A field study investigating road safety effects of a front brake light

Merlin Monzel1,2 | Kristof Keidel1,2 | Wolfgang Schubert2 | Rainer Banse1,2

1 Legal and Social Psychology, University of Bonn, Bonn, Germany
2 Institute for Legal and Traffic Psychology (BIRVp), Bonn, Germany

Correspondence
Merlin Monzel, Legal and Social Psychology, University of Bonn, Kaiser-Karl-Ring 9, Bonn 53111, Germany.
Email: monzel@uni-bonn.de

Funding information
Lumaco Swiss GmbH
Merlin Monzel and Kristof Keidel are joint first authors

Abstract
Recent research shows that braking of vehicles equipped with a front brake light is identified significantly earlier than braking of vehicles without front brake lights. Moreover, the absence of front brake lights leads to more conservative road crossing decisions. These results suggest that front brake lights are able to facilitate the pedestrians’ anticipation of dangerous traffic situations, thereby increasing road safety. The present research investigated the effects of front brake lights in the real traffic of the Berlin Tegel Airport airside. A total of 102 vehicles were equipped with front brake lights and circulated in airport traffic for a period of three and a half months. Before and after this test period, 197 staff members were asked about their experiences with and their attitude towards front brake lights. The results show that front brake lights rarely led to misunderstandings, whereas they were significantly more often perceived to facilitate communication avoiding dangerous situations. The attitude towards front brake lights was already positive at the first interview and improved significantly during the measurement period. Overall, a great majority of participants stated that front brake lights improve communication between road users and thus increase road safety.

1 | INTRODUCTION

In their laboratory study on potential safety effects of front brake lights, Petzoldt et al. [1] highlighted the information asymmetry between motor vehicle drivers and pedestrians. While drivers can use information such as the pedestrians’ gaze direction or body posture in order to deduce the pedestrians’ intentions in road traffic, the pedestrians—at least from a frontal point of view—have hardly any indicators of the drivers’ intentions. The absence of signal lights at the front of motor vehicles makes it very difficult for pedestrians to detect braking at crosswalks or junctions, although the German “Unfallforschung der Versicherer” (UDV) assumes that the majority of pedestrian accidents caused by motor vehicles occur in these two situations [2]. This information asymmetry can have serious consequences, especially for pedestrians: In 2016, the Federal Statistical Office of Germany recorded 31,793 pedestrian accidents involved in road accidents (30,248 within towns and villages), of whom 490 were killed (356 within towns and villages) [3]. Compared to 1980, the statistics have declined considerably, but in recent years, the trend has stagnated (see Figure 1) [4]. Given the high proportion of accidents in towns and villages, additional communication tools between pedestrians and motor vehicle drivers might be helpful to improve this situation. Intelligent Transport Systems (ITS) can be broadly defined as systems that are designed to influence the mobility behaviour of road users by providing traffic-relevant information [5]. Therefore, such a communication system could serve as the required ITS technology to improve traffic flow and avoid accidents.

Várhegyi investigated drivers’ behaviour when approaching crosswalks and noticed that pedestrians are often not given priority [6]. It is reasonable to assume that this is not always a deliberate act but that pedestrians may simply be overlooked due to restrictions of vision [7,8] and lack of lighting [9]. A misinterpretation of the pedestrians’ intentions would also be possible [10]. In view of their high risk of injury or death, it is therefore appropriate to improve the situation of pedestrians. One tool might be a front brake light which can be easily implemented and informs road users located in front of vehicles about the braking process. Already in 1938, a patent contained a warning that the classic brake light did not include any information for the road users ahead [11]. Initial considerations of front brake lights have even been around since the 1920s [12,13]; more
Based on this, Petzoldt et al. [1] investigated whether front brake lights (e.g. at night) and the possibility to consciously emphasize was placed on the impact under restricted environmental lighting (e.g. at night) and the possibility to consciously use front brake lights to communicate behavioural intentions. Both groups regarded front brake lights as useful in using them. A control group which had not been in contact with the front brake lights was asked to evaluate merely the concept. Both groups regarded front brake lights as useful for communication with other drivers and pedestrians. Special emphasis was placed on the impact under restricted environmental lighting (e.g. at night) and the possibility to consciously use front brake lights to communicate behavioural intentions. Based on this, Petzoldt et al. [1] investigated whether front brake lights actually facilitate the identification of braking, with the possible consequences of accelerating traffic flow and increasing security. The results of the computer-based laboratory study showed that brake applications on vehicles with front brake lights were identified significantly faster than on vehicles without front brake lights. Moreover, the absence of braking signals (e.g. on non-equipped vehicles) led to more conservative reactions among participants. In case of a mixed traffic including vehicles with and without front brake lights, participants interpreted the absence of the green brake lights as non-braking signals, even if the vehicles were not equipped with front brake lights at all. It can therefore be assumed that front brake lights increase safety because pedestrians would wait until the car had passed or stopped completely before crossing the road. In other words, front brake lights can lead to substantial security effects when they are equipped but not visible or even when they are not equipped to some vehicles in a mixed traffic situation. This is consistent with a study by de Clercq et al. [16], who showed using a head-mounted display that pedestrians felt safer to cross when a vehicle used a front brake light than when it did not. Furthermore, assessments suggest that damage to the cervical spine can be reduced in severity or prevented entirely by lack of a front brake signal, as the early warning can initiate a physical protective posture or evasive movements in sufficient time before the collision [17]. Finally, the perception of stress in traffic could also be reduced, as the front brake light provides an additional source of information that increases the perceived control of traffic participants [18].

