TOLERABILITY OF UNEXPECTED AUTONOMOUS EMERGENCY BRAKING MANEUVERS ON MOTORCYCLES - A METHODOLOGY FOR EXPERIMENTAL INVESTIGATION

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ABSTRACT

Motorcycle riders are subject to a high risk of suffering severe or fatal injuries. Previous research has identified autonomous emergency braking for motorcycles (MAEB) as one of the most promising technologies to increase safety for riders (e.g., [2]).

Compared to drivers of two-track vehicles, emergency braking maneuvers are much more challenging for motorcyclists. As there is no restraint system such as a safety belt, riders need to support their upper body movement and they need to control and stabilize their vehicle. This requires attention, situation awareness and body tension. Before applying maximum deceleration, the rider has to achieve this ‘prepared-for-braking’ state.

To generate optimal crash mitigation or even crash avoidance, the velocity should be reduced even before this state is achieved. Therefore, it is necessary to determine applicable preparatory braking profiles. As sudden unexpected braking maneuvers are critical for unprepared riders, there is still a great uncertainty on how high these decelerations can be. The identification of the limits would enable to determine the safety benefit of MAEB, when the full deceleration potential before reaching the ‘prepared-for-braking’ state is used.

One of the main challenges in MAEB studies is the rider state. On one hand, to evaluate to what extent autonomous interventions can support riders, participants need to be unprepared to receive unbiased results. On the other hand, due to safety and ethical reasons, it is out of question to determine the limits of controllable decelerations with unprepared riders. For this purpose, the experiments within this project are split up:

In a first study with experts, the deceleration limits are identified. The experts are asked to evaluate if different automatically applied braking interventions are controllable for unprepared average riders. By increasing the decelerations until the experts rate them as intolerable for unprepared riders, maximum tolerable decelerations for different braking profiles in real riding scenarios are defined.

In a following participant study, average riders experience a realistic emergency braking scenario (suddenly braking vehicle ahead). The deceleration profiles defined during the expert study are applied. With these experiments, the reaction of the unprepared participants to unexpected autonomous braking maneuvers are analyzed. The result is an evaluation on how partial braking maneuvers can help to reduce the transition time and on the potential decrease of velocity during the transition period.

In a third study, more critical scenarios (different secondary tasks) and the influence of warnings prior to the autonomous braking intervention are investigated on a dynamic motorcycle simulator.

The studies provide empirically obtained data on maximum deceleration values for different automatic braking interventions that are tolerable for average riders in unexpected emergency braking situations. The results also show the maximum amount of velocity – and thus kinetic energy – that can be reduced during the partial automatic braking phase before the maximum deceleration can be applied. The simulator experiments show the influence of different secondary tasks and the effect of visual-auditory warnings. The described method can be used as a reference for future development and configuration of MAEB.

INTRODUCTION

In previous research projects, it has been shown that autonomous emergency braking systems for motorcycles (MAEB) offer a high safety potential to reduce consequences of accidents or even avoid them (e.g., [3]). In these projects, important aspects of MAEB have already been discussed.

Project PISa investigated the influences of braking interventions on the stability of a motorcycle rider on his vehicle [4]. Other studies have shown that low decelerations up to 3 m/s^2 can be applied automatically without making the rider feel like losing control [5]. Within the MOTORIST project the researchers evaluated usual behavior of riders in different braking situations and showed that riders themselves do mostly not use the full deceleration potential [2]. The described projects are examples for a variety of research that has been performed in terms of MAEB. This research is highly important to develop a base line for the design of automatic brake applications.

The contents of the previous work are important aspects for the development and design of autonomous emergency braking systems for motorcycles. In particular, it has been shown that decelerations up to 3 m/s^2 are controllable for motorcycle riders and do not negatively affect the rider‘s postural stability. However, to our knowledge there is no study that determines the maximum autonomous deceleration that is controllable for unprepared riders.

The aim of an AEB is to maximize the reduction of kinetic energy prior to a collision to mitigate the consequences of an accident. In case of an emergency scenario, this requires building up a maximum deceleration as fast as possible. The achievable decelerations are subject to certain limits. Besides the physical limits, these include limits that the rider sets to the applicability. As an integral part of the rider-vehicle system, the rider must be able to control the MAEB intervention. This is essential to avoid destabilizing the vehicle or cause a fall.

The approach of the work described in this paper is based on the assumption that the rider must be in a prepared-for-braking state to be able to control an autonomous maximum deceleration. In order to bring him/her into this state and at the same time being already able to achieve a reduction of speed before reaching the braking readiness, preparatory partial braking maneuvers are used. These partial braking interventions are the main content of the investigations within the project.

