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ANALYSIS OF DRIVER BEHAVIOUR IN AUTONOMOUS EMERGENCY HAZARD BRAKING SITUATIONS

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ABSTRACT

This paper describes the methods employed and results obtained from test drives with 90 test persons to assess driver behaviour using autonomous braking systems. The main focus was placed on the drivers' responses in autonomous hazard braking situations and drivers responses to malfunctions of autonomous hazard brakes. Test drives with passenger cars and trucks were carried out using the Darmstadt Dummy Target EVITA, a tool for simulating emergency braking situations with test drivers.

Over the last three years, several concepts have been presented for collision mitigation through braking. The Honda Collision Mitigation Brake System (CMBS) (1), the Mercedes BAS PLUS (2), the Audi Braking Guard (3) and the Lexus PCS (4) are some examples. For the assessment of different designs of autonomous braking systems, an interdisciplinary research team of automotive and ergonomic engineers of the Technische Universität Darmstadt, worked on behalf of six German OEMs and suppliers (Audi, Bosch, BMW, MAN, Opel, SIEMENS VDO) within the scope of the German research initiative "Aktiv" (Adaptive and Cooperative Technologies for the Intelligent Traffic) which was founded by the Federal Ministry for Economics and Technology (BMWi). "Active Hazard Braking" (AHB) (5) is a sub-project of this initiative.

INTRODUCTION

Although throughout Europe the trend in the number of accidents is declining despite the simultaneous rise in the continent's vehicle fleet, a glance at the accident statistics shows that there is still potential for active and preventive safety systems. According to findings by the *TÜV Rheinland* Technical Control Board (6), every fourth accident in Germany is caused by rear-end collision. Moreover, approximately 10% of all accidents are due to frontal collision. In nearly half of all serious accidents in passenger cars the driver did not actuate the brakes. The severity of the consequences of such accidents depends directly on the kinetic energy and hence on the square of the speed of collision. The task of safety assistance systems is to avoid accidents or to "prepare" the vehicle ready for an unavoidable accident. This is done by assisting the driver in avoiding accidents and/or mitigating the consequences of the accident for the passengers.

One approach to mitigating the severity of the accidents are systems which automatically actuate the brakes and assist the driver in this way. With this approach, the driver is prompted to actuate the brakes in a multi-stage process, ranging from an audio alarm to a brake jerk. Should the driver still not react despite these prompts, the automatic emergency brake (AEB) system engages, which up to now has only applied about half of the maximum possible deceleration. Future systems are to utilise the full braking power and be triggered early enough to even completely avoid an impending collision.

The goal of the present research subproject within the project AKTIV – AS (Active Safety) – AHB (Active Hazard Braking) was to assess how different configurations of active hazard braking impact on the momentum of the vehicles and survey the drivers' reactions.

OBJECTIVES

This study aimed to investigate two AHB variants with two different braking intensities: active hazard braking with full deceleration "AHB full" and active hazard braking with partial deceleration "AHB partial".

The effectiveness of each variant was to be determined in the case of justifiable interventions, i.e. when there is an acute danger of collision. The control comparison was the baseline where the test persons were given no AHB assistance. The parameter definitions of the examined AHB variants are shown in Table 1.

Table 1: Definition of the AHB variants to be examined

	AHB Full		AHB Partial	
	Pass. car	Truck	Pass. car	Truck
Deceleration [m/s²]	10	7	6	4
Time of engagement [s]	1.3			
TTC at engagement [s]	2.0			

Compared with previous studies (7), this test series was the first to also examine non-justified interventions in the system. The non-justified interventions (abrupt triggering of an AHB without danger of collision) examined in this study covered the three following potentially feasible faulty activations:

- Faulty activation of "AHB partial" with subsequent brake release
- Faulty activation of "AHB full" with subsequent brake release
- Faulty activation of "AHB full" to a halt

Table 2 indicates the parameters of these variants as determined in identification tests. They reflect the characters of the experimental vehicles and their installed braking systems.

