in this study was the missing information on tyres in STRADA and the low response rate in the questionnaires (17%). The low response rate could depend on a number of reasons. One reason could be the fact that drivers may be ashamed, or just unwilling, to answer questions about their involvement in a crash were they are to blame as the striking part. This was also suggested by the high proportion (67%) of struck cars in the respondent group. The low response rate could naturally affect the representativeness and reliability of the result on a national level. However, the result could still be assumed as valid as the calculations were based on relative risk. Also, there is no reason to believe that the striking/struck proportion would vary in the respondent group dependent on the type of tyre.

In a case and control study with an induced exposure approach it is important to ensure that no confounding factors could influence the crash or injury risk. One obvious confounder could be the presence of Anti-lock Brake System (ABS) that is more prevalent on modern cars. However, the group fitted with non-studded tires involved newer cars making the result conservative. Control calculations with regards to other road, vehicle and driver characteristics are shown in Appendix 1. No significant differences between the case and control group were found. It could also be discussed weather being the struck part in a rear-end crash is a non-sensitive event related to studded tyres. Naturally, better braking performance could lead to a higher risk of being the struck vehicle. Thus, the result of this study could possibly also be influenced by a higher risk of the vehicles with studded tires of being the struck part in a rear-end crash.

Fatal LOC crashes

Loss-of-control is the most common crash scenario in fatal crashes in Sweden during the winter period and since these account for 64% of all fatalities (Strandroth et al., 2012), interventions addressing stability could be assumed to have great benefits on roads covered with ice and snow. In this study, the effect of studded tyres and ESC were analysed based on in-depth studies of fatal crashes that occurred in the period 2003-2014. On cars without ESC, studded tyres were found to reduce the risk of a fatal LOC crash by 65%, compared to non-studded winter tyres. That corresponded to an overall risk reduction of fatal crashes by 42% during the winter period.

ESC has been proven to be very effective in reducing LOC crashes (Ferguson, 2007). In fatal LOC crashes, excluded non-conformities (i.e. crashes where ESC is basically not expected to have any benefits), Lie (2012) estimated the effect to be 98%. The results of the present study were found to be in line with previous research, showing large benefits of ESC, independent of type of winter tyre. The number of LOC crashes with ESC cars were very few, 5 fatalities in Sweden 2003-2014 (further 5 when including data from Norway), which made it difficult to analyse studded and non-studded winter tyres separately. However, when ESC cars with studded (n=30) and non-studded (n=14) winter tyres were grouped and compared to non-ESC cars, the risk reduction of LOC crashes were 83%. If ESC cars were compared to non-ESC cars with non-studded winter tyres the risk reduction was 92%.

The very low number of LOC crashes with ESC cars and the consequent result in risk reduction suggested that ESC may be effective in reducing LOC crashes regardless of type of winter tyres fitted on the car. However, due to the small number of LOC crashes with ESC cars these results should also be taken with some caution; further studies are also needed on a population with a higher proportion of non-studded winter tyres.

It should also be noted that calculations based on in-depth data could be subject to subjectivity and thereby somewhat biased. In this study, the parameters subject to the analysis were clearly specified a-priori and precise guidelines were developed to classify LOC-crashes. Regarding the classification of different winter tyres, experts were sometimes consulted to distinguish between summer tyres and non-studded winter tyres. While studded tyres are fairly easy to recognize, it may be more difficult to determine whether a non-studded winter tyre is of Nordic or Central European type. There are mainly two types of non-studded winter tyres on the Swedish market, one suited for Nordic conditions and one for Central European conditions. Nordic non-studded winter tyres are mostly designed for roads covered with ice and snow and Central European non-studded winter tyres are designed for milder conditions and higher speeds (STRO, 2010). In this study, they were both grouped together as non-studded winter tyres.

CONCLUSIONS

There were a number of important findings in this research.

- ESC in combination with approved winter tyres reduces fatal LOC-crashes on ice and snow by 92%.
- One fatal LOC-crash on ice and snow occurs in Sweden every two years.
- Overall, similar results were found in the Norwegian in-depth dataset.
- Studded tyres on non-ESC cars reduce fatal crashes during the winter period by 9% in southern Sweden and by 32% in northern Sweden.
- Rear-end crashes on ice and snow account for 2-8% of all injury crashes annually in Sweden. In these crashes, studded tyres reduce the risk of being the striking part in a rear-end crash on ice or snow by at least 27%. A statistically significant result was found for northern Sweden, but not for mid or southern Sweden.

ACKNOWLEDGMENTS

The authors gratefully acknowledge Magnus Larsson at the Norwegian Public Roads Administration (NPRA) for providing in-depth data and valuable input on this research.

REFERENCES

Auto Motor & Sport (Swedish variant), 2008. Test of non-studded winter tyres. Nr. 22, 2008, Stockholm, Sweden.