The discussed research questions are:

- Can partial braking maneuvers be used to prepare the rider for a maximum deceleration, i.e., to motivate him/her to get to the prepared-for-braking state?
- How fast is the transition to the prepared-for-braking-state completed using different braking profiles?
- What is the potential velocity reduction during the transition phase, i.e. what is the maximum deceleration that is controllable for an unprepared rider?

METHOD

One of the main challenges with investigating MAEB is the fact that on one hand emergency braking situations are always critical scenarios but on the other hand riders need to be unprepared in order to provoke realistic reactions in the studies.

For safety reasons, it is not possible to identify the limits with unprepared participants. Due to this fact, the test track experiments were split up into two studies. First, in an expert study, it was analyzed which decelerations and decelerations profiles would be controllable for average riders. This identification of the deceleration limits was performed with riding instructors and trainers as these people are assumed to be particularly suitable to assessing the skills of unexperienced riders.

However, while the expert study is appropriate for determining the limits of controllable decelerations, it cannot be used to assess the rider reaction because the experts were informed that there will be an automatic deceleration. As mentioned above, riders need to be unprepared to analyze how the partial braking interventions influence the transition to the prepared-for-braking state. Thus, the expert study was followed by a participant study. In this study, average riders were confronted with unexpected emergency braking situations which were followed by autonomous braking interventions according to the deceleration profiles identified in the expert study. The focus was to analyze the riders' reactions, particularly how different deceleration profiles affect their transition to the prepared-for-braking state. Moreover their subjective evaluation of the interventions was examined.

In the real life experiments, especially those with unprepared motorcycle riders, automatic braking interventions are only applied while going straight (roll angle close to zero) and with the riders' full attention to the riding situation.

In addition to these two studies, a simulator study was conducted. This simulator study aimed for analyzing the influence of visual-manual distraction on the riders' ability to control the motorcycle. This offered the opportunity to analyze potentially critical situations in a controlled environment without exposing the participants to the risk of getting injured.

Figure 1 gives an overview of the performed studies.

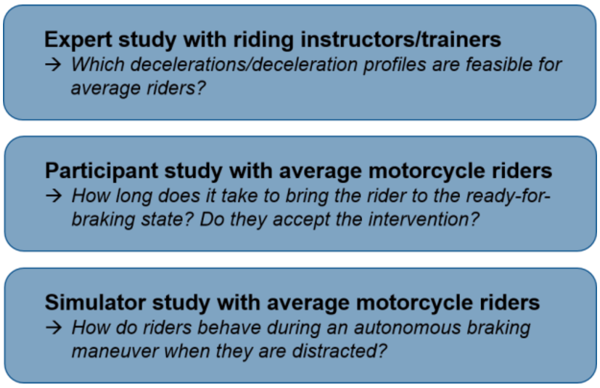


Figure 1. Overview of the performed studies

Test tools

The experiments on the test track were performed with a test motorcycle equipped with a variety of sensors to evaluate the state of the vehicle. These include, e.g., an inertial measurement unit to record translational and rotational accelerations, pressure sensors to monitor the brake pressures and a GPS antenna to track the vehicle.
In order to decelerate the vehicle without an intervention of the rider, the vehicle is equipped with an actuator that operates the foot brake. The test vehicle has a combined brake system. This means that by operating the foot brake, brake pressure is not only built up at the rear wheel, but also at the front. With this setup, automatic decelerations up to 7 m/s^2 can be applied. Figure 2 shows the three implemented braking profiles. The brake actuator is activated via remote control. To ensure that the engine is not stalled and that the rider is not able to accelerate unintendedly during an automatic braking intervention, the clutch is also actuated automatically by an external actuator.

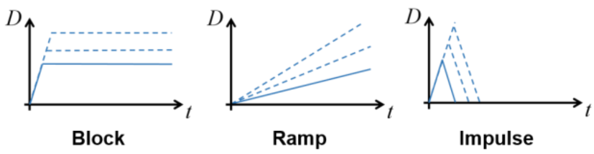


Figure 2. Implemented braking profiles

To evaluate the rider state, additional measurement technology is installed. During the experiment, the rider is equipped with a 3-axis acceleration sensor to analyze the upper body movement. The sensor is mounted on the back at the level of the shoulder blades. To monitor the rider inputs, forces on the handlebar as well as brake actuation, clutch actuation and throttle are also recorded.