Beyond that, more recent research regarding front brake lights was primarily concerned with their design and how they could be used as external human–machine interface (eHMI) in autonomous driving [19–25]. Regarding the green colour of the front brake light, Keidel et al. [21], Bazilinskyy et al. [22–24] and Dey et al. [25] come to the conclusion that green, as compared to other colours, indicates more intuitively that pedestrians can safely cross the road, although some confusion might be possible in the evaluation whether the green light signals the observer to go or the vehicle’s intention to go. Still, however, Bazilinskyy et al. [22–24] recommend green rather than red to be used since pedestrians seem to take an egocentric perspective rather than an allocentric perspective in traffic [26] and thus intuitively consider green as safety and go signal from their own perspective. Furthermore, the intuitiveness ratings for green showed only small individual differences between participants.

The present study aimed to investigate the experiences with a green front brake light in a large-scale longitudinal field study in real traffic. In contrast to Post and Mortimer [15], the purpose was to interview not only the drivers whose vehicles were equipped with front brake lights but also other road users who came into contact with them. In order to make this possible, the study was conducted in a closed traffic zone, the airside of Berlin Tegel Airport. This location had the advantage that the equipped vehicles were not within the scope of the German traffic regulations (StVZO) allowing technical modifications beyond the general traffic regulations and the model approval of the vehicles. The duration of the field trial was substantially longer than Post’s and Mortimer’s test period in order to provide participants with a range of encounters with the front brake lights in various traffic situations. The airside size of Berlin Tegel Airport and the constantly high density of traffic were particularly suited for the investigation of the research question. Pedestrians and drivers who came into contact with the front brake lights at different frequencies were surveyed about their experiences with and their evaluation of the front brake lights. The focus was mainly on experiences in the field of crosswalks and crossing traffic because these traffic situations promise the greatest potential safety gain of front brake lights.

It was expected that situations in which front brake lights entail a safety advantage would be reported more frequently.
than situations in which front brake lights lead to misunderstandings or dangerous situations (Hypothesis 1). Furthermore, it was expected that participants who came into contact with front brake lights would show a more positive attitude towards the front brake lights at the T2 measurement (i.e. after three and a half months) compared to the T1 measurement before the field trial (Hypothesis 2). This effect should not occur for participants who did not come or only rarely came into contact with front brake lights (Hypothesis 3). It was also expected that participants would widely approve of a general introduction of front brake lights in normal road traffic (Hypothesis 4).

1.2 Contribution statement

Our study contributes to empirical research on the front brake light. Specifically, it (1) represents the first large-scale field study that assesses real-life experiences with a front brake light in different road users; (2) as such, it indicates its potential effects on (perceived) road safety and efficiency, as suggested by reports of users and those provided with traffic-relevant information (e.g., pedestrians); and (3) finally, it contributes to the general field of ITS and, interpreted more broadly, eHMI by showing that laboratory effects of these interfaces can, at least in part, be generalized to the field.

2 METHODS

2.1 Sample

In order to ensure a sufficiently large sample for the longitudinal study, a total of 516 employees of Berlin Tegel Airport were interviewed, which corresponds to approximately 9–10% of the airside workforce. A total of 421 of them took part in the first survey, that is, before the introduction of front brake lights (T1), and 292 in the second survey, that is, after the end of the three and a half month test period (T2). Detailed demographic data of the sample are reported in the extensive report of the field study (Banse et al., 2018). A total of 197 participants participated both at the first and the second measurement occasion and thus constituted the sample of the longitudinal study.

