ANALYSIS OF DRIVER-VEHICLE-INTERACTIONS IN AN EVASIVE MANOUEUVRE - RESULTS OF „MOOSE TEST“ STUDIES

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Paper Number 98-S2-W-35

ABSTRACT

In 1997 a so-called „moose test“, an evasive manoeuvre without braking at a speed between 60 and 65 km/h, led to improvements in the Mercedes A-class after two vehicles rolled over in this manoeuvre. The new A-class was presented to the press in January '98: more than 450 journalists from all over Europe tested the improved vehicle during a vehicle dynamics workshop at the Goodyear Proving Ground in Mireval/France. Five vehicles were equipped with data acquisition units providing data on the driver's input at steering wheel (angle and velocity) and foot pedals as well as on vehicle reactions (speed, lateral acceleration, yaw rate) and the interference of the Electronic Stability Programme (ESP). More than 2.000 tests conducted by over 400 journalists and experts were analysed in detail and compared to 131 moose tests performed by normal drivers. In addition, 30 normal drivers drove more than 15.000 km in real road traffic. The evaluation produces characteristic values of driver performance in extreme evasive manoeuvres on a test track compared with normal driving. The influences of individual driving style on test performance are analysed.

INTRODUCTION

The enhancement of Active Safety requires detailed data on driver-vehicle-interactions in critical driving situations. Based on the concept of "Real Life Safety", Daimler-Benz conducts test series with experts and with normal drivers at the Daimler-Benz driving simulator and in real world. Besides studies on driver behaviour, which form the basis for the development of assistance systems, standard manoeuvres are applied to verify the active safety of Mercedes vehicles at the highest level possible (e.g. ISO lane change).

The so-called "moose-test", which was not known in Germany before 1997, is supposed to test vehicle reactions in an emergency steering manoeuvre at (constant) speeds above 60 km/h (Figure 1). In order to assess the value of this manoeuvre as a test procedure for vehicle stability, the questions of test objectivity, reliability and validity have to be answered.

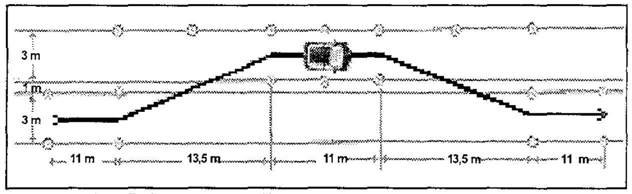

Figure 1. "Moose-Test".

In order to generate a sound basis for the evaluation of driver behaviour in this specific evasive manoeuvre, different driver groups are included: experts, motor journalists and normal drivers. Field tests with normal drivers serve to provide measures of steering behaviour in real road traffic (Table. 1). Results are also utilised for the evaluation of the "moose-test".

Table 1.
Data Base: Number, Conditions and Subjects of Tests

CONDITIONS	DRIVERS		
	Experts	**Journalists**	**Normal Drivers**
Proving Ground ("Moose-tests")	*Goodyear (France)* 12 drivers, 100 tests	*Goodyear (France)* 399 drivers, 1.957 tests	*Mercedes (Germany)* 30 drivers, 131 tests
Real Road Traffic			*Field Tests (Germany)* 30 drivers, 15.583 km

"MOOSE-TESTS"

Procedure

During the workshop journalists were given the opportunity to test the new A-class in 5 different manoeuvres. One of them was the "moose-test", where 5 vehicles were equipped with data acquisition devices to record measures of driver behaviour and dynamic vehicle reactions (Table 2). Two of these vehicles were loaded with additional weight (3*68 kg) on the back seats. It was noted for each test whether pylons were knocked over.