Although, the emergency braking shall be unexpected, it should not get the character of a false positive braking intervention. Therefore, it is necessary to create a situation that presents a realistic true positive emergency braking scenario, like a suddenly decelerating target vehicle, to the rider. In order to avoid the risk of collisions between the motorcycle and the target vehicle, the dummy target EVITA (Experimental Vehicle for Unexpected Target Approach) was used. This test tool was developed to allow collision free investigation of anti-collision systems [6]. The dummy target consists of a towing vehicle and a trailer with a vehicle rear. The trailer can be decelerated independently from the front vehicle to simulate a rear-end collision situation. If the time-to-collision (TTC) between the following vehicle and the dummy target gets too short, the trailer is pulled forward to avoid a collision. The system is shown in Figure 3.

Figure 3. Dummy target EVITA

The simulator experiments were carried out at the Würzburg Institute for Traffic Sciences (WIVW). The dynamic motorcycle riding simulator DESMORI is based on a 6-degrees-of-freedom motion base. A real motorcycle body is mounted on the platform so that the rider can operate the virtual motorcycle with authentic control elements (clutch, throttle, brake levers etc.). The simulator allows the rider not only to steer the motorcycle by applying steering torque to the handlebar, but also with shifting his/her body relatively to the motorcycle. The visual representation of the environment is realized by a cylindrical screen (4.5 m diameter, 2.8 m height, 220° horizontal field of view) while sound is displayed via in-helmet speakers. Velocity and acceleration dependent haptic cues are delivered via a G-vest simulating forces to the rider torso [7]. The simulation is implemented in WIVW's simulation software SILAB, the virtual motorcycle is simulated in VI-BikeRealTime (VI-grade).

Figure 4. DESMORI Dynamic Motorcycle Riding Simulator at WIVW

RESULTS

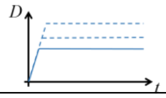
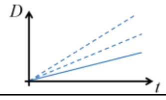
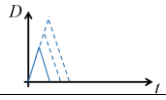
Expert Study

As explained before, the expert study was supposed to identify the limits of deceleration that are controllable for average riders who do not expect an automatic braking intervention. There were three braking profiles (shown in Figure 2) to be investigated:

- block braking (deceleration is built up quickly and then is kept at the required level)
- deceleration ramp (deceleration is built up slowly to a maximum of 7 m/s^2)
- braking impulse (deceleration is only is short to 'wake up' the rider)

For each of the profiles, limits of decelerations or deceleration gradients that can be used in the participant study, needed to be identified. The experts were decelerated by remote control while driving straight ahead and then they were asked to give a rating as to whether the respective braking intervention is reasonable for an average unprepared rider without affecting the controllability of the situation. If the assessment was positive, the deceleration or the deceleration gradient was increased for the next braking maneuver until the braking intervention was classified as no longer acceptable. The varied parameters and the identified limits are summarized in Table 1. A detailed description of the evaluation of the expert study was introduced in [8].

Table 1. Varied parameters

Braking profiles	**Varied parameters**		**Determined maximum**
Block braking	Level of deceleration		5 m/s^2
Deceleration ramp	Gradient		9.1 m/s^3
Braking impulse	Level of deceleration		4.7 m/s^2

With these results from the expert study, limits for unexpected autonomous decelerations are identified.

Participant Study

With the knowledge of which decelerations are acceptable for average riders, the participant study was carried out. This study examined to what extent the different types of interventions (braking profiles) are suitable to assist the rider in an emergency braking situation and which increase in safety this offers compared to the rider himself/herself carrying out an emergency braking maneuver.

During the experiments, the test persons followed the dummy target EVITA on the test motorcycle at a pre-determined distance (time headway 1.5 s, see Figure 5). The initial velocity for the experiments was 70 km/h. At an appropriate point (correct distance between the vehicles, correct velocity, enough straight track left), the dummy target was decelerated and the remote-controlled braking intervention was triggered synchronously. EVITA served merely to make the automatic braking intervention plausible as true positive for the rider.

The study was carried out with 18 participants. Apart from the braking profiles (block, ramp and impulse), reference experiments without automatic braking interventions were performed in order to create a baseline to evaluate how the autonomous interventions can help to decrease the velocity.

With the aim of receiving unbiased assessments and to avoid habituation effects, only two braking maneuvers are performed per participant. After elimination of the invalid runs, 19 braking maneuvers can be evaluated (5x block, 5x ramp, 5x impulse, 4x reference).

Figure 5. Participant study with EVITA

The following paragraphs summarize the evaluation and the results of the participant study. Figure 6 explains how the measured data is presented for the different braking profiles. The upper diagram always shows the vehicle state. It contains the velocity v and acceleration a_{Vx} as well as the brake pressure at the foot brake $p_{MBC,foot}$ that is automatically built up by the braking actuator. In Figure 6 the vehicle state diagram also shows the target deceleration $a_{Vx,tg}$.