Auto Motor & Sport (Swedish variant), 2010. Test of winter tyres. Nr. 22, 2010, Stockholm, Sweden.

Elvik R, 1999. The effects on accidents of studded tyres and laws banning their use: a meta-analysis of evaluation studies. Accident Analysis & Prevention 31, 125-134.

Elvik R, Fridstrøm L, Kaminska J, Meyer SF, 2013. Effects on accidents of changes in the use of studded tyres in major cities in Norway: a long-term investigation. Accident Analysis & Prevention 2013 May;54:15-25.

Ferguson SA, 2007. The Effectiveness of Electronic Stability Control in Reducing Real-World Crashes: A Literature Review. Traffic Injury Prevention 8, 329-338.

Folksam, 2015. Customer Guidance for Choosing Winter Tyres. http://www.folksam.se/testergodarad/sakeritrafiken/bilsakerhet/1.91156 (2015-03-06).

Gustafsson M, Berglund CM, Forsberg B, Forsberg I, Forward S, Grudemo S, Hammarström U, Hjort M, Jacobson T, Johansson C, Ljungman A, Nordström O, Sandberg U, Wiklund M, Öberg G, 2006. Effects of winter tyres – state of the art. VTI-rapport 543. Swedish National Road and Transport Research Institute, Linköping, Sweden.

Johansson, C., M. Norman, G. Omstedt, and E. Swietlicki. Partiklar i stadsmiljö – källor, halter och olika åtgärders effekt på halterna mätt som PM10. SLB Analysis Report 4:2004.

Lie A, Tingvall C, Krafft M, Kullgren A, 2006. The Effectiveness of Electronic Stability Control (ESC) in Reducing Real Life Crashes and Injuries. Traffic Injury Prevention 7, 38-43.

Lie A, 2012. Nonconformities in Real-World Fatal Crashes – Electronic Stability Control and Seat Belt Reminders, Traffic Injury Prevention, 13:308–314.

Scandinavian Tyre and Rim Organization, 2010. Different winter tyres are good at different things. http://www.dackinfo.se/ (2010-09-28).

Stockholm Municipality, 2015. Banning studded tyres on Hörnsgatan. http://www.stockholm.se/Fristaende-webbplatser/Fackforvaltningssajter/Trafikkontoret/vinterdack/Dubbdacksforbud-pa-Hornsgatan/ (2015-03-06).

Strandroth J, Rizzi M, Olai M, Lie A, Tingvall C. The effects of studded tyres on fatal crashes with passenger cars and the benefits of Electronic Stability Control (ESC) in Swedish winter driving. Accident Analysis & Prevention 2012;45:50–60.

Tuononen A, Sainio P. 2014. Optimal proportion of studded tyres in traffic flow to prevent polishing of an icy road. Accident Analysis & Prevention, 2014. Nro 65, 53-62.

APPENDIX 1

Table A.
Controls for the study on rear-end injury crashes.

	Studded tyres	Non-studded tyres
Injury severity		
Severely injured	5 %	4 %
Slightly injured	57 %	53 %
Uninjured	34 %	40 %
Unknown	5 %	4 %
Sum	100 %	100 %
Road conditions		
Snow	20 %	15 %
Dry	33 %	54 %
Thin ice	32 %	20 %
Thick ice/packed snow	15 %	11 %
Sum	100 %	100 %
Driver age		
18-24 y	9 %	9 %
25-65 y	75 %	80 %
65< y	15 %	11 %
Sum	100 %	100 %
Driver gender		
Male	55 %	61 %
Female	45 %	39 %
Sum	100 %	100 %
Speed restriction		
30-60 km/h	38 %	39 %
70-90 km/h	33 %	29 %
100-120 km/h	21 %	23 %
Unknown	8 %	9 %
Sum	100 %	100 %
Car Model Year (MY)		
Mean MY	2002	2004

APPENDIX 2

Frågor om däck vid olycka

1. Var du förare av:

- ☐ Den bil som körde på bilen framför
- ☐ Den bil som blev påkörd bakifrån

2. Om du var förare av den bil som körde på bilen framför, hann du bromsa innan kollisionen:

- ☐ Ja
- ☐ Nej
- ☐ Vet ej

3. Den bil du körde när olyckan inträffade, hade den

- ☐ dubbade vinterdäck
- ☐ dubbfria vinterdäck
- ☐ sommardäck
- ☐ vet ej

4. Om du körde med dubbfria vinterdäck, var de

- ☐ dubbfria vinterdäck gjorda för nordiska förhållande
- ☐ dubbfria vinterdäck gjorda för centraleuropeiska förhållande
- ☐ vet ej

5. Övriga kommentater

....

....

vti TRAFIKVERKET

Figure A. Questionnaire sent to retrieve information on type of tyre (in Swedish).