Table 2: Definition of the AHB faulty activation variants to be tested

	AHB Partial with Release		AHB Full with Release		AHB Full to a Halt	
	Car	Truck	Car	Truck	Car	Truck
Max. deceleration [m/s²]	7.0	3.9	9.8	8.0	9.9	8.1
Deceleration build-up [m/s³]	12	31	12	56	10	58
Reduction in deceleration [m/s³]	-42	-25	-48	-25	-	-

Faulty brake activation "AHB partial to a halt" was discarded, as it was assumed that this would not occur later in series systems because of the long braking times due to cut-off algorithms.

METHODOLOGY

The Darmstadt test and evaluation method with EVITA - Experimental Vehicle for Unexpected Target Approach - was used to test the active hazard braking (8, 9).

The EVITA tool allegorizes the momentum of a vehicle ahead in a car-to-car convoy at a static distance in the event of abrupt braking. The model is a combination of a drawing vehicle, a trailer and the tailgate collision vehicle being tested (see Fig. 1). To put the test drivers in a situation typical for rear-end collision accidents during the trials and determine the effectiveness of the variants, they are distracted by a secondary task. This task consists of reading navigation data from a printed route planner held by the front-seat passenger (test supervisor) at the level of the lower centre-console. This secondary task, which is a proved and tested element of the procedure, can distract the test persons from the traffic situation for up to 2 seconds. During this time, the trailer (the Dummy Taregt) suddenly brakes, taking the test person driving the test vehicle by surprise. Independently of whether the test person reacts to the manoeuvre in time or not, the trailer is actively pulled out of the collision area.

Figure 1: The tool of Darmstadt Test and Evaluation Method (8)

To evaluate the active hazard braking an assessment period was established. This period begins at the time the autonomous braking is triggered and ends at the moment of the imaginary, non-braked impact of the test vehicle on the Dummy Target ahead which brakes uninterruptedly. The collision is "fictive", because with EVITA a collision is automatically avoided. The assessment period to test the active hazard braking is 2.0 s.

To determine the effectiveness of the active hazard braking, the speed of the test vehicle is measured at the beginning of the assessment period and the speed difference Δv is calculated from the extrapolated (fictive) velocity plot after 2.0s.

In addition to the CAN data, the driver's behaviour was surveyed using videos of the surroundings, data of driver eye movements, physiological data and questionnaires. The findings of the eye movement data are presented in (10).

TEST PERSONS

In order to make useful statements on how the driver's age influences the results, the passenger car trials were carried out with 60 test persons in two age groups. The younger age group covered drivers aged 25 to 40 years (Ø 30 years), the older age group drivers 50 to 65 years (Ø 59 years). Gender effects were investigated by having the same number of male and female drivers in each age group. Three test series were carried out, in which 20 test persons each experienced the variants "AHB full", "AHB partial" und baseline as their first test.

Test drives with the experimental truck were carried out with 30 test persons between 19 and 58 years of age (Ø 37 years). Attention was paid to ensuring that the majority were professional drivers. No subdivision was made according to age or gender. The baseline test series were carried out with five test persons, and the "AHB full" and "AHB partial" series with ten test persons each.

RESULTS - EFFECTIVENESS

Figure 2 shows the cumulated percentage of effectiveness in passenger cars for the variants AHB "partial" and "full" compared with the baseline test. It is particularly noticeable that while the higher effectiveness of both AHB variants is extremely significant compared to the baseline, they only differ slightly from each other. In the baseline test, the only way the drivers can notice that EVITA is strongly decelerating and causing a risk of collision is by occasionally glancing up front to check. Hence the first perception of danger mainly depends on the frequency and the timing of the forward glances. The driver then has to assimilate that a hazardous situation has occurred, move the foot to the brake pedal and actuate the brake. When assisted by an active hazard braking system, on the other hand, a brake jerk warns the drivers of the impending collision. Moreover, the driver does not have to assimilate the situation and actuate the brakes as described above, because this is done automatically by both systems.