The sample of the longitudinal study consisted of 180 men and 17 women aged 21 to 68 years ($M = 41.59$, $SD = 9.71$). The level of education was predominantly at the secondary school level (1.52% no high school diploma, 15.75% completion of compulsory basic secondary school, 55.84% general certificate of secondary education, 16.75% SAT exam/vocational baccalaureate diploma, 9.14% university degree). The majority of participants has had a driving license ($92.39\%$) for an average 22 years ($SD = 10.87$). The retest correlations between the demographic variables for both measurement occasions were high ($r > 0.82$) but nevertheless indicate a certain inaccuracy in the responses to the questionnaires.

Data on the work situation showed that 65.48% of the sample worked both in day and night shifts. However, due to the ill-defined time periods and shift work in general, it can be assumed that almost 100% of the sample worked at day and night. According to their own report, 186 employees worked on the airside. Besides, it was not possible to recruit a control group not working in direct contact with the front brake lights because only 11 participants reported not to work on the airside at all. The movement on the airside was mainly by car or by foot ($71.07\%$ car, $66.50\%$ foot, $33.50\%$ luggage vehicle, $22.34\%$ truck, $7.11\%$ bus, $7.61\%$ other). The average working time on the airside relative to the total working time was $62.23\%$ ($SD = 29.04$, see Figure 2).

![Figure 2: Histogram of average working time on the airside (in percent).](image)

2.2 Scales

In addition to demographic data and data concerning the traffic situation on the airside of Berlin Tegel Airport, five scales were assessed (see Appendix Tables A1–A5):

- **Potentially Relevant Traffic Situations:** The frequency of potentially relevant traffic situations was assessed using a frequency scale (never, rarely, occasionally, often, very often). The internal consistency of the scale (8 items) was $\alpha_1 = 0.84$ at T1 and $\alpha_2 = 0.83$ at T2.

- **Attitude Towards The Front brake Light:** The attitude towards front brake lights was assessed using an agreement scale (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree). The internal consistency (7 items) reached values of $\alpha_1 = 0.84$ and $\alpha_2 = 0.87$ for T1 and T2, respectively. In addition, participants were asked whether they would vote in favour of or against a hypothetical introduction of front brake lights in real road traffic. Furthermore, they were asked about a possible change of opinion regarding the front brake light at T2 (change for the better, no change, change for the worse).

- **Contact With The Front brake Light:** Contact with the front brake light was only assessed at T2. The scale consisted of five items using a frequency scale (never, rarely, occasionally, often, very often). However, due to the low internal consistency ($\alpha_2 = 0.51$), the scale was not combined into an overall score but examined on the level of the individual items.

- **Experiences With The Front brake Light:** Experiences with the front brake light were only assessed at T2. The scale consisted of
twelve items using a frequency scale (never, rarely, occasionally, often, very often). The scale was divided into the two subscales: Experiences with the front brake light on others’ vehicles (7 items, $\alpha_2 = 0.74$) and experiences with the front brake light on own vehicles (5 items, $\alpha_2 = 0.60$). Both scales assessed positive and negative experiences with front brake lights. Experiences with vehicles of others were only collected if the subjects had driven a vehicle on the airside during the test period while experiences with own vehicles were only collected if at least one of the vehicles driven by the participant had been equipped with a front brake light.

Finally, participants were asked to report positive and negative impressions of the front brake light in an open comment section at T2.

### 2.3 Procedure

The survey was conducted at an interval of three and a half months on the airside of Berlin Tegel Airport (see Figure 3). The employees of AAS Aviation & Airport Services GmbH, Berliner Flughafen Gesellschaft, Lufthansa Technik AG, SCK Sky Catering Kitchen GmbH, WISAG Airport Services Berlin GmbH & Co. KG, AeroGround, Aviation Ground Service Berlin and HSD Flughafen GmbH as well as employees of other companies located at the airport took part in the survey. To avoid disrupting the work process, most of the employees were interviewed in their brake rooms. Participants received a compensation of 5€ (approx. $6) at each measurement occasion for participating in the survey. The interviewers reported a high motivation to participate in the survey. Only few people approached did not want to take part.

Immediately after the first survey, 102 out of approximately 650–700 stationary vehicles at the airport (e.g., baggage vehicles, service cars, fuel trucks, passenger buses) were equipped with front brake lights in the form of a green LED strip (see Figure 4). This corresponds to an implementation rate of 14−16% and ensured in combination with the high frequency usage of these vehicles that enough encounters with the front brake lights took place. Initially, the front brake lights were planned to be in use for 3 months exactly. This period was chosen because the observation period had to be (a) long enough to ensure that the airport staff gained sufficient experience with the front brake light and (b) short enough to ensure that the same employees could participate in a pre- and post-survey despite the high fluctuation of workers at the airport. Due to administrative delays, the initially planned observation period was extended to three and a half months, which still meets these criteria. In agreement with the insurance companies involved (Allianz, AXA, R+V), the insurance protection of the vehicles