Table 2.
Data Obtained to Quantify Driver-Vehicle Interactions During the "moose-test"

Category	Measures
Driver Behaviour	vehicle speed
	steering wheel angle
	steering wheel velocity
	brake actuation
Dynamic Vehicle Reactions	lateral acceleration
	yaw velocity
	ESP-lamp
Test Performance	passed vs. not passed

Journalists were given information about the manoeuvre several times in advance, especially about the recommended speed for their first "moose-test" (50-70 km/h) and about the fact that braking within the manoeuvre is not allowed. They were free to choose a vehicle without acquisition devices if they did not want to be measured. Journalists who took one of the measuring vehicles were given feedback on their performance at the end of the workshop. Most of the participants drove at least 4 times. Usually vehicles were occupied by 2 journalists.

Entering Speed

Entering speed varied from 40 up to 85 km/h (mean 68 km/h), for valid tests up to 82 km/h (mean 62 km/h, Figure 2). Each journalist performed several tests, mean individual maximum entering speed for a valid test is 65 km/h. Speed decreased in the course of most tests (mode: - 7 km/h).

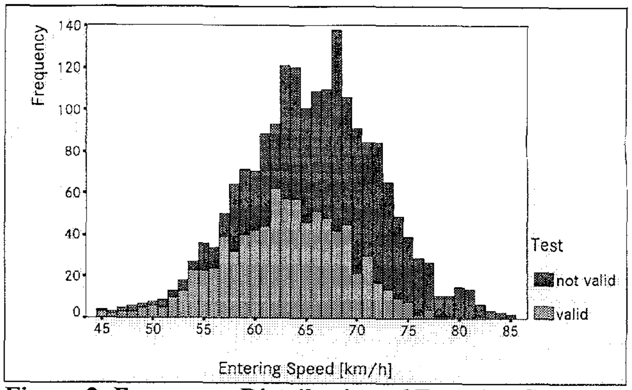

Figure 2. Frequency Distribution of Entering Speed for Valid and for Invalid "Moose-Tests" (399 Journalists, 1.957 Tests).

Test Performance

Tests were rated as valid if the driver did not brake or knock over pylons. In 11,8% of all tests, the brake pedal was actuated - 14% of 399 journalists did brake during their first test (Figure 3). Most of them were not aware of this fact when asked afterwards. This indicates that braking is included in many persons' subconscious reaction programme in a critical driving situation.

In 53% of all 1.957 tests, pylons were knocked over. This finding may be attributed to the difficulty of the manoeuvre as well as to the specific motivation of some journalists to test the behaviour of the A-class at the driving limits regardless of manoeuvre requirements. 43% of all tests are rated as valid and form the basis for further evaluation.

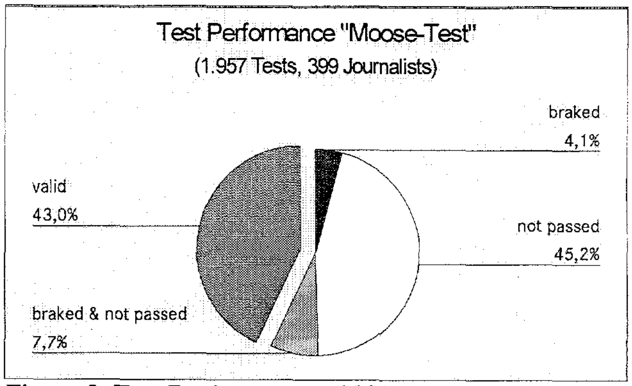

Figure 3. Test Performance of 399 Journalists in 1.957 "Moose-Tests".

Adaptation Effects

Changes in the individual behaviour in the course of several tests were expected due to increasing adaptation to vehicle and manoeuvre. Yet test performance does not increase, instead the percentage of valid tests decreases over 5 or more runs from less than 50% down to around 20%. This can be explained by a significant increase in speed. For valid tests, the mean increase in entering speed is 10%.