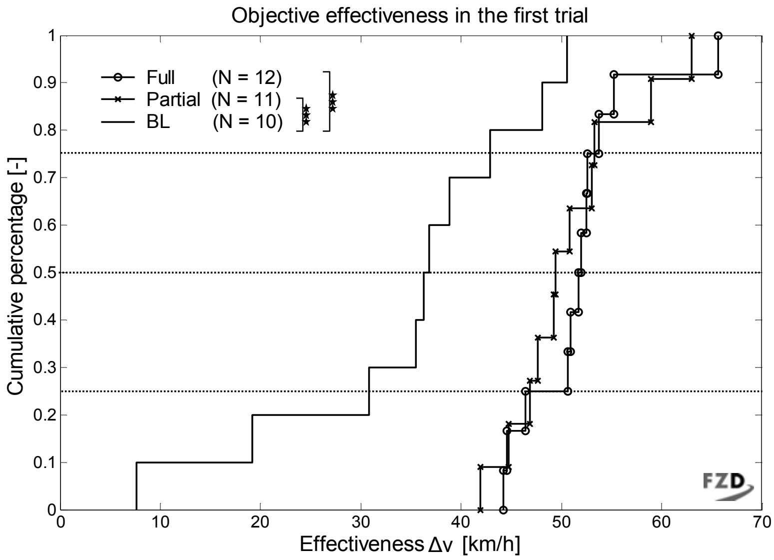

Figure 2: Cumulated percentage of the effectiveness in the first trial (passenger car)

While it could be assumed with the braking variant "AHB full" that the system itself would generate a greater deceleration and hence be more effective, the hypothesis of an analogous distribution among the two variants cannot be statistically refuted. The reason for this is that in the experimental vehicle used for the trials, the deceleration build up for both AHB variants is configured with almost identical gradients and the "AHB full" variant does not differ in terms of higher deceleration from that of the "AHB partial" until c. 800 ms at the earliest after commencement of braking. As the strong braking of most drivers overrides the braking actuation triggered by the system, full braking which is activated so late cannot achieve any higher degree of effectiveness. However, greater effectiveness could, for example, be realised by a more rapid deceleration build-up at the beginning of braking, before the driver is in the control cycle. In this way, with ideally rapid full braking, a mathematical deceleration of 20 m/s = 72 km/h could be projected.

Figure 3 illustrates the effectiveness in trials with the experimental truck. In contrast to the results obtained with passenger cars, there is a clear effectiveness rating at least at the "very significant" level: "AHB-full" is higher than "AHB-partial" is higher than baseline. The effectiveness of both AHB-variants is far superior to baseline. However, the test truck has a higher effectiveness level of statistically "very significant" for "AHB full" than for "AHB partial". This vehicle uses a very dynamic electro-pneumatic braking system with accumulator which allows "AHB full" to build up a higher deceleration than "AHB partial" as early as 300 ms after braking begins. The test drivers were able to override the system and actuate the brakes themselves after 500 ms at the earliest, which explains the advantage of the "AHB full".

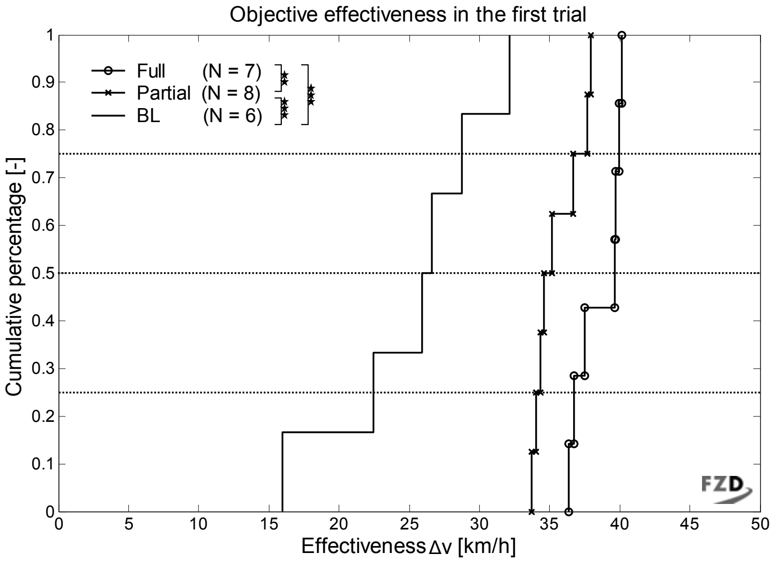

Figure 3: Cumulated percentage of the effectiveness in the first trial (truck)

RESULTS - EFFECTIVENESS ASSESSED BY THE DRIVERS

Without knowing which AHB variant they were had experienced, the test persons were asked whether subjectively they noticed a difference between the variants.

