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Vehicle in-use tyre characteristics evaluation during winter driving training

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Abstract. After the substantial number of fatalities in road traffic increase with the start of icy 2014–2015 winter conditions in Latvia drivers have been offered complimentary winter driving training. Having numerous drivers with their cars performing the same braking actions on restricted and safe test ground gave a good opportunity for evaluating driver skills and vehicle in-use tyre condition. Tyre age and tread depth were measured and driving instructions have been given to more than a thousand participants. Instrumented braking and manoeuvring measurements were made for thirty cars. The equipment included GPS receiver and decelerometer. Measurement results have been compared against physical observations and hints given by professional driving instructors. The comparison indicated that although the suggestions given to drivers by professional instructors clearly contribute to safer driving, the visual evaluation without measuring may lead to various errors in messages conveyed to drivers. The most questionable statement was about the influence of the vehicle mass on braking distance. The investigation did not show essential vehicle mass influence on tyre grip and correspondingly on braking characteristics. Tyre tread depth effect on braking performance demonstrated the relevance of technical requirements for winter tyres. The advantage of using public training for winter tyre in-use experiments is lower cost for getting tyre samples with various technical conditions. The disadvantages are the different skills of car owners, the need for individual instructions and the necessity to reckon with the training format, the limited choice of the testing variables and substandard conditioning of the road surface. The tests gave valuable information for further training sessions and coming winter tyre tests.

Key words: traffic safety, braking, tyre grip.

INTRODUCTION

The start of 2014–2015 winter season on Latvian roads turned out tragic. Due to fast changing weather conditions, the road maintenance was not capable of fast and effective road surface treatment. Many drivers failed to act adequately on icy highways and rural roads. During two months with winter conditions the number of deaths compared to the previous year almost tripled. Latvian Road Traffic Safety Directorate decided to offer complimentary winter driving training hoping both to increase skill levels of the participants and to draw more attention to safer driving on icy roads. Area at state owned car race track Bikernieki in Riga was offered for training.

Equipping test vehicles with different tyres having various technical condition is labour and resources intensive. Renting and conditioning a safe test ground is quite costly and there are no many test grounds on offer in the region. Therefore having numerous drivers with their cars in constrained area performing the same braking and manoeuvring actions seemed a worthy chance to perform research on certain driving skills and in-use tyres grip on icy and snowy surface.

While observing the training process certain misinterpretation of vehicle dynamics by professional driving instructors has been noted. Although absolute majority of practical advice given to the drivers was accurate, the theoretical interpretation of driving mechanics rose interest in how proficient trainers came to certain theories. The most questionable were statements about vehicle mass influence on braking distance. This supplemented the initially planned subject of the research of finding updated in-use tyres braking characteristics variations on winter road surfaces by analysis of winter driving training blunders.

The history of winter tyres and road grip improvement in snowy and icy conditions goes back to 1930-s. From 1970-s many countries have introduced laws relating to mandatory use of winter tyres during certain winter period or meeting specified winter conditions. However various countries having different weather conditions and temperature range variations, having or lacking mountainous regions or many roads with steep gradient, face different winter problems and therefore the legislation varies from country to country. Currently the usage of winter tyres with tread depth at least 4 mm is mandatory in Latvia from 1st December to the end of February; studded tyres are prohibited from 1st May till the end of September.

The road and tyre friction has a great impact on traffic safety (Wallman & Åström, 2001). To provide ground for legislation change and to develop and promote new tyre models, a lot of research has been done in many countries. The tyre friction on ice and snow is tested in tribology laboratory experiments (Skouvaklis et al., 2012); (Ella et al., 2013), on special tyre traction testing machines, (Gießler, 2007), on full scale conditioned test grounds (Hjort & Eriksson, 2015) and on winter roads (Walus, 2016). Since there is no tyre production in Latvia, the most interest is in the process of deterioration of tyres and performance of used winter tyres on snowy and icy roads.