| month | May | June | July |
|-------|-----|------|------|
| CW    | 21  | 22   | 23   |
|       | 24  | 25   | 26   |
| interview T1 | 422 vehicles were provided with the fit | testing phase |
| month | July | August |
| CW    | 27  | 28   |
|       | 29  | 30   |
|       | 31  | 32   |
| testing phase |

| month | August | September |
|-------|--------|-----------|
| CW    | 33     | 34        |
|       | 35     | 36        |
|       | 37     | 38        |
| testing phase | interview T2 | deinstallation of the fit |
was maintained despite the technical changes. The T2 survey was conducted immediately after removing the front brake lights. In order to be able to interview the same participants at both measurement occasions, notices, telephone calls and information from colleagues and superiors were used.

3 | RESULTS

3.1 | Potentially relevant traffic situations

Potentially relevant traffic situations were judged to occur “occasionally” at both measurements (T1: $M = 3.18, SD = 0.69$; T2: $M = 3.32, SD = 0.63$). The mean difference was significant, $t(184) = 2.79, p = 0.006$, and $d_{RM} = 0.20$.

3.2 | Attitude towards the front brake light

At T1, the average attitude score was 3.48 ($SD = 0.91$) and at T2, the average attitude score was 3.70 ($SD = 0.93$). A $t$-test showed a significantly more positive attitude towards the front brake light at T2, $t(185) = 3.52, p = 0.001$, and $d_{RM} = 0.26$.

Furthermore, a moderated multivariate regression analysis was conducted to determine whether a change in attitude was moderated by contact with front brake lights (item 18: “How often have you seen the front brake light in action?”). The interaction between the attitude towards front brake lights at T1 and the frequency of contact with front brake lights was not significant ($\beta = -0.15, p = 0.67$). The hypothetical vote on the general introduction of front brake lights led to the following results: At T1, 132 participants voted in favour of and 49 voted against a general introduction; at T2, 137 voted in favour and 44 voted against. A chi-square test (Table 1) showed no significant difference, $\chi^2(1) = 0.92, p = 0.34$. The question about a change of opinion regarding the front brake lights resulted in 59.14% of the participants reporting a change in positive direction, 33.33% reporting no change, and 3.76% reporting a change in negative direction.

3.3 | Contact with the front brake light

The mean values of the items concerning contact with front brake lights are shown in Figure 5. The difference in frequency of situations in which subjects reported positive ($M = 3.35, SD = 1.15$) versus negative ($M = 1.99, SD = 1.07$) experiences with front brake lights was significant, $t(184) = 10.52, p < 0.001$, $d = 1.23$. Equally significant was the difference of hearing about positive ($M = 2.46, SD = 1.18$) or negative ($M = 1.89, SD = 1.02$) experiences with the front brake lights from others, $t(185) = 5.14, p < 0.001$, and $d = 0.52$. Moreover, the frequency of contact with front brake lights correlated with the perception of positive situations ($r = 0.42, p < 0.001$) but not with the perception of negative situations ($r = -0.07, p = 0.36$). This difference in correlations was statistically significant, $z = 4.58, p < 0.001$.

3.4 | Experiences with the front brake light

The subgroup of employees who drove a vehicle on the airside during the test period ($N = 166$) stated that they had “occasionally” ($M = 3.25, SD = 0.95$) made positive experiences with front brake lights on others’ vehicles while having only “rarely” made negative experiences ($M = 2.09, SD = 0.96$). The difference between positive and negative experiences was significant, $t(165) = 10.86, p < 0.001$, $d = 0.84$ (see Figure 6).
The subgroup of employees who drove vehicles equipped with front brake lights \((N = 122)\) stated that they had “occasionally” \((M = 3.20, SD = 1.07)\) made positive experiences with front brake lights on their own vehicles while having only “rarely” \((M = 1.73, SD = 0.80)\) made negative experiences. The difference between positive and negative experiences was significant, \(t(121) = 11.39, p < 0.001, d = 1.03\) (see Figure 7).

3.5 Open comment section

Additional positive comments were made by 38 participants. A total of 10 comments were related to the fact that braking of vehicles could be detected more quickly (anticipation and reaction), 7 were generally positive, 7 dealt with an increased sense of safety and 6 emphasized the visibility of the front brake lights (especially in the dark). The remaining comments dealt with improved traffic communication, positive aspects of the green colour and the assistance front brake lights provide to the parking process. Five comments did not fall into any of these categories.

Additional negative comments were made by 25 people. Of these, 10 comments were related to malfunctions that occurred during the field trial and 7 comments were related to the colour of the front brake light. Some participants preferred the colour red. The remaining comments criticized the visibility (too low or too dazzling) and the general use of front brake lights. Five comments did not fall into any of these categories.