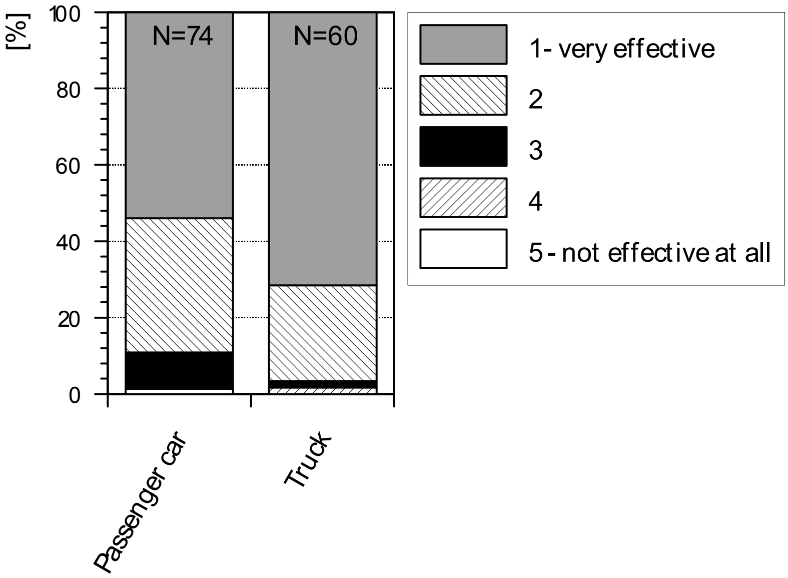

Figure 4: Driver assessment of the effectiveness of AHB interventions (2 test series, two journeys)

The majority of the passenger car and truck test drivers assessed the active hazard braking system they experienced as "effective" or "very effective" (Figure 4).

The test car drivers intensified the braking by actuating the pedal themselves before partial and full deceleration become distinguishable.

Truck drivers also gave no significantly different assessment of the effectiveness of the variants.

RESULTS - DISTURBANCE

The disturbance Δv is defined, analogously to effectiveness, as change in speed over the assessment period of 2.0s following faulty activation of the active hazard braking.

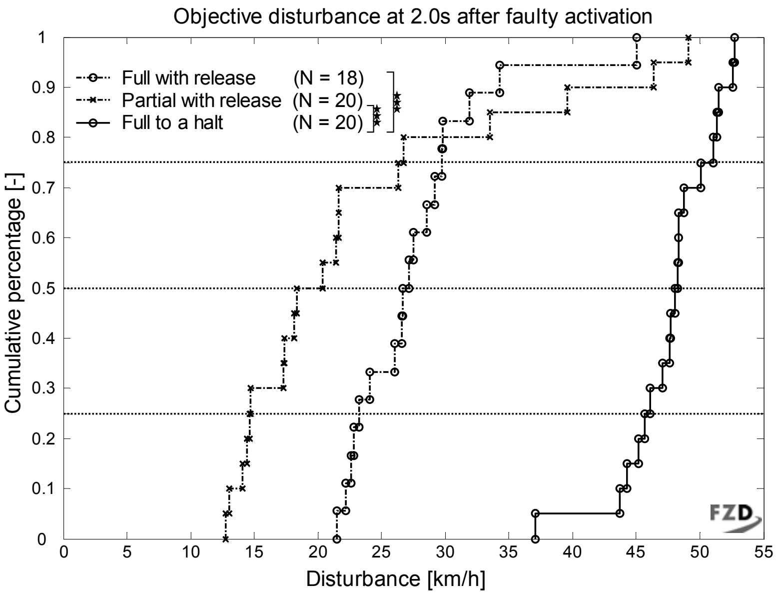

Figure 5: Cumulated percentage of the disturbance (passenger car)

Figure 5 indicates the disturbance findings from the passenger car trials as the cumulated percentage of disturbance. There is an extremely significant difference between "full braking to a halt" compared to "full braking with release" and "partial braking with release". In contrast to the justified activation tests (danger of collision), in the faulty activation tests with the "partial release" variant only very few test persons intensify the automatic braking by actuating the brake themselves. Most test persons recognise that a faulty activation has taken place, so that most "partial with release" and "full with release" situations do not cause higher disturbance. The hypothesis of the analogy of these two "with release" variants cannot be statistically refuted. Here also, there is an apparent impact of the already described dynamic characteristics of the deceleration build-up in the experimental passenger car. As a higher braking intensity can only build up after approximately 800 ms with the full braking variant, but the braking terminates after 1.3 s, the resulting impact on the difference in speed is only small. With "full to a halt", however, the disturbance is considerable, as is the hazard for vehicles behind.

