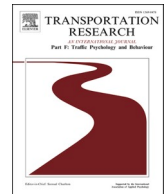




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Enhancing perceived traffic safety with a front brake light (FBL): Findings from a field test in real road traffic

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ABSTRACT

In a field study in Slovakia, a Front Brake Light (FBL) was tested in everyday traffic. The FBL works similar and simultaneously to established rear brake lights, but it is signaling to the front via a green light. A longitudinal design was conducted with 210 drivers of FBL-equipped vehicles who were interviewed before the FBL was fitted to their vehicle and again six to eleven months later. Additionally, in a cross-sectional design, 2476 drivers of FBL vehicles were interviewed after participating in the field study, and another 621 other road users who did not drive an FBL vehicle themselves were also interviewed, making this study the largest field test of FBLs to date. The focus of the interviews was on perceived safety effects and attitudes towards the device, but also potential misunderstandings, dangerous traffic situations experienced, and accidents. Results were in line with findings from previous studies and clearly indicated a positive effect of the FBL on perceived traffic safety. Overall, 77.4% of FBL drivers as well as 86.2% of other road users supported the general introduction of the FBL after the test period. Only a small number also reported that the FBL was occasionally misunderstood as a stopping signal of the vehicle. In addition to the questionnaire-based survey, accident data from Slovakian police were analyzed. Overall, the data show that the implementation of the FBL works well in everyday road traffic and that it can lead to an increased sense of safety among road users.

1. Introduction

In the history of motorized road traffic, there have always been frequent innovations regarding the safety of road users, including the introduction of the seat belt and the airbag. These safety measures are directed towards the occupants of a vehicle, whereas other safety measures are directed towards other road users. One key example is the brake light, which indicates the braking process to following road users. But what about road users who encounter a vehicle from the front? The idea of a Front Brake Light (FBL) is not new. First patents date from nearly 100 years ago (Douglass, 1924; Pirkey, 1925; Radclyffe Barry, 1938) and the idea has been revisited through history, but it has never become standard (e.g., Annas, 1972; Debaillie, 2004; Jandron, 1998; O'Sullivan, 1994; Pitcher, 1997;

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Post & Mortimer, 1971; Sarokin, 1990).

1.1. Recent research

Recently, research and discussion of the FBL has again gained momentum: In 2017 [Petzoldt et al. \(2017\)](#) conducted a laboratory study, testing whether an FBL enables persons to more quickly recognize that a vehicle is braking. Participants were presented videos of approaching vehicles and were asked to press a key as soon as they recognized the beginning of the braking process. It was shown that participants recognized braking much more quickly in the FBL condition compared to a control group. Moreover, participants made more conservative (i.e., they observed the vehicle for longer before deciding whether it was still safe to cross the road) decisions when some vehicles had an FBL but some vehicles did not (mixed traffic).

These results have recently been replicated in a similar online study by [Eisele and Petzoldt \(2024\)](#) in which participants were asked their willingness to cross the street instead of their perception of the start of the braking. Again, it was found that the FBL had positive effects on safety-relevant decisions of road users, even in mixed traffic. Furthermore, it was shown that the willingness to cross was more uniform when an FBL was present.

Following the 2017 laboratory study, the FBL was tested in a field study at the airside of Berlin Tegel Airport (TXL; [Monzel et al., 2021](#)). In this study 102 vehicles were each equipped with an FBL for three months. A total of 197 persons (drivers and non-drivers) were asked about their opinions of the FBL via a survey before the introduction of the FBL and after the three months. Although participants already had a positive attitude towards the FBL at the beginning, the positive evaluations increased over the course of three months. Moreover, the frequency of contact with FBLs was related positively to positive experiences with it. Thus, the more experience a person had with the FBL, the more positive that person's attitude became. Overall, more than 75% of the interviewees were in favor of a general introduction of the FBL after the field trial. The results replicated the findings of an early field study by [Post and Mortimer \(1971\)](#) in which a general positive attitude towards an FBL was found.

In another recent sequence of studies, the FBL's potential to prevent and mitigate consequences of crashes at intersections was assessed through professional accident analysis by simulations, based on real accident data. In a pre-study a specific sub-type of motorcycle crashes was investigated ([Weyde & Böck, 2021](#)). In the main study, 200 real-life accidents that fell within certain accident categories were analyzed, and it was concluded that the FBL has the potential to prevent 7.5 to 17.0% of accidents of those types and to positively influence (e.g., reduce severity of) another 9.0 to 25.5% of them ([Tomasch et al., 2025](#)).