Steering Behaviour

Interindividual variations in steering behaviour are considerably high: maximum steering wheel angles vary between 98° and 335° in valid tests (mean 187°, Figure 4). Maximum steering velocity ranges between 292 and 1.335 °/s (mean 746 °/s, Figure 5). In 77% of all valid tests the maximum occurs when steering into the 3rd lane, in 22% the maximum occurs when stabilising in the 2nd lane. Values for maximum steering wheel and maximum steering velocity are correlated (r^2=0,67), Figure 6. Maximum values of yaw velocity range between 21 and 55 °/s (mean 37 °/s, Figure 7), of lateral acceleration between 4,2 and 12,1 m/s² (Figure 8).

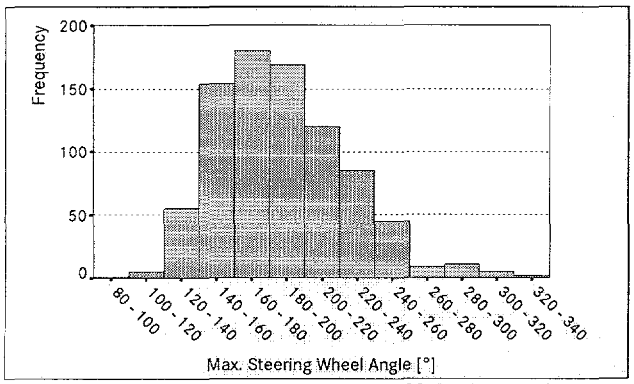

Figure 4. Frequency Distribution of Maximum Steering Wheel Angle (841 Valid "Moose-Tests" by 399 Journalists).

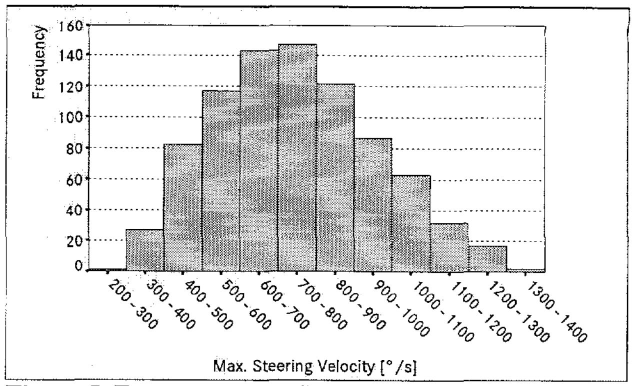

Figure 5. Frequency Distribution of Maximum Steering Velocity (841 Valid "Moose-Tests" by 399 Journalists).

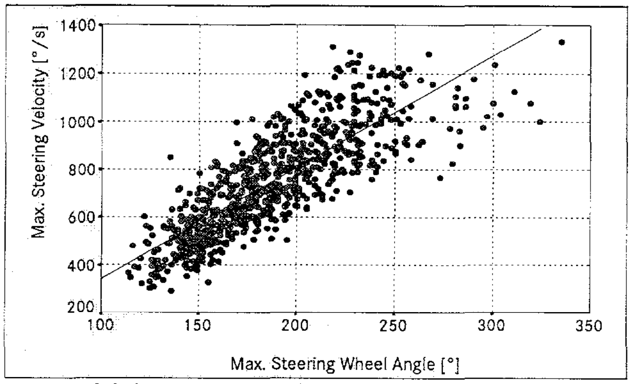

Figure 6. Maximum Steering Velocity as a Function of Maximum Steering Wheel Angle (841 valid "Moose-Tests" without ESP-Interference, Linear Regression: r^2 = 0,67).

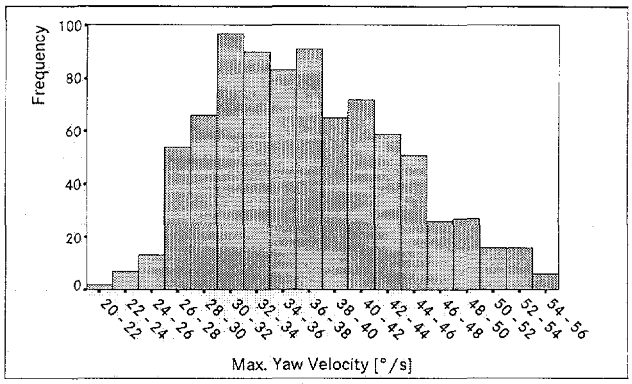

Figure 7. Frequency Distribution of Maximum Yaw Velocity (841 Valid "Moose-Tests" by 399 Journalists).