4 DISCUSSION

To be able to detect changes in attitudes towards front brake lights, it was necessary that relevant situations occurred sufficiently often on the airside (e.g. at crosswalks or junctions). The results show that this requirement was met. Participants who came into contact with the front brake light at T2 reported at both measurements that such traffic situations occurred “occasionally”. Unexpectedly, there was even a slight increase in the report of these potentially relevant traffic situations. This could either be due to an actual increase in the number of potentially relevant situations or to an increased attention towards them caused by the first inquiry.

Concerning the attitude towards the front brake light, a rather positive evaluation of the front brake light was already apparent at T1. Nevertheless, over the observation period of three and a half months, the attitude improved significantly confirming Hypothesis 2. However, this effect was not related to the frequency of contact (rejection of Hypothesis 3). Yet it turned out that the frequency of contact was related to the description of positive but not to the description of negative observations of front brake lights. Hence, in contrast to the positive observations, the negative observations were probably not based on experience but more of a principal nature, for example, change resistance [27].

The positive attitude towards the front brake light became also apparent in the consistently positive results of the hypothetical voting: Approximately three quarters of the participants voted in favour of generally introducing front brake lights in road traffic and only one quarter voted against it (confirmation of Hypothesis 4). In the self-report of their own change of opinion, a majority of participants \((59.14\%)\) stated that their attitude towards front brake lights had improved over the duration of the field study. Only very few participants \((3.76\%)\) reported a change in negative direction. Overall, the positive attitudes at both measurements and the improvement in attitudes suggest that the vast majority of respondents had positive experiences and perceived a positive impact of the front brake light on road safety.

In accordance with these results, participants reported that situations in which the front brake light had been useful had occurred “occasionally” and situations in which it had led to misunderstandings or hazards had occurred “rarely” (confirmation of Hypothesis 1). Both findings were regardless of whether participants drove a vehicle equipped with a front brake light themselves or merely observed it. Furthermore, it should be mentioned that front brake lights represent a completely new feature of communication, and that any kind of human communication system can lead to misunderstandings. For instance, a road user could conclude from the onset of a front brake light that the vehicle will stop even though the driver just accidentally touched the pedal (although this problem could be minimized by calibrating a specific pressure point or be eliminated in automated driving). Therefore, the relative frequency of benefits in communication through front brake lights compared to the frequency of misunderstandings is a crucial factor in evaluating this new feature. For comparison, the seat belt can also cause a passenger to drown or burn in a vehicle after an accident: If it had not been worn, the passenger might have been ejected and rescued in case of collision. However, the number of people who are rescued by the seat belt is so much higher that nobody
questions its usefulness and its obligatory use. Moreover, it has to be considered that, after a possible introduction of front brake lights, road users may need to get accustomed to the new signal [see 28,29] in order to develop a communication with a minimum of misunderstandings. For example, it could become a custom that drivers briefly tap the brake several times to signal to pedestrians that they can safely cross the road, just as the rear brake light or the hazard-lights are informally used to indicate the end of a traffic jam.

However, the results of the present study suggest that the front brake light is even useful for both pedestrians and drivers immediately after its introduction because hardly any misunderstandings were reported, although this new feature had not even been announced by media communication or instruction. The predominantly positive comments of participants additionally demonstrate a high level of acceptance of front brake lights. Nevertheless, some negative comments regarding the technical configuration, position, brightness and colour should be taken into account in future research and optimization of the front brake light.

4.1 Limitations

According to the participants’ comments, technical problems occurred occasionally during the test period. These may have biased the opinion formation about the front brake lights. To prevent this, the technical problems that affected seven vehicles were resolved very quickly. Thus, the operation of the vehicles equipped with a prototype test kit of the front brake lights did work well. A bias due to technical problems would presumably have worked in negative direction, making the evaluation of front brake lights more conservative.

Finally, it should be pointed out that an analysis of objective data such as the frequency of accidents and near accidents on the airside would have been desirable. In the present study, all accidents during the field trial and in a control period before have been recorded. However, the total number of accidents on the airside during the three and a half months of the field trial was close to zero. It was therefore not possible to draw any conclusions about a safety effect of the front brake light based on these accident data. More generally, it would not even be possible to test the safety gain of the front brake light even if the accidents were recorded over several years.