A leading Swedish National Road and Transport Research Institute VTI is located in Östergötland region where weather conditions are quite similar to Latvia. Therefore apart from doing some local tests it has been always worth to follow the VTI findings in traffic safety. In the most recent research (Hjort & Eriksson, 2015) on tyre test equipment and on properly prepared test grounds studies how the road grip on ice and snow for different types of winter tyres degrade by age and degree of wear, how Nordic and European, budget and premium brands produce different results. Investigation of the correlation between grip on rough ice of winter tyres and their age, tread depth and tread rubber hardness (Nordström, 2003) emphasizes the advantage of studded and new tyres but due to very few tyres with tread below the minimum does not show the consequences of ignoring the law. Although new tyres show better performance (Nordström, 2004), contrary to the opinions of tyre advisors, investigation of the influence of tyre age in the range from 5 to 15 years did not prove tyre grip change.

The research objectives were to supplement and update tyre in-use grip characteristics in winter conditions, to develop tyre characteristics evaluation techniques without costly test ground conditioning, to test the hypothesis about car braking intensity dependence on vehicle mass and to comprehend how this hypothesis has emerged. The scope of the research was limited by the cars participating in the training and does not represent the full range of in-use tyres, the findings were limited by the weather and road surface conditions available, no tests were performed on smooth ice or in deep snow.

MATERIALS AND METHODS

The driver training was done according to organizers plan. To benefit from having more trainees, the number of activities by each vehicle was limited to one straight braking and four to six braking with manoeuvring trials. The participants were asked to accelerate to 50 km h^{-1} and from the line marked by lying traffic cones in a corridor to perform a full emergency braking to standstill (Fig. 1).

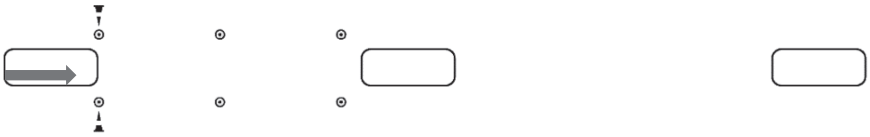


Figure 1. Braking schematics showing car positions from the start of braking to standstill.

To perform vehicle manoeuvring and braking trials the braking section was supplemented with cones displaced closer than the vehicle stopping distance (Fig. 2), requiring a manoeuvring similar to braking with line change. The participants were asked to accelerate to 50 km h^{-1} and from the line marked by lying traffic cones to stop the vehicle without hitting the traffic cones.

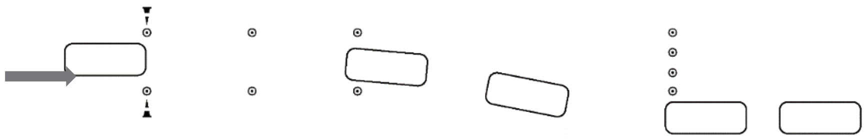


Figure 2. Manoeuvring with braking schematics, showing car positions from the start of braking to standstill.

The trainers evaluated braking distance for braking trials and the ability of drivers to avoid cones and return into driving direction after manoeuvring effort. To calculate the tyres in-use grip characteristics and to appraise the trainers' capability of decision making based on visual evaluations for each participant group, one car was equipped with VBOX GPS meter Driftbox logging GPS and speed data every 0.1 s and Inventura decelerometer XL Meter logging longitudinal and lateral acceleration every 0.05 s. Logged data were downloaded to Excel and processed and visualized using Excel VBA code and Uniplot software. The braking start positions, vehicle trajectories and braking distances were calculated from GPS data using flat Earth model, braking speed found from GPS speed recordings and accelerations calculated both from speed recordings and decelerometer logs. Since all trainees did not fully comprehend the tasks, and several of trainer's conclusions dissipated to trainees needed to be checked, some planned tests were done on the same training sectors while the trainees groups changed and received instructions.

In total the measurements were done for ten training days until the training was interrupted by too warm weather conditions. Measurements were done for 30 cars, including two cars for planned tests, 200 runs measured, 69 straight braking events and 131 braking events with manoeuvring trials. Various car models equipped with appropriate size winter tyres have participated in the tests: Audi 80, A4, Q3, Q7, BMW 3 and 5 Series, Chrysler PT Cruiser and Voyager, Citroen C2, Dodge Caliber, Honda Accord and Civic, Lexus IS200, Mazda 6 and 626, Mercedes-Benz C Class, Opel Astra and Zafira, Seat Ibiza, Subaru SVX, Toyota Land Cruiser, Volvo S60 and XC70, VW Golf 7, Tiguan and Tuareg. Only cars equipped with ABS system were selected for the tests. For each vehicle the tyres year of production was determined and minimal tread depth recorded. The training ground was covered with 3 to 5 cm of packed snow with patches of ice underneath, the temperature was between -7°C and +3 °C.