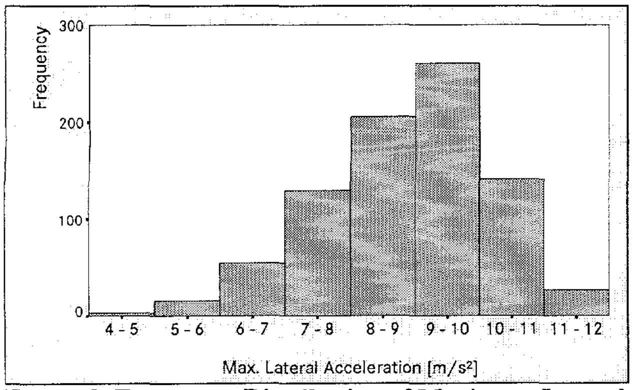

Figure 8. Frequency Distribution of Maximum Lateral Acceleration (841 Valid "Moose-Tests" by 399 Journalists).

ESP-Interference

26% of all valid tests were conducted without ESP-interference at entering speeds of up to 74 km/h (mean 58 km/h, Figure 9)). Especially steering wheel velocity is significantly lower for tests without ESP-interference (mean: 523 °/s vs. 824 °/s for tests with ESP-support).

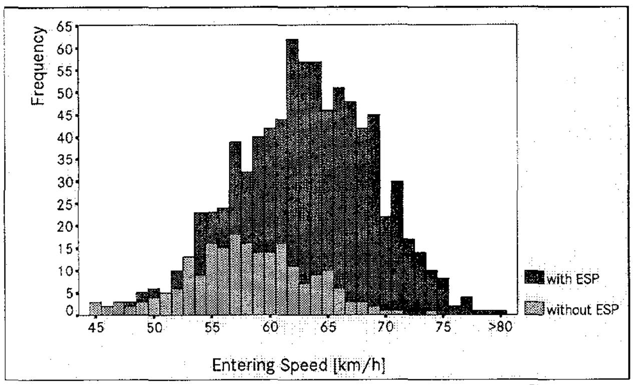

Figure 9. Frequency Distribution of Entering Speed for "Moose-Tests" with and without ESP-Interference (841 Valid Tests by 399 Journalists).

Loading and Road Surface

The percentage of valid tests was lower on wet road surface (205 tests) than on dry road surface (38 vs. 44%). While entering speeds did not differ significantly, values for lateral acceleration and yaw velocity were significantly lower (Table 3).

Table 3.
Significant Differences in Valid "Moose-Tests" on Dry (n=764) and Wet (n=77) (Differences: dry = 100%)

Measure		Surface dry	Surface wet	*Δ*
ESP-Interference	[%]	75	69	*- 8,0 %*
Lateral Acceleration	[m/s²]	8.9	8.5	*- 4,5%*
Max. Steering Velocity (Steering into 2nd lane)	[°/s]	148	121	*- 18,2%*
Max. Yaw Velocity				
Steering into 2nd lane	[°/s]	29	26	*- 10 ,3%*
Stabilising in 2nd lane	[°/s]	34	32	*- 5,9%*

Test in vehicles with maximum total mass do not differ in terms of test performance and steering behaviour. Entering speeds and lateral acceleration are slightly lower, yaw velocity is higher (Table 4). More tests were supported by ESP in vehicles with maximum total mass.