The lower diagram mainly presents the rider state and rider inputs. It shows the acceleration measured at the upper body of the rider a_R, the force on the handlebar F_{hand} and the brake pressure at the front brake $p_{MBC,hand}$ applied by the rider. For comparison purposes for the rider body acceleration, the vehicle acceleration is also shown in this diagram. Diagrams for the impulse profile and for reference scenarios also contain the clutch signal.

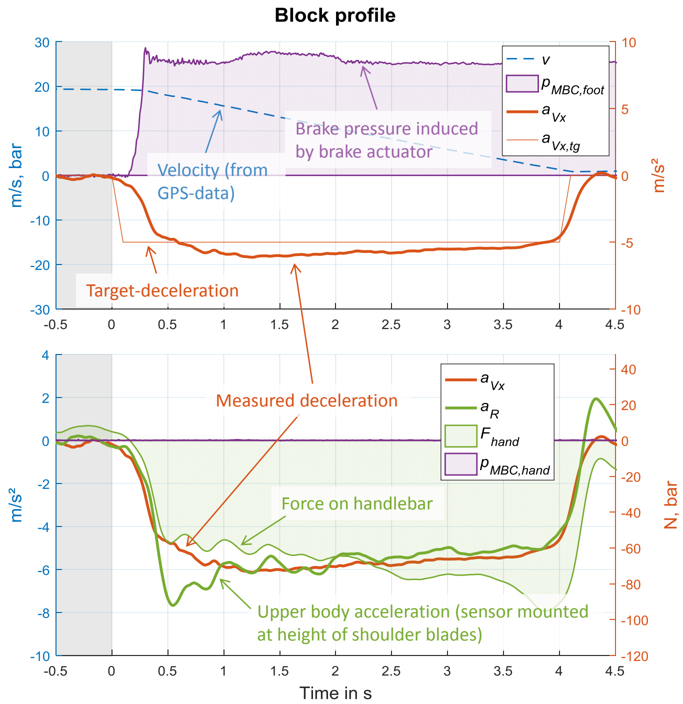


Figure 6. Scheme of measurement data representation

Figure 7 shows the data for a braking maneuver with the block profile. The brake pressure is built up within less than 0.3 s. All block braking maneuvers are analyzed concerning their transition time. The diagram in Figure 7 shows that first, the vehicle deceleration is built up. The deceleration of the rider's upper body then follows with a small time lag. This can be explained by the fact that the upper body is at the first moment moved forward relatively to the vehicle due to the unexpected deceleration. By supporting the resulting force with the arms on the handlebar and straightening the upper body, the upper body deceleration is then adapted to the vehicle deceleration. The transition is considered as completed, as soon as the force on the handlebar or the upper body deceleration does not increase anymore. The earlier of these two points is defined as the end of the transition period.

The mean transition time for the block profile braking maneuvers is at 0.57 s. Within the transition, a mean of 1.48 m/s of velocity reduction can be achieved.

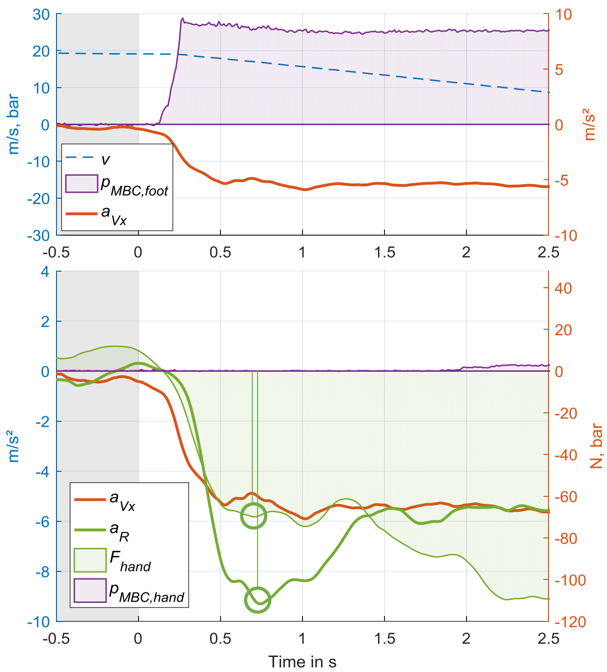


Figure 7. Block profile

Unlike in the block profile, the brake pressure is built up more slowly in the ramp profile braking maneuvers. The built up of the pressure starts at about 0.3 s with a low gradient and then increases progressively, until the target deceleration level of 5 m/s^2 is achieved. The target deceleration gradient (9.1 m/s^3, system-related scattering) starts at about 0.5 s.

The evaluation of the transition period follows the same scheme as for the block profile (see Figure 8). With a mean time of 1.04 s, the transition takes significantly longer than for the block profile. This shows that the block profile appears more effective in terms of motivating the rider to get to the prepared-for-braking state. Due to the slow brake pressure built up, the decrease of velocity is only slightly higher. The mean velocity reduction is 1.69 m/s.