The measurement data processing algorithm was formed in accordance to the results obtained from the passive experiment strategy. The braking characteristics and trajectories in relation to the acceleration line of each individual car for every measured run are shown on Fig. 3.

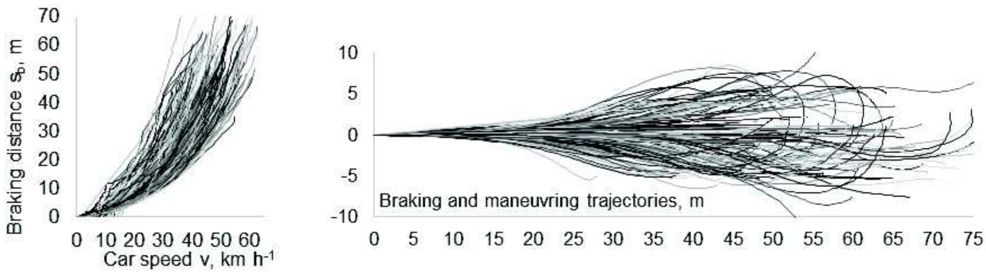


Figure 3. Braking distance (left) and trajectories (right) for all cars measured.

Both graphs show a huge variety in results. The braking distance from 30 km h^{-1} varies almost four times, not all cars have braked to standstill, many cars have not reached the target braking start speed 50 km h^{-1}, the trajectories of manoeuvres show essential discrepancy from the task, the loss of car control and running off the imagined road lane. Braking distance variations from 40 km h^{-1} can be seen on the right side of Fig. 4 while on the left side – the number of cars performing braking on the given stretch of the training ground.

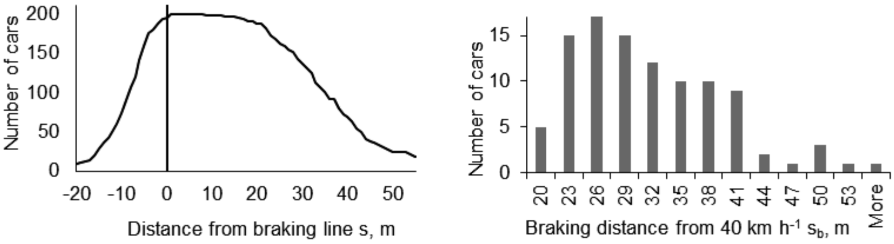


Figure 4. Braking start poin (left) and braking distance distribution from 40 km h^{-1} (right).

Both graphs show that more than 70 metres of the test ground have been used for braking and drivers have started braking even more than 20 m before the braking line. Although the braking test grounds were changed to other location and conditioned for the training almost every day, the number of cars performing training influenced the state of the road surface. The snowy surface of the training area was tamped by snow tractor or bulldozer and overrun by test driving. After the training sessions the condition of the training ground may be characterized by Fig. 5 where average deceleration of the cars has been plotted along the braking track. The average deceleration change by nearly 1 m s^{-2} or by over 50% results from the more intensive usage of the area between braking cones than the further area where both straight braking and avoiding the obstacles from both sides evens the road load. On the left graph the deceleration values are given both for braking without and with manoeuvring trials, indicating that on the most slippery braking ground stretch there was no essential difference between the test modes while manoeuvring along the obstacle cones was done at the expense of some braking efficiency.