Table 4.
Significant Differences in Valid "Moose-Tests" in vehicles without additional loading (n=472) and in vehicles with maximum total mass (n=369) (Differences: without additional loading = 100%)

Measure		Mass < max	Mass max	*Δ*
ESP-Interference	[%]	69	81	*+ 17,4%*
Entering speed	[km/h]	64	61	*- 4,7%*
max. lat. acceleration	[m/s²]	9,0	8,7	*- 3,3%*
max. yaw velocity				
steering into 2nd lane	[°/s]	27	29	*+ 7,4%*
steering into 3rd lane	[°/s]	33	36	*+ 9,1%*
stabilising in 3rd lane	[°/s]	32	36	*+ 12,5%*

Experts vs. Journalists

Compared to journalists, experts for vehicle dynamics from Mercedes-Benz perform „moose-tests" at significantly higher speeds with lower values for steering wheel angle and steering velocity (see example in Figures 10-11).

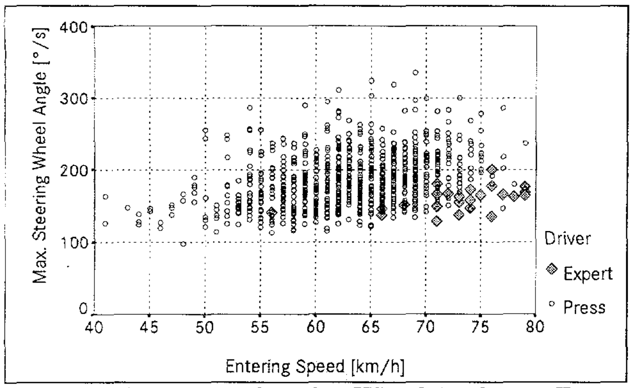

Figure 10. Maximum Steering Wheel Angle as a Function of Entering Speed in valid tests (Journalists vs. Expert Driver).

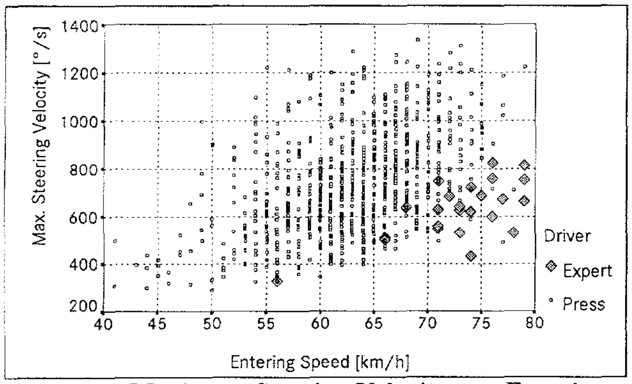

Figure 11: Maximum Steering Velocity as a Function of Entering Speed in valid tests (Journalists vs. Expert Driver).

Normal Drivers

30 normal drivers performed the „moose-test“ at the Mercedes test track in Stuttgart with one of the test vehicles (without additional loading, dry road surface). 77 out of the 131 tests were valid (59%; journalists: 43%), 40 out of which without ESP-support (52% vs. 26%). In 11,5 % of all tests the brake pedal was actuated (vs. 14,5%). Values for entering speed and steering velocity were significantly lower than those of the journalists. The relation between maximum steering wheel angle and steering velocity is equal for normal drivers and journalists (Figures 12 and 6).

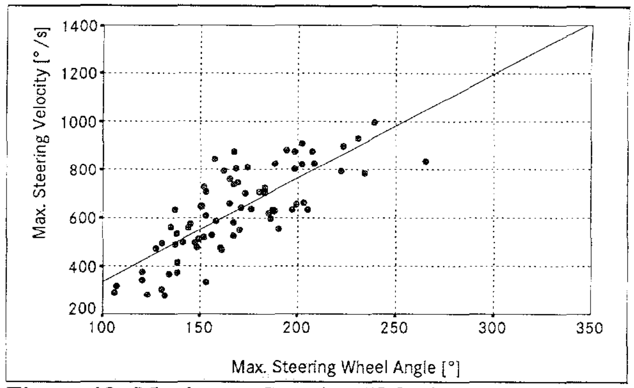

Figure 12. Maximum Steering Velocity as a Function of Maximum Steering Wheel Angle (77 Valid „Moose-Tests“ by 30 Normal Drivers, Linear Regression: r^2 = 0,61).