4.2 Implications

The present study is pioneering the possible introduction of a front brake light. However, there are some hurdles to be considered along the way as both the introduction of the front brake light itself and the introduction of a green light signal on motor vehicles in general have to be approved by the EU Commission in Europe. Our study has provided initial data that has already triggered a political debate as well as further research on the topic of a front brake light. For example, a possible introduction of the front brake light has already been discussed at a parliamentary conference with traffic experts and members of the European parliament and a city-wide model trial is about to start in Bratislava [30]. Furthermore, Weyde [31] was able to show in a model calculation that motorbike accidents at road junctions could be almost completely avoided by the use of front brake lights, since the motorcyclists concerned are given life-saving seconds by the absence of the illumination of the front brake light, which enables timely braking. Outside the EU, a front brake light could possibly be introduced earlier due to less stringent requirements.

5 Conclusion

In line with the assessments of stress [18] and cervical spine damage [17] reduction as well as other studies on the safety effects [1,16], the present field study provides further empirical evidence for a safety gain from front brake lights. However, technical characteristics of front brake lights need further elaboration since false positive and false negative signals can have divergent consequences. While false positive signals (e.g. the erroneous indication of braking due to an excessively sensitive pressure point on the pedal) might result in a danger to road users which should be absolutely avoided, false negative signals (e.g. the absence of a signal due to a failure of the front brake light) may lead to a more conservative behaviour of participants in crossing traffic which should not adversely affect safety. The latter is particularly important for the expected mixed traffic after an introduction of the front brake light and can therefore be regarded as positive. Further studies should also investigate the optimal configuration of the front brake light concerning colour, light intensity, shape and positioning (see [19–25] for promising first results). The need of those studies is shown by the numerous participants who made comments on these technical aspects in the present study. Especially, the green colour led to conflicting opinions: The supporters interpreted green as a safety signal, whereas the opponents did not associate green with a braking process due to the conventional red brake lights. Similar results were found by Dey et al. [25] who described participants’ confusion that it is not completely clear whether the green light signals the observer to go or the vehicle’s intention to go [26]. However, this problem would probably lose its relevance with a general introduction of the front brake light and the growing experience that would go with it. For example, Faas et al. showed in a longitudinal video study that using an eHMI communicating the vehicle status yields effects increasing with time, such as earlier crossing onset as well as higher perceived safety, trust, learnability and reliance on eHMI [28]. Lee et al. [29] were able to show that the learning effect with regard to the crossing onset occurs relatively quickly (however, it was dependent on the design of the eHMI).

Overall, the results available from the laboratory and field studies so far suggest that the improvement of reaction times and the experience-based positive evaluation of front brake lights are based on a real contribution of front brake lights to enhanced road safety. Front brake lights provide road users with additional information on the behaviour of drivers that seem to
be useful for their own plans and actions in traffic. Thus, the front brake light improves communication between road users by making it possible to detect a braking process from a frontal perspective as well. It is expected that this will not only increase the comfort of road users and improve traffic flow but will also help them to anticipate and better cope with critical traffic situations as well as to prevent accidents.

ACKNOWLEDGEMENTS

The authors want to thank Lumaco Swiss for funding the reported investigation. Major portions of this paper have been published in Zeitschrift für Verkehrssicherheit (ZVS), a German language periodical [16]. The publication of this English version of the paper has been approved by the publisher of ZVS.