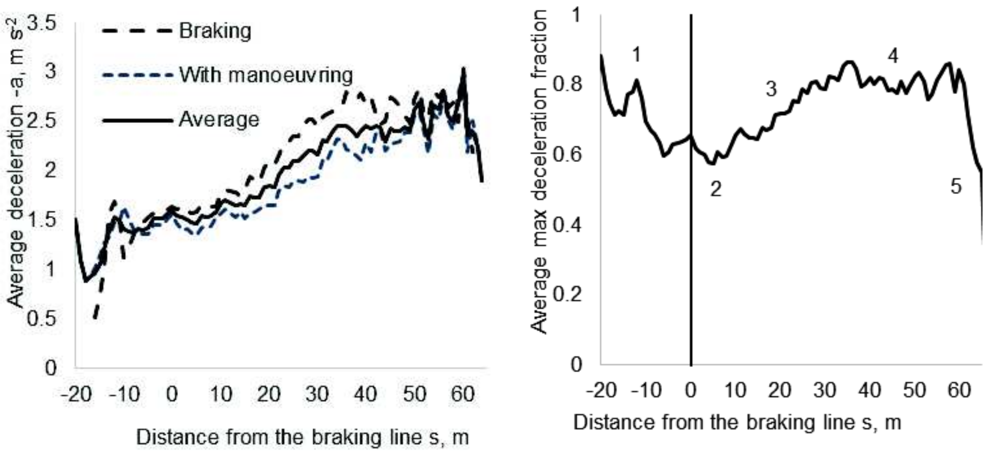


Figure 5. Average deceleration (left) and the fraction from the maximum deceleration (right) along the braking track.

If the braking efficiency along the track is characterized by the fraction from the maximal deceleration of each individual run then quite clearly five zones can be seen on the right graph of Fig. 5: 1 – early braking on less slippery surface; 2 – braking on the most slippery stretch between the traffic cones; 3 – start of the manoeuvring; 4 – less hurt road surface with higher grip; 5 – end of braking. Due to the changing road friction along the test track, the braking intensity calculations were made for separate track parts characterized by the distance from the intended braking line marked by traffic cones in increments of 1 m and 5 m.

Distribution of braking intensity (number of cars braking at given intensity range) is shown on Fig. 6. It can be seen that almost at every braking track section wide range of braking intensity is present. Nevertheless the most represented area is the same as for the zone of average values. The graphs indicate that along the whole braking track emergency braking may have not been applied and the maximum deceleration values are more informative than average values, therefore braking results have been evaluated by maximum deceleration in segments of distance and in segments of every 10 km h^{-1}.

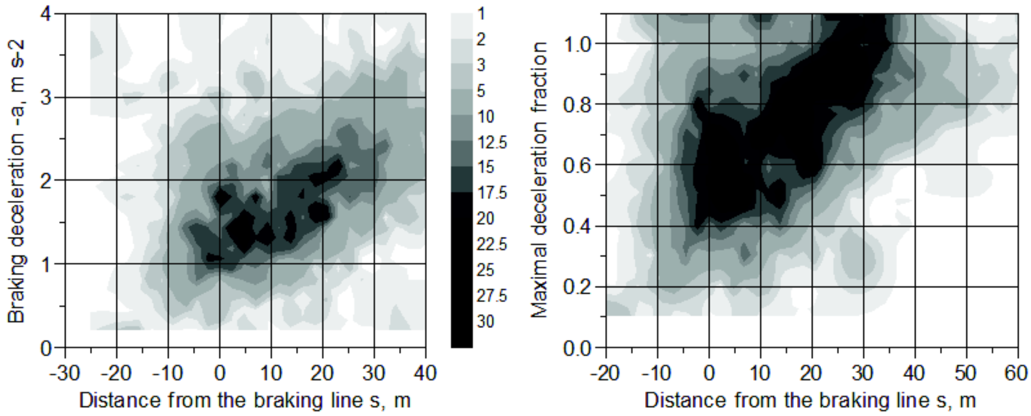


Figure 6. Distribution of the braking deceleration (left) and the fraction from the maximum deceleration (right) along the braking track.

Driver training started by theoretical instruction. Among other practical and correct driving tips the trainers developed the hypothesis that the car braking distance for heavier cars on snow is essentially longer than for lighter cars. Appreciating the practical experience of the instructors it was decided to check the stated hypothesis.