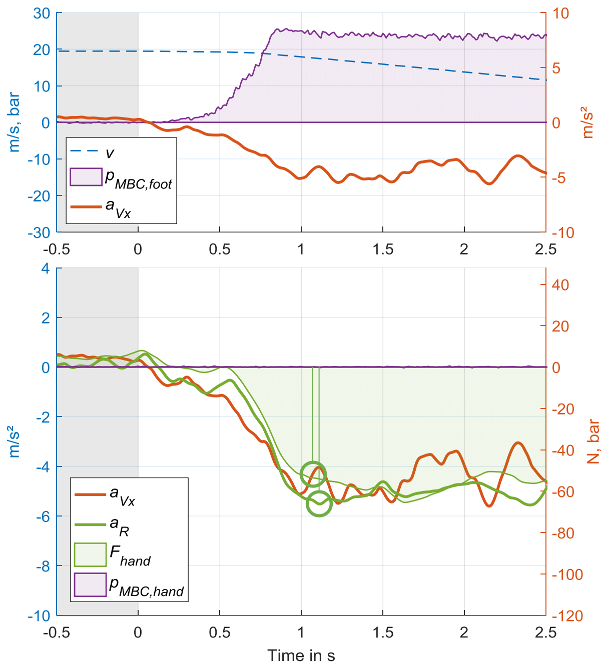


Figure 8. Ramp profile

Unlike the block or ramp profile, the impulse profile only offers a short automatic deceleration without actuating the clutch. Due to the fast increase and decrease of the vehicle deceleration and the resulting pitch movement, the rider is forced to a phase-shifted upper body movement (see Figure 9). Due to the immediate decrease of the deceleration, the upper body swings back. This even results in a pulling force on the handlebar (sign change in the force signal), as the rider needs to retain this movement. Consequently, the force on the handlebar or the no longer increasing upper body deceleration cannot be used as an indicator for the completed transition for the impulse profile.

For the impulse – which is supposed to 'wake up' the rider – the transition is defined as completed, as soon as the rider reacts to the automatic intervention in terms of rider inputs, such as applying the brakes (more than 0.5 bars on the hand- or foot brake) or actuating the clutch (increase of the clutch parameter, see blue marking in Figure 9). The earliest of the inputs represents the end of the transition period for the impulse profile.

The impulse causes a mean transition time of 1.37 s. It is thus longer than the time for the block or ramp profile. Due to the fact that the clutch is not actuated and the deceleration is very short, the velocity is only slightly reduced. The mean velocity reduction is 0.77 m/s.

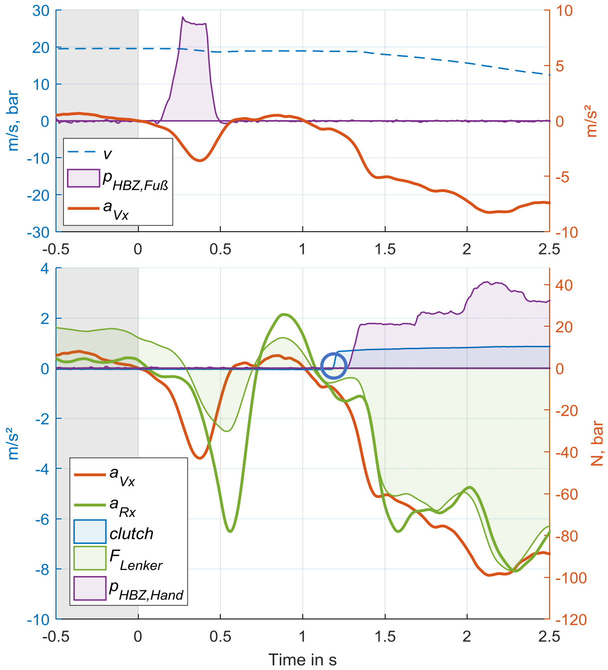


Figure 9. Impulse profile

The reference maneuvers (see Figure 10) were supposed to show how much time the rider needs to initiate a braking maneuver himself/herself after an incident occurs. The incident is represented by the release of EVITA at $t = 0$. The characteristics for the completed transition comply with those for the impulse profile, i.e., the transition is completed as soon as the rider actuates the clutch or the brakes.

In average, it took the participants 1.65 s to react to the deceleration of the dummy target. Within this time, a mean velocity reduction of 0.57 m/s can be observed. This small reduction results from the fact that until the rider reacts, no brake pressure is built up automatically. The deceleration only is only achieved by throttling back.