ORCID

Merlin Monzel https://orcid.org/0000-0001-7012-9350

REFERENCES

1. Petzoldt, T., Schleinitz, K., Banse, R.: Potential safety effects of a frontal brake light for motor vehicles. IET Intell. Transp. Syst. 12(6), 449–453 (2018)
2. GDV Unfallforschung der Versicherer. Innerörtliche Unfälle mit Fußgängern und Radfahrern [Inner-city accidents with pedestrians and cyclists] (2013)
3. Statistisches Bundesamt (Destatis). Verkehrsunfälle 2016 [Road accidents 2016] (2017)
4. ADAC e.V. Zahlen, Fakten, Wissen. Aktuelles aus dem Verkehr [Numbers, facts, knowledge. News from traffic] (2015)
5. Bock, E.: Die Verkehrstelematik [Traffic telematics]. In: Telematik im Personenverkehr, pp. 49–86. Springer (1998)
6. Várhelyi, A.: Drivers’ speed behaviour at a zebra crossing: A case study. Accid. Anal. Prev. 30(6), 731–743 (1998)
7. Wood, J.M.: Effect of visual impairment on driving. Hum. Factors 36(3), 476–487 (1994)
8. Wood, J.M.: Age and visual impairment decrease driving performance as measured on a closed-road circuit. Hum. Factors 44(3), 482–494 (2002)
9. Theeuwes, J., Riemersma, J.: Daytime running lights as a vehicle collision countermeasure: The Swedish evidence reconsidered. Accid. Anal. Prev. 27(5), 633–642 (1995)
10. Schmidt, S., Färber, B.: Pedestrians at the kerb—Recognising the action intentions of humans. Transp. Res. Part F: Traffic Psychol. Behav. 12(4), 300–310 (2009)
11. Radclyffe Barry, D., Fraser, R.P.: Improvements in or relating to motor road vehicles. 493, 510, 1938
12. Douglass, S.E.: Motor vehicle signal, 1,519,980, 1924
13. Pirkey, O.S.: Signal for automobiles, 1,553,959, 1925
14. Annas, J.T.: Vehicle driver-actuated safety signal light assembly. US3665392, 1972
15. Post, D.V., Mortimer, R.G.: Subjective evaluation of the front-mounted braking signal. Highway Safety Research Institute, The University of Michigan (1971)
16. de Clercq, K., et al.: External human-machine interfaces on automated vehicles: Effects on pedestrian crossing decisions. Hum. Factors 61(8), 1353–1370 (2019)
17. Hell, W.: An opinion on the biomechanics of trauma. In: The Front Brake Light - Its Conception and Theoretical and Experimental Evidence for Increasing Traffic Safety, pp. 31–39. Bonn Institute for Forensic and Traffic Psychology (2019)
18. Reschke, K., Kranich, U.: Reducing stress in traffic by the use of a front brake light. In: The Front Brake Light - Its Conception and Theoretical and Experimental Evidence for Increasing Traffic Safety, pp. 41–49. Bonn Institute for Forensic and Traffic Psychology (2019)
19. Ackermann, C., et al.: An experimental study to investigate design and assessment criteria: What is important for communication between pedestrians and automated vehicles? Appl. Ergon. 75, 272–282 (2019)
20. Faas, S.M., Mathis, L.A., Baumann, M.: External HMI for self-driving vehicles: Which information shall be displayed? Transp. Res. Part F: Traffic Psychol. Behav. 68, 171–186 (2020)
21. Keidel, K., Monzel, M., Banse, R.: Psychological effects of the colours green and red. In: The Front Brake Light - Its Conception and Theoretical and Experimental Evidence for Increasing Traffic Safety, pp. 51–58. Bonn Institute for Forensic and Traffic Psychology (2019)
22. Bazilinsky, P., et al.: How should external human-machine interfaces behave? Examining the effects of colour, position, message, activation distance, vehicle yielding, and visual distraction among 1,434 participants. Appl. Ergon. 95, 103450 (2021)
23. Bazilinsky, P., Dodou, D., De Winter, J.: External human-machine interfaces: Which of 729 colors is best for signaling “please (do not) cross”? In: IEEE Transactions on Systems, Man, and Cybernetics: Systems, pp. 3721–8 (2020)
24. Bazilinsky, P., Dodou, D., De Winter, J.: Survey on eHMI concepts: The effect of text, color, and perspective. Transp. Res. Part F: Traffic Psychol. Behav. 67, 175–194 (2019)
25. Dey, D., et al.: Color and animation preferences for a light band eHMI in interactions between automated vehicles and pedestrians. In: Conference on Human Factors in Computing Systems - Proceedings, New York, pp. 1–13. Association for Computing Machinery (2020)
26. Eisma, Y.B., et al.: External human-machine interfaces: Effects of message perspective. Transp. Res. Part F: Traffic Psychol. Behav. 78, 30–41 (2021)
27. Forsell, L.M., Åström, J.A.: An analysis of resistance to change exposed in individuals’ thoughts and behaviors. Compr. Psychol. 1, 09.02.10.CP.1.17 (2012)
28. Faas, S.M., Kao, A.C., Baumann, M.: A longitudinal video study on communicating status and intent for self-driving vehicle - pedestrian interaction. In: Proceedings of the Conference on Human Factors in Computing Systems. Association for Computing Machinery (2020)
29. Lee, Y.M., et al.: Learning to interpret novel eHMI: The effect of vehicle kinematics and eHMI familiarity on pedestrians’ crossing behaviour [Internet]. https://psyarxiv.com/2xub4/ (2020)
30. Milestones | Front brake light - Another safety dimension [Internet]. https://vorderebremsleuchte.com/en/milestones/
31. Weyde, M.: Die intelligente Vordere Bremsleuchte – aus Sicht der Unfallanalyse [The intelligent front brake light - from the point of view of accident analysis]. Talk at Parliamentary Web Conference 17.11.2020

How to cite this article: Monzel, M., et al.: A field study investigating road safety effects of a front brake light. IET Intell. Transp. Syst. 15, 1043–1052 (2021). https://doi.org/10.1049/itr2.12080
# APPENDIX