FIELD TESTS

Procedure

30 subjects took part in field experiments (Table 5). They were given one of the test vehicles for one or two days with the instruction to drive approx. 500 km, mainly on state and country roads. As the A-class is a very new product, none of the subjects was familiar with the test vehicle before.

Data on driver behaviour and vehicle reactions was stored at a frequency of 50 Hz. Subjects were interviewed after the test and provided additional information on driving conditions. A total distance of over 15.000 km was recorded. 17 tests were conducted under wet road conditions.

Table 5.
Field Tests with 30 subjects (14 female, 16 male): Sample Description (Minimum, Mean ± Standard Deviation, Maximum)

Measure		min	∅ ± sd	max
Age	[a]	19	34 ± 10	56
Driving Experience	[1000 km/a]	20	376± 320	1.500
Distance	[km/subject]	109	519 ± 181	938
Max. Speed	[km/h]	107	160 ± 22	199
Passengers		0	1,4 ± 1,0	4

Driver Behaviour

As expected (Bielaczek et al., 1996), measures of steering behaviour are closely related to speed: maximum values of steering wheel angle and steering velocity decrease over speed (Figures 13-14) like yaw velocity and lateral acceleration (Figures 15-16). Variations within the speed categories are assumed to be caused by differences in driving style, traffic and route characteristics (Breuer et al., 1996) which will be the matter of future analyses.

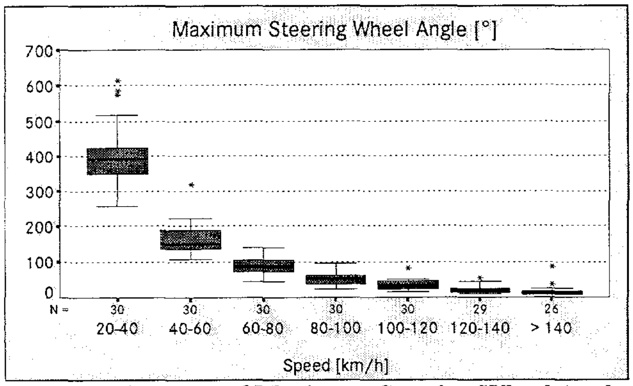

Figure 13. Boxplot of Maximum Steering Wheel Angle as a Function of Speed (30 Field Tests with Normal Drivers).

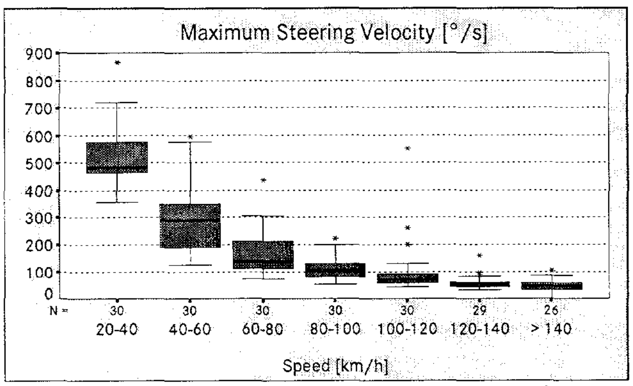

Figure 14. Boxplot of Maximum Steering Velocity as a Function of Speed (30 Field Tests with Normal Drivers).