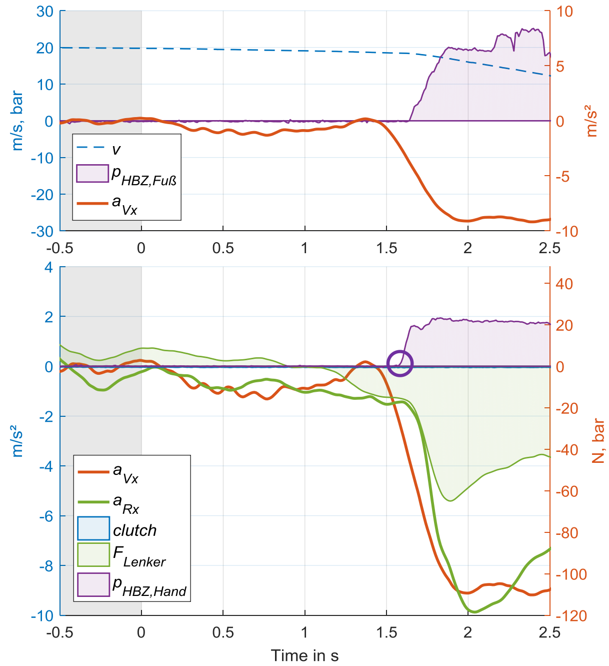


Figure 10. Reference braking maneuver

The test track experiments with participants show that the block profile is the most promising profile in terms of motivating the rider to get ready for full deceleration. The block profile leads to the shortest transition time and at the same time, it leads to the highest velocity reduction within the reference time of 1.65 s. For the ramp and impulse profile, the transition periods become longer, while the velocity reduction within the reference time decreases.

The velocity reduction within the reference time is calculated based on the assumption that as soon as the transition is completed, the deceleration can be raised to a maximum level. This maximum is not represented by the physical limits of the braking maneuver, but it is set to 7 m/s^2. This deceleration still allows some friction potential in case the rider decides to perform an evading maneuver during the automatic braking.
To determine the potential velocity reduction Δv_{Red} within the reference time T_{Ref} for each braking profile, it is assumed that after the transition period T_{Trans}, the rest of the reference time span is used to decelerate at D_{max} = 7 m/s^2. The calculation is exemplarily shown for the block profile in (Equation 1). Within the transition time of 0.57 s, the velocity is reduced by 1.48 m/s (mean reduction determined during experiments). The rest of 1.08 s within the reference phase are used to decelerate at 7 m/s^2. This results in a total velocity reduction of 9.04 m/s.

$$\begin{aligned}\Delta v_{Red,Block} &= \Delta v_{Trans,Block} + \left(T_{Ref} - T_{Trans,Block}\right) \cdot D_{max} \\ &= 1.48\ \frac{\mathrm{m}}{\mathrm{s}} + (1.65\ \mathrm{s} - 0.57\ \mathrm{s}) \cdot 7\frac{\mathrm{m}}{\mathrm{s}^2} \\ &= 9.04\ \frac{\mathrm{m}}{\mathrm{s}}\end{aligned} \qquad \text{(Equation 1)}$$

Within the transition time of 0.57 s, the velocity is reduced by 1.48 m/s (mean reduction determined during experiments). The rest of 1.08 s within the reference phase are used to decelerate at 7 m/s^2. This results in a total velocity reduction of 9.04 m/s.
The starting velocity of 70 km/h equals 19.4 m/s. A velocity reduction of 9.04 m/s thus means a decrease of 47 %.

A summary of all test track results including the determined potential velocity reductions is given in Table 2.

Table 2. Summary of test track experiments

Profile	**Mean transition time T_{Trans} in s**	**Mean velocity reduction within transition period Δv_{Trans} in m/s**	**Potential velocity reduction within 1.65 s Δv_{Red} in m/s**
Block	0.57	1.48	9.04
Ramp	1.04	1.69	5.96
Impulse	1.37	0.77	2.73
Reference	1.65	0.57	0.57

Not only the objective assessment of the measured data is important for identifying the potential of MAEB. A safety system can only be successfully engaged, if it is accepted by the users.
For this purpose, the participants were asked to subjectively assess the controllability of the single braking interventions. The rating follows the scale from Neukum et al. [9]. Within this scale, the participant can first classify the intervention on a rough ordinal scale (not noticeable, noticeable, disturbing, dangerous, not controllable) and afterwards refine the assessment within these categories (0 to 10, see Figure 11).
As expected, the participants rated the reference experiments less critical. In these braking maneuvers the brakes were actuated by the riders themselves and thus did not surprise them. The maneuvers were mostly rated at the lower end of the scale within the 'noticeable' category. The block profile was also mostly classified in this category. The mean rating for the block (2.8) is only slightly higher than for the reference maneuvers (2.67).
The other two braking profiles (ramp and impulse) were rated more critical. According to the mean rating, the ramp profile still falls into the same category ('noticeable') as the block profile and the reference maneuvers. However, there is a greater spread of the ratings and the mean (3.4) is close to the upper border of the category. The ratings for the impulse profile were more critical. The mean rating (4) falls into the 'disturbing' category. Although this is the most critical rating, the subjectively experienced criticality is still far away from 'dangerous'.