The test persons were not given the possibility of overriding and thus terminating the faulty activation of the system, for example by accelerating. Indeed, the analysis of foot pedal movements revealed that none of them tried to do this. When the system was wrongly activated, no driver kept his/her foot on the accelerator. With all variants, about half of the drivers also actuated the brake, no matter how intense the faulty activation was.

Figure 6 shows the disturbance in the truck trials. Compared to the disturbance in passenger car trials it is noticeable that with trucks the course of the faulty activation reaches higher values for "full with release". This is because the higher dynamics of the braking system generate objectively higher speed differences. Consequently, a statistical rating of disturbance is obtained with a maximum probability of error of 5% (level of significance).

FA "full to a halt" > FA "full with release" > FA "partial with release"

An analysis of pedal actuation – not detailed in this paper – shows in the truck trials a correlation between the frequency of brake actuation and increasing intensity of the faulty activation variant. Whereas only two out of six drivers themselves actuated the brakes with the "partial faulty braking", nine out of ten drivers put on the brakes with "full braking to a halt" while even eight of eleven drivers put on the brakes with the "full with release".

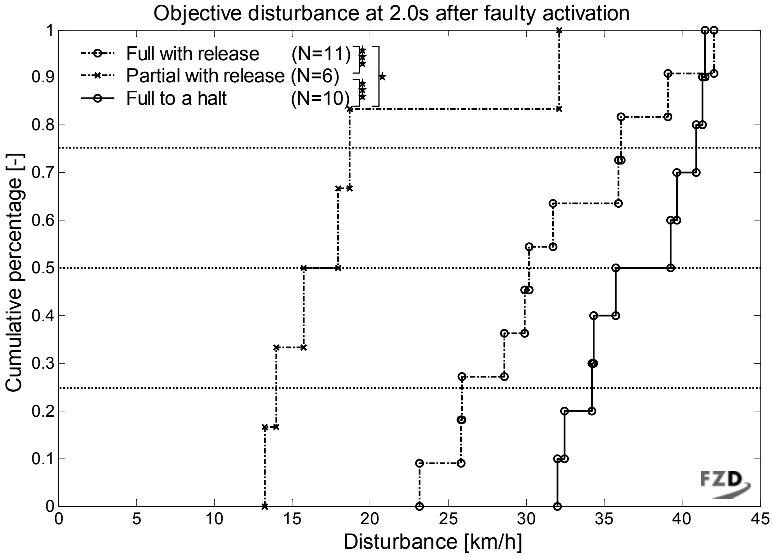

Figure 6: Cumulated percentage of disturbance (truck)

RESULTS - DRIVERS' ASSESSMENT OF FORGIVENESS OF FAULTY ACTIVATION

Without knowing which variant of faulty activation they had experienced, the test persons were questioned as to how they rate the "forgiveness" of the faulty activation they had just experienced.