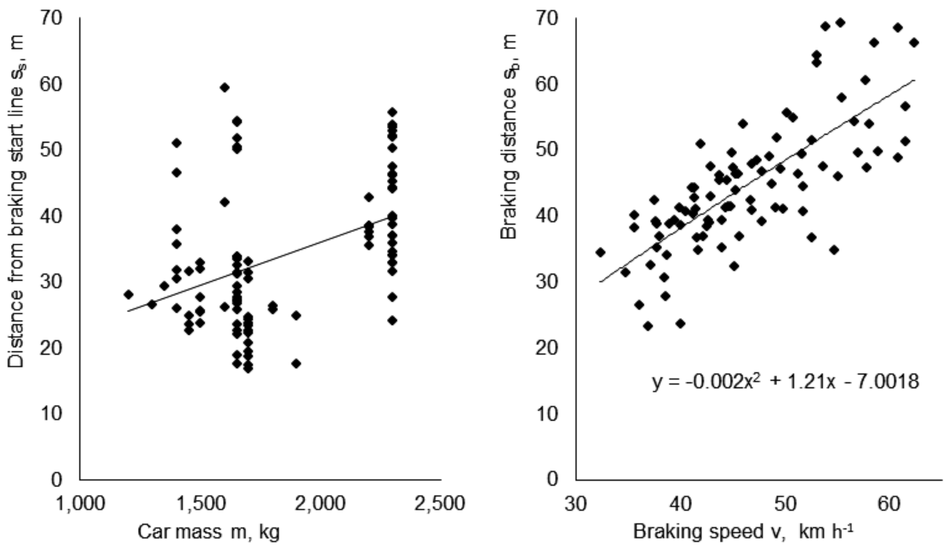


Figure 7. Confusing graphs with trendlines from the training: braking distance dependancy on mass (left) and braking distance dependancy on braking commencement speed (right).

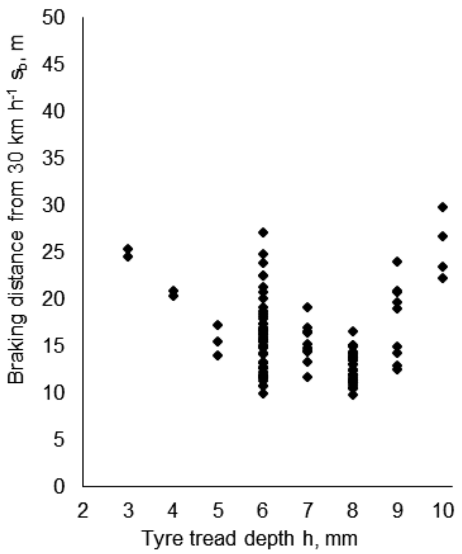
The draft results of the mass influence is shown on the left of Fig. 7 where car stopping position that can be fixed by trainers allegedly indicates that heavier cars may have some ten extra meters of braking distance from 50 km h^{-1}. Other draft graph shown on the right of Fig. 7 suggested that braking distance on snow is almost linear to the braking speed. Both confusing findings have been analysed along with tyres in use influence on braking efficiency in snowy conditions.

RESULTS AND DISCUSSION

The car in-use tyre characteristics have been evaluated by measuring car braking speed, deceleration and GPS coordinates on uneven snowy road segments during winter driving training at the dedicated test track area. The influence of tyre tread depth, tyre age, using studs and vehicle mass on braking distance, maximal deceleration and average deceleration in speed and distance intervals have been analysed.

Tyres with equal tread depth for the tested cars have been manufactured in five year range and no essential difference in braking characteristics on snowy surface has been found for this short period and the limited number of cars. Only six cars equipped with studded tyres have been used for training. The studs did not demonstrate advantage on snowy surface but due to the small number of tests the results have not been further analysed and the cars have been excluded from the analysis of tyre tread depth influence on braking characteristics.

Braking distance graphs from 30 and 45 km h^{-1} are shown on Fig. 8. Cars that did not fully stop or braking intensity reduction in speeds below the test speed has been noticed in the braking or manoeuvring process have been excluded from the results, but even the limited size of the test sample shows essential difference in braking intensity with tyre tread depth below 6 mm.



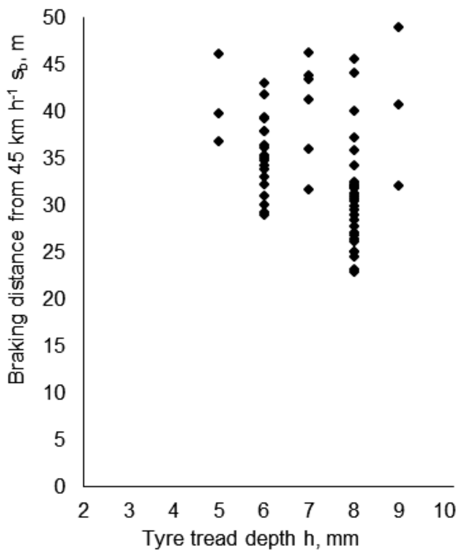


Figure 8. Braking distance from 30 km h^{-1} (left) and 45 km h^{-1} (right).