The subjective assessment shows that the block profile is not only most promising in terms of transition time and velocity reduction (objective criteria), but also in terms of subjective perception of the criticality of the intervention.

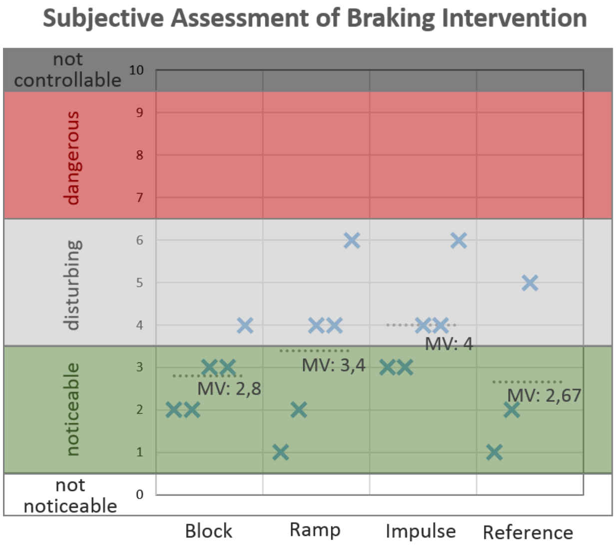


Figure 11. Subjective assessment

Simulator Study

Due to safety reasons, autonomous emergency braking scenarios have usually been tested on the test track while riding straight with full concentration on the riding task. However, MAEB is expected to support the rider especially in situations where the rider is not fully concentrated on the riding task. Thus, the rider might not be in an ideal state (e.g., being visually distracted or not having both hands on the handlebar) to cope with the intervention of an MAEB. Therefore, it is important to investigate the influence of these non-ideal rider states on the controllability of MAEB interventions. For this purpose, a simulator study was conducted. The two main aims of the simulator study were

- to investigate how both-, one- and free-handed riding in combination with visual distraction (eyes not focused on the lead vehicle) affect the riders' behavior and system acceptance in case of an MAEB intervention and
- to assess the potential of a visual-acoustic warning to improve acceptance and controllability of a MAEB intervention.

The test scenario was similar to the test track participant study regarding the primary riding-task. The participants had to follow a lead vehicle in the simulated scenario (with a velocity of 100 km/h) which triggered the autonomous braking maneuver (maximum deceleration of 6 m/s²). To manipulate hand position and visual distraction the riders were instructed to fulfill different secondary tasks which are summarized in the following table:

Table 3. Different secondary tasks used in the simulator study to manipulate hand position and visual attention.

Task	Hand position	Distraction	Implementation
surrogate reference task according to [10]	both handed	visual + manual	controlled via two buttons at the handlebar
operation of a navigation device	one-handed	visual + manual	navigation device mounted at the handlebar
free-handed lateral control	free-handed	manual	simulation of adaptive cruise control for longitudinal guidance

In order to assess the potential of a visual-acoustic warning the riders experienced each condition either with or without a visual-acoustic warning prior to the MAEB intervention in permuted order.

Rider behavior was analyzed by means of brake and clutch operation (i.e., frequency of additional brake reactions and brake reaction time) and steering behavior. Both can be used as indicators for a rider take-over or the rider being back in the control loop. Subjective ratings of controllability based on the scale of [9] were obtained after each intervention like in the test track studies. In addition, the riders received a questionnaire at the end of the study to assess the acceptance of interventions with/without warnings.

The frequency of additional brake reactions for the front brake lever does not indicate differences between MAEB with or without warnings. In all conditions more than 50% of the riders showed additional brake reactions on the front brake lever (with warning: 57%-61%; without warning: 52%-65%). However, riders in all conditions (both-handed, one-handed and free-handed) respond slightly faster to the autonomous emergency braking of the motorcycle if a warning is presented prior to the onset of the intervention (cf. Figure 12). In addition, the reaction times seem to be more homogenous if a warning has been presented (please note that this interpretation is only based on descriptive data).