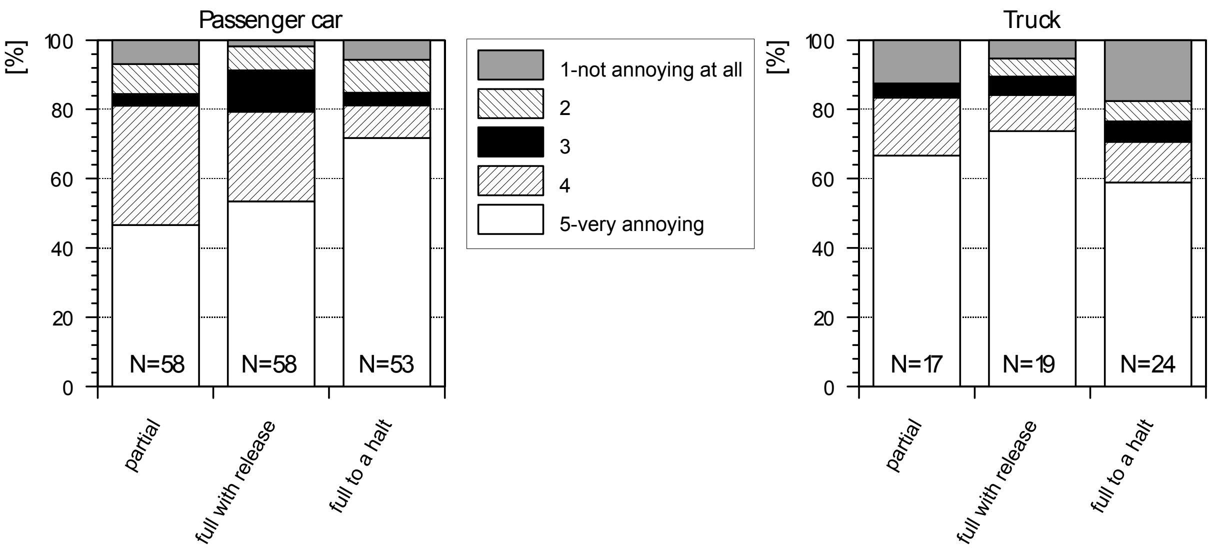

Figure 6: Subjective forgiveness of faulty activation for the variants "AHB partial" "AHB full with release" "AHB full to a halt" for passenger cars (left) and trucks (right)

All test persons, independently of the test series, had each experienced two faulty AHB activations. Immediately after, they assessed to what extent they had been disturbed by the faulty activations. Figure 6 shows that the majority of test drivers of both cars and trucks found them to be very annoying. The drivers' assessment of forgiveness did not vary according to the faulty activation variant employed.

RESULTS - PHYSIOLOGICAL REACTIONS WITH A JUSTIFIED AHB INTERVENTION

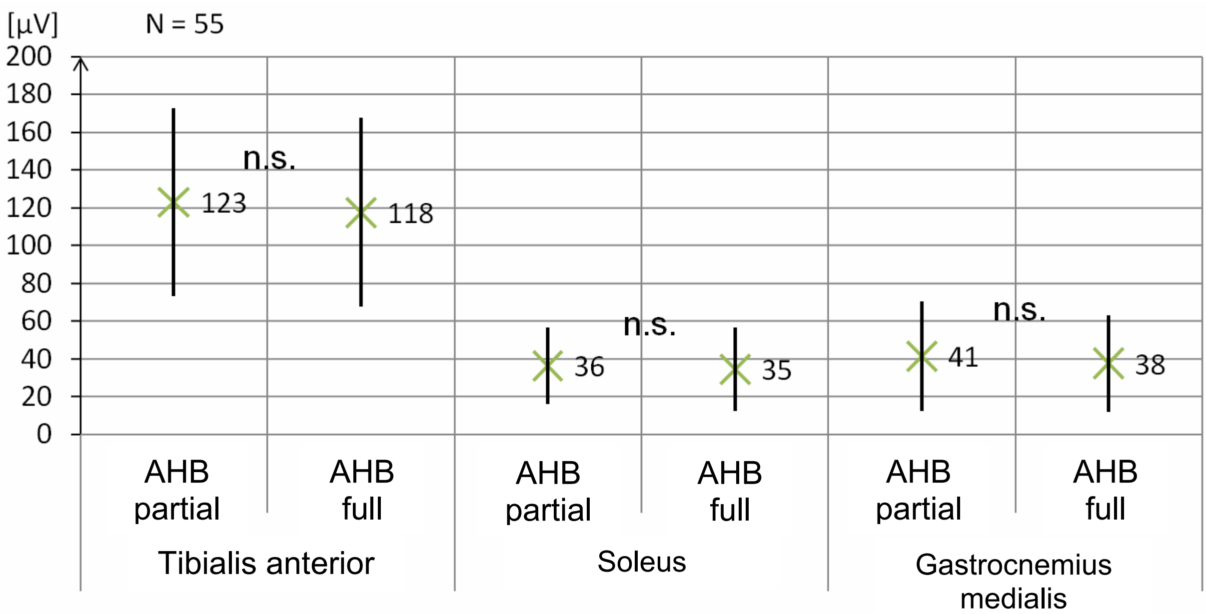

Figure 7: Tibialis anterior, soleus and gastrocnemius medialis Muscleactivities with "AHB partial" and "AHB full" (passenger car)