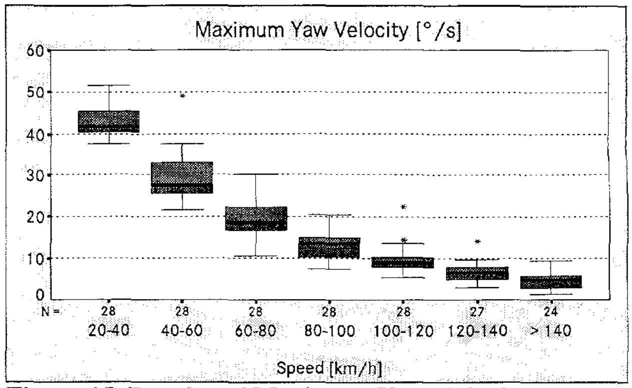

Figure 15. Boxplot of Maximum Yaw Velocity as a Function of Speed (30 Field Tests with Normal Drivers).

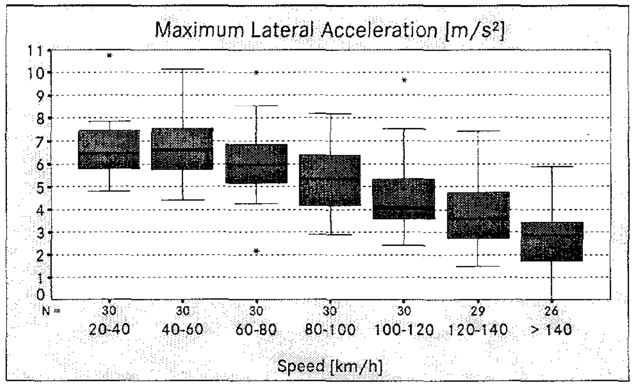

Figure 16. Boxplot of Maximum Lateral Acceleration as a Function of Speed (30 Field Tests with Normal Drivers).

DISCUSSION

Objective data prove that the new A-class passes the "moose-test" even at high speed. Depending on steering behaviour, the test can be passed at speeds up to 74 km/h without interference of ESP.

Steering reactions in this manoeuvre are extreme compared to real road traffic: steering wheel angles between 98 and 335° (mean 187°), steering velocity between 292 and 1.335°/s (mean 746°/s) and yaw velocity between 21 and 55°/s (mean 37°/s). As can be seen in Figures 17-20, the values obtained in "moose-tests" are far from those obtained in real road traffic at comparable speeds between 60 and 80 km/h.

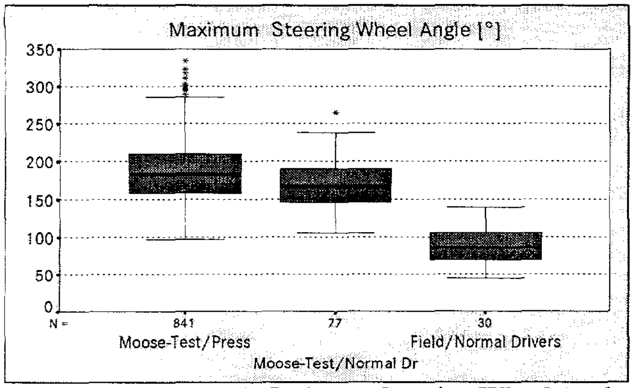

Figure 17. Boxplot of Maximum Steering Wheel Angle for 399 Journalists and 30 Normal Drivers in Valid „Moose-Tests" and for 30 Normal Drivers in Real Road Traffic at a Driving Speed Between 60 - 80 km/h.

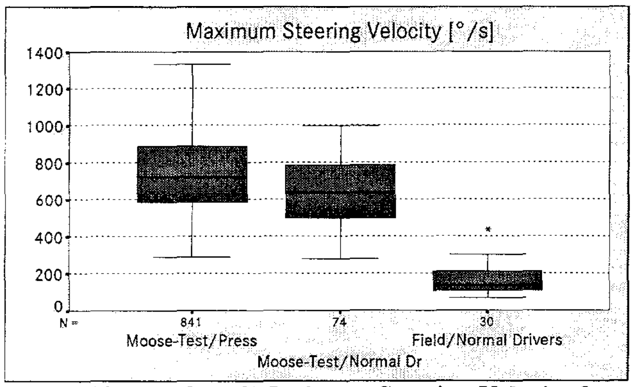

Figure 18. Boxplot of Maximum Steering Velocity for 399 Journalists and 30 Normal Drivers in Valid „Moose-Tests" and for 30 Normal Drivers in Real Road Traffic at a Driving Speed Between 60 - 80 km/h.