## TABLE A1  Scale “Potentially relevant traffic situations”

| Items                                                                 | rit1 | rit2 |
|-----------------------------------------------------------------------|------|------|
| How often do dangerous situations occur between vehicles and pedestrians when traffic is crossing? | 0.61 | 0.64 |
| How often do dangerous situations occur between several vehicles when traffic is crossing? | 0.66 | 0.61 |
| How often do dangerous situations occur on pedestrian crossings?     | 0.50 | 0.51 |
| How often do you, as a pedestrian, feel unsure whether intersecting traffic is slowing down? | 0.48 | 0.43 |
| How often do you, as a driver, feel unsure whether intersecting traffic is slowing down? | 0.61 | 0.58 |
| How often do dangerous traffic situations occur on the apron?         | 0.66 | 0.65 |
| How often do you feel stressed by hectic traffic on the apron?        | 0.57 | 0.57 |
| How often is the traffic flow on the apron delayed by crossing traffic? | 0.53 | 0.46 |
| Cronbach’s Alpha                                                      | 0.84 | 0.83 |

Note: Item-total correlations and Cronbach’s Alpha for both measurements are presented.

## TABLE A2  Scale “Attitude towards the front brake light”

| Items                                                                 | rit1 | rit2 |
|-----------------------------------------------------------------------|------|------|
| The front brake light is a good idea.                                | 0.73 | 0.77 |
| The front brake light would have more disadvantages than advantages in the long run. (–) | 0.16 | 0.36 |
| The front brake light can make road traffic safer.                   | 0.77 | 0.75 |
| The front brake light can prevent accidents.                         | 0.70 | 0.71 |
| The front brake light is unnecessary. (–)                            | 0.46 | 0.69 |
| The front brake light increases the safety of pedestrians.           | 0.70 | 0.71 |
| The front brake light can facilitate advancement in road traffic.    | 0.68 | 0.64 |
| Cronbach’s Alpha                                                      | 0.84 | 0.87 |

Note: Item-total correlations and Cronbach’s Alpha for both measurements are presented. Items with reversed polarity were marked with (–).

## TABLE A3  Scale “Contact with the front brake light”

| Items                                                                 | rit1 | rit2 |
|-----------------------------------------------------------------------|------|------|
| How often have you seen the front brake light in action?              | 0.35 |      |
| How often have you positively noticed the front brake light (e.g. faster progress, improved safety etc.)? | 0.32 |      |
| How often have you negatively noticed the front brake light (e.g. misinterpretation, distraction etc.)? | 0.12 |      |
| How often have you heard something positive about the front brake light from others? | 0.44 |      |
| How often have you heard something negative about the front brake light from others? | 0.19 |      |
| Cronbach’s Alpha                                                      |      | 0.51 |

Note: The scale was only used at measurement 2. Item-total correlations and Cronbach’s Alpha are presented.
### Table A4: Scale “Experiences with the front brake light on others’ vehicles”

| Items                                                                 | r_{rt1} | r_{rt2} |
|-----------------------------------------------------------------------|---------|---------|
| How often has the front brake light on someone else's vehicle made it easier for you to understand what another road user was planning to do? | 0.56    |         |
| How often has the front brake light on someone else's vehicle made a traffic situation easier for you? | 0.61    |         |
| How often has the front brake light on someone else's vehicle caused misunderstandings? (–) | 0.45    |         |
| How often has the front brake light on someone else's vehicle led to a dangerous situation? (–) | 0.44    |         |
| How often has the front brake light on someone else's vehicle reduced or prevented a dangerous situation? | 0.43    |         |
| How many times have you mistakenly assumed that another road user was stopping because of a front brake light on their vehicle? (–) | 0.19    |         |
| How often have you noticed that another road user stopped because of a flashing front brake light on other vehicles? | 0.57    |         |

Cronbach's Alpha 0.74

Note: The scale was only used at T2. Item-total correlations and Cronbach's Alpha are presented. Items with reversed polarity were marked with (–).

### Table A5: Scale “Experiences with the front brake light on own vehicles”

| Items                                                                 | r_{rt1} | r_{rt2} |
|-----------------------------------------------------------------------|---------|---------|
| How often has the front brake light on your vehicle caused misunderstandings? (–) | 0.41    |         |
| How often have you had the impression that the front brake light on your vehicle has improved traffic flow? | 0.31    |         |
| How often have you had the impression that the front brake light on your vehicle has helped other road users to better predict your driving manoeuvres? | 0.43    |         |
| How often have you had the impression that the front brake light on your vehicle has led to misunderstandings among other road users? (–) | 0.37    |         |
| Cronbach's Alpha                                                      | 0.60    |         |

Excluded: How often have you turned off the front brake light on your vehicle during driving? (–) | 0.16    |         |

Note: The scale was only used at measurement 2. Item-total correlations and Cronbach's Alpha are presented. Items with reversed polarity were marked with (–).