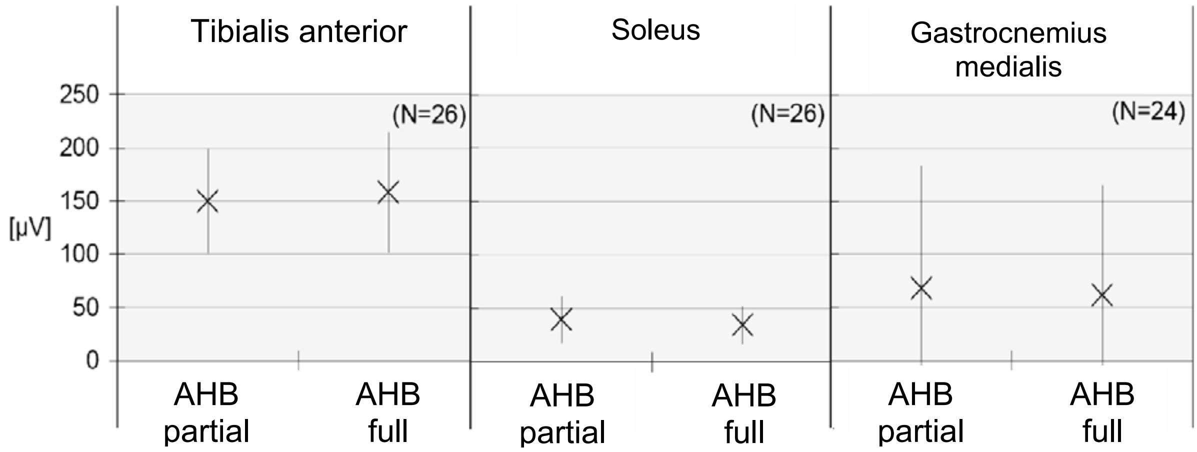

Figure 8: Tibialis anterior, soleus and gastrocnemius medialis Muscleactivities with "AHB partial" and "AHB full" (truck)

The AHB configuration did not influence the individual activity of the driver's leg muscles. In both passenger car trials (Figure 7) and truck trials (Figure 8) the individual activities of the selected leg muscles are comparatively high for the braking situation with full and partial release. This shows that in this critical situation the drivers actuate the brakes as intensively as possible independently of the degree of AHB assistance.

This reaction suggests that, at least at the beginning of the brake application, the test persons could not differentiate between full and partial deceleration.

CONCLUSION

The results of the present study show that the major development goal of active hazard braking has been achieved. The effectiveness, expressed as difference in speed during the hazard situation, is to an extremely significant degree higher than in situations in which the drivers are not assisted by AHB. The assessment of different variants of AHB examined a full braking variant and a partial braking variant of approximately 60%. Only the truck trials identified a clear difference in the effectiveness of the variants. These test vehicles had a clearly more dynamic deceleration build up which is perceivable by the test drivers particularly at the beginning of the braking.

Increasing the braking force in the 60% "AHB partial" is not necessary, i.e. higher effectiveness is not expected when, as in the present case, this AHB can only be built up slowly because of the ESP pumps installed nowadays. Increasing the braking force, however, leads to greater disturbance and thus to a lower forgiveness rating. Only a more rapid deceleration build up leads to a greater advantage for full braking, but the disturbance is also increased.

The test persons could not establish a difference between the full and partial braking variants and consequently they actuated the brakes with the same force. The majority of the test persons assessed the variants as effective or very effective.

These results were obtained with uniform trigger thresholds and only with the intervention types indicated. However, they cannot be extrapolated for systems with different characteristics (e.g. earlier partial braking or rapid full braking, as is possible with other actuator concepts). Nor did these trials investigate the impact of early warning, as used by most anti-collision systems.

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