Plotting results for braking maximal deceleration within limited speed or distance ranges on Fig. 9 allows the usage of data from cars that did not fully stop, diminished the braking force during braking or manoeuvring. The results confirm the same trend of strong influence of tyre tread depth on braking intensity.

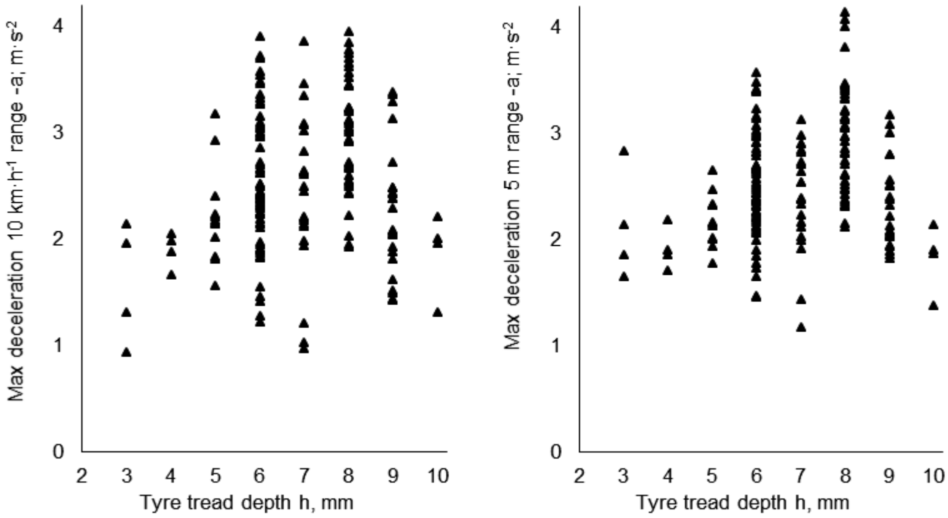


Figure 9. Braking maximal deceleration within 10 km h^{-1} range (left) and 5 m range (right).

Even more regular results have been obtained from the analysis of maximal deceleration achieved on particular distance from the braking line shown on Fig. 10. The results approve the tread depth requirements for winter tyres in use and suggest that mounting tyres close to minimum requirements at the start of winter season compromises with safety on snowy roads.

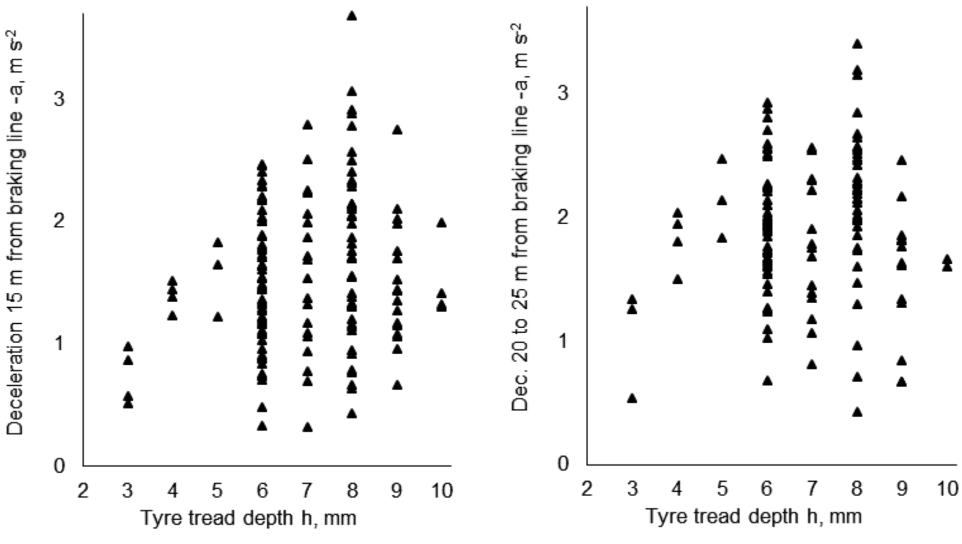


Figure 10. Braking deceleration 15 m (left) and 20 to 25 m (right) from braking line.