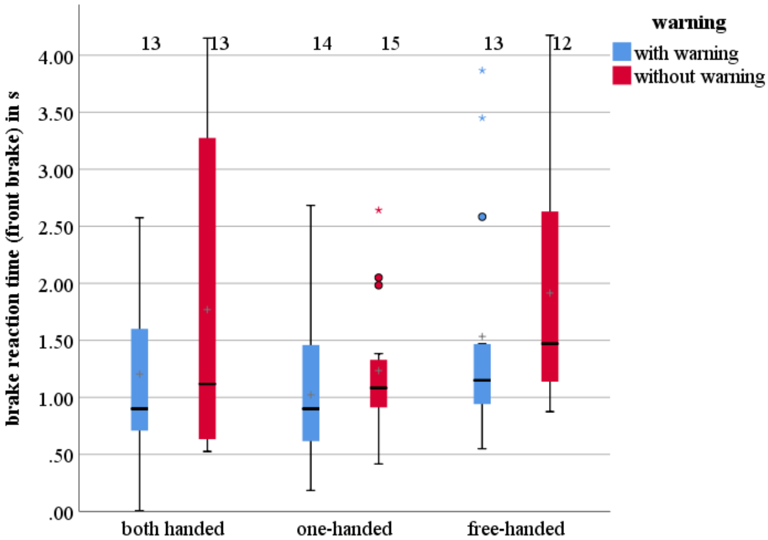


Figure 12. Reaction time depending on warning availability and type of secondary task

The subjective controllability ratings obtained after each intervention show that riders rated autonomous braking interventions with a prior warning as more controllable than interventions without a prior warning ($F(1,120) = 8.99$, $p = .003$)). This is especially reflected in the distribution of the ratings according to the rating categories (cf. Figure 13).

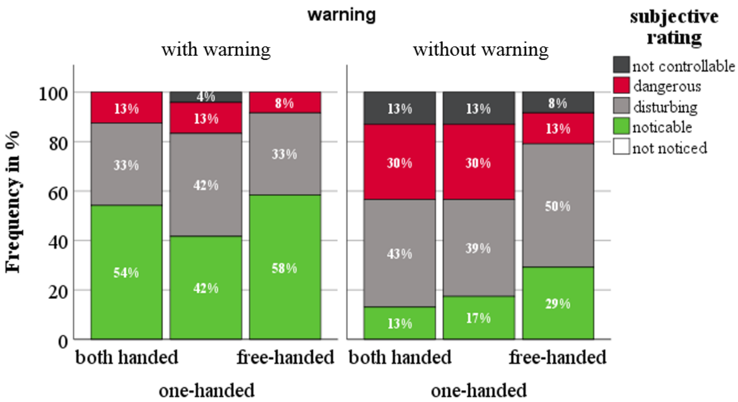


Figure 13. Subjective assessment of intervention controllability depending on warning availability and type of secondary task

The overall rating of acceptance at the end of the study revealed that riders rated autonomous braking interventions with a warning to be *more helpful*, *more relieving* and *safer* compared to interventions with no warning. In addition, the riders showed high consent with the statement that "*the warning made the intervention more controllable*".

Consequently, the results of the simulator study indicate that warnings can not only support the rider in his/her reaction, they also have a positive influence on the acceptance of the interventions. However, it has still to be verified whether the results regarding the effects of warnings can be replicated on a real motorcycle. Furthermore, studies should test how the warning should be designed (visual, auditory, haptic or kinesthetic) to ensure that riders are able to perceive the warning and it's meaning in time to react adequately.

CONCLUSION

With the work described in this paper, a method for the evaluation of controllability and acceptance of autonomous emergency braking for motorcycles has been developed and validated. Furthermore, it has been shown how the prepared-for-braking state of the rider can be detected. The proposed methods prove that automatic braking maneuvers can be applied to and controlled by unprepared riders in participant studies. Thereby, this work provides an important foundation for the future design of MAEB and the assessment and evaluation of its safety potential. The results indicate that the block profile offers the greatest potential to decrease velocity while being well accepted by the riders. This design leads to a high potential of future MAEB solutions. In the tested scenarios with autonomous interventions, the velocity can be reduced by up to 47 % compared to reference scenarios without interventions (due to the delay in the braking response by the rider). In addition, the simulator experiments show that visual-acoustic warnings prior to autonomous braking interventions have the potential to reduce reaction times and further increase the acceptance of the system.

Limitations

So far, the participant study has only been performed at one specific initial velocity (70 km/h) on a specific vehicle. Therefore, it should be considered that the achieved results are only applicable for the setup used in our studies. In addition, we expect that the vehicle geometry has a significant influence on the controllability and acceptance of autonomous braking interventions. Future studies should focus on the influence of the vehicle type, the influence of the initial velocity and the influence of the test scenario (e.g. braking while driving in a straight line vs. braking while cornering).

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