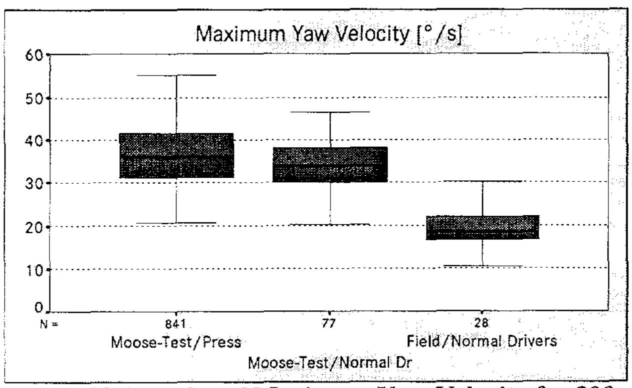

Figure 19. Boxplot of Maximum Yaw Velocity for 399 Journalists and 30 Normal Drivers in Valid „Moose-Tests" and for 30 Normal Drivers in Real Road Traffic at a Driving Speed Between 60 - 80 km/h.

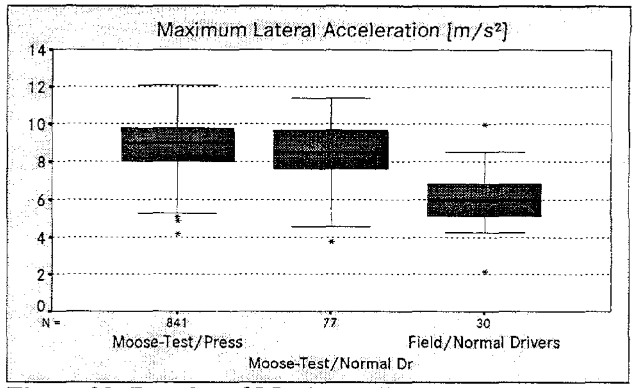

Figure 20: Boxplot of Maximum Lateral Acceleration for 399 Journalists and 30 Normal Drivers in Valid „Moose-Tests" and for 30 Normal Drivers in Real Road Traffic at a Driving Speed Between 60 - 80 km/h.

Performance in the "moose-test" with a given vehicle is mainly determined by the individual steering behaviour which is dependent on the driver's capabilities and motivation. Significant differences between groups of drivers (motor journalists, expert drivers, normal drivers), high variations within the groups and considerable intraindividual variations lead to the conclusion that this manoeuvre cannot be classified as an objective and reliable test for the active safety of a car.

The "moose-test" is supposed to test the vehicle reactions in an evasive manoeuvre caused by an obstacle which suddenly appears in front / at the right hand side of the vehicle. In earlier research work at Daimler-Benz concerning driver behaviour in critical situations (driving simulator and real vehicles, different kinds of obstacles, different speeds from 60 -120 km/h), braking or braking combined with steering were found as the most frequent reaction. Drivers who tried to cope by steering produced lower values for steering wheel angles and steering velocities than those found in the "moose-test" (see e.g. Zomotor, 1991). So it can be said that the test procedure requires a driving behaviour which does not seem to be typical for all drivers in critical situations.

Within the concept of Real Life Safety, further work at Daimler-Benz will concentrate on the detailed analysis of real driver behaviour in critical situations in order to derive realistic, objective and efficient test procedures and design criteria for enhanced Active Safety.

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ACKNOWLEDGEMENT

This paper is dedicated in deep gratefulness to my father, Professor Dr. Bert J. Breuer, who strongly promoted and successfully encouraged both research work and research workers in the fields of man-machine-interactions in road traffic safety.