The recorded influence of tyre tread depth on maximal deceleration in the region from 3 mm to 8 mm exceeds the trend shown in publications (Nordström, 2004, Jansen, 2014). This may be caused by the small number of runs with tyres with low and high tread depth.

Several tests and calculations have been done to test the hypothesis of car mass influence on braking intensity. The main graphs for these tests are shown on Fig. 11.

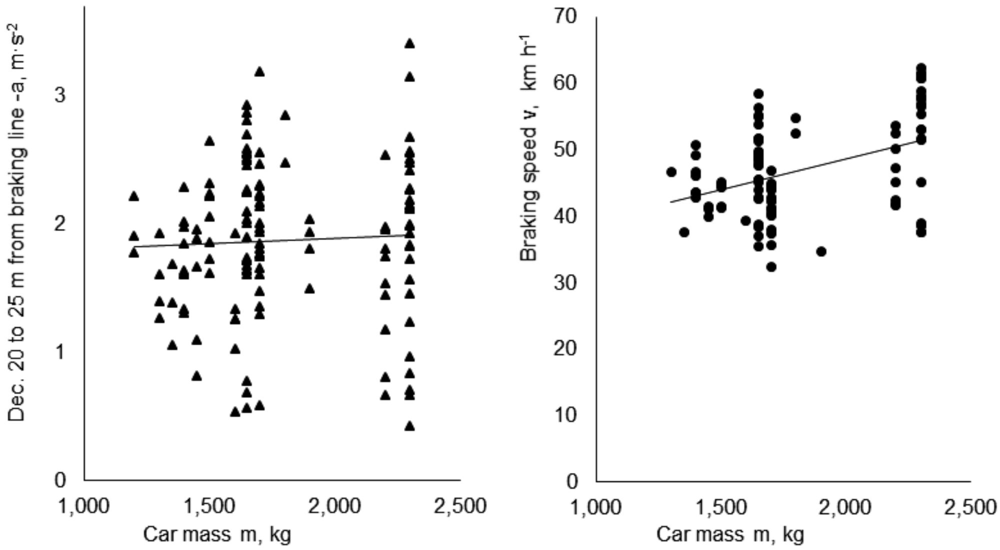


Figure 11. Car mass influence on braking intensity: deceleration (left), braking speed (right).

Although car mass may influence coefficient of friction (Skouvaklis et al., 2012; Gießler, 2012), no braking intensity decline has been recorded during the tests, including several separate tests where the same car has been tested with driver only and fully loaded with passengers. The perceptions of driving trainers about problems with heavier cars were clarified when car acceleration and braking speed was plotted against the car mass (Fig. 11, right). The proportion of all-wheel drive cars among the lighter cars is smaller than among the heavier cars. Due to safety reasons limited car acceleration distance has been offered for the trainees therefore cars with better tyre grip accelerated to higher speeds. This also explains the confusing graph on Fig. 7 right, where braking from higher speed is compensated by higher tyre grip, therefore the graph may have this form only when limited acceleration distance is available.

CONCLUSIONS

The vehicle in-use tyre characteristics evaluation in winter conditions can be done using events like driver training without setting up the training ground and specifically planning the experiments but the results obtained may be limited to existing road surface and weather conditions, tyre condition and models used by the participants and activities scheduled. Having less conditioned and less uniform braking ground for tests can be partially compensated by performing separate analysis on road sections with dissimilar grip, evaluating the maximal braking deceleration achieved in speed and distance intervals.

For the snowy winter conditions tyre tread depth has essential influence on road grip. Thread size below the legally allowed limit of 4 mm may reduce braking efficiency more than three times if compared with tyres with full tread.

Performing braking trials without instrumentation even by professional trainers may lead to incorrect judgements. The hypothesis of the driving trainers that heavier cars have essentially longer braking distance in slippery conditions was rejected. No essential mass influence on braking intensity was found and the inaccurate hypothesis has been originated from the wrong evaluation of initial braking speed.

Experience with tyre characteristics evaluation during winter driving training will help setting up more fundamental tyre grip tests in winter conditions.

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