One of the most recent simulation studies on the topic of FBL examined the effects of FBL on an especially vulnerable group of road users: children ([Bluhm et al., 2023](#)). Children's willingness to cross the road in front of a vehicle with or without an FBL was analyzed in a simulation study. It was found that the effects were comparable to the effects in previous samples of adults. Thus, previous findings on the FBL can be generalized to children as well.

1.2. Current study

Since previous studies lack the ecological validity, a large field trial in real road traffic was conducted in Slovakia. A total of 3072 vehicles in the counties of Trenčín and Žilina, as well as a small number of vehicles in Bratislava, were equipped with the FBL for a time period of six to eleven months. [Fig. 1](#) shows an image of the installed FBL used in this study. In addition, [Fig. 2](#) shows the FBL in traffic action.

In accordance with previous studies, it was expected that a majority of the interviewees would report positive experiences and attitudes towards the FBL and be in favor of a general introduction. In past research ([Monzel et al., 2021](#); [Post & Mortimer, 1971](#)), positive experiences as well as attitudes outweigh negative ones, and thus the same pattern was anticipated in the present study. Moreover, it was predicted that the more contact a person has with the FBL, the more positive his or her attitude towards it will be.



Fig. 1. Close-up of the FBL.



Fig. 2. FBL in traffic action.

Thus, we hypothesized that findings from previous FBL studies, especially from [Monzel et al. \(2021\)](#), would be replicated in this large-scale field trial.

A subset of the sample of FBL drivers was interviewed before and after the introduction of the FBL (T1 & T2) to allow for longitudinal analyses. In this subsample, FBL drivers should report a more positive opinion of the FBL at T2 compared to T1. In line with the results reported by [Monzel et al. \(2021\)](#), this effect should increase the more experience the individuals had with the FBL during the field trial.

2. Methods

2.1. Sample

Three different groups were targeted in this study. The first group consisted of 237 individuals who drove a vehicle equipped with an FBL and who took part in an interview at T1 and T2 (FBL drivers T_{12}). For 27 of these cases, the birth year reported at T1 and T2 did not match, indicating that the data therefore did not originate from the same person or some other error occurred, so they were removed and the final sample consists of only $N_{T12} = 210$ individuals. The second group consisted of $N_{T2} = 2476$ persons who drove an FBL vehicle but only took part in the survey at T2 (FBL drivers T2). The third group consisted of $N_{others} = 621$ road users who did not drive an FBL vehicle and only took part in the survey at T2 (other road users). More details on the sample groups can be found in [table 1](#). Note that the reduced n for the age variables in the groups of FBL drivers at T2 and for other road users is due to the removal of

Table 1
Demographics.

	FBL drivers T1	FBL drivers T_{12}	FBL drivers T2	Other road users
	$N_{T1} = 311$	$N_{T12} = 210$	$N_{T2} = 2476$	$N_{others} = 621$
Sex				
Male	90.4%	88.1%	91.2%	52.3%
Female	9.6%	11.9%	8.8%	47.7%
Age				
$M (SD)$	46.93 (11.18) ^a	48.03 (11.49)	48.06 (10.71) ^b	33.44 (17.41) ^c
Range	20 - 75 ^a	21–76	18 - 91 ^b	14 - 77 ^c
Driver's license				
Years holding a driver's license $M (SD)$	27.25 (11.37)	28.33 (11.78)	27.39 (11.24)	–
Missing	12.2%	5.2%	4.0%	–

Note. Age reported for FBL drivers T_{12} refers to age at T2. Information on the age at which the driver's license was obtained was only taken into account if the answers were plausible (i.e., age at which the driver's license was obtained was at least 15 years).

^a $n = 284$.

^b $n = 2452$.

^c $n = 620$.

participants who had likely inaccurate (e.g., mismatched) reports of birth years and/or missing data. In the two groups of FBL drivers, more than 60% of the participants reported to work or had been working as professional drivers.

2.2. Procedure

In total 3072 vehicles, mainly from the counties of Trenčín and Žilina, were equipped with FBLs (table 2). Interviews for T1 data collection were conducted in November 2022 to January 2023 by trained (post-graduate) students and staff of the university of Žilina. Typically, interviews were conducted while the FBL was being mounted on the vehicle. T2 data collection took place in August and September 2023 and, again, was carried out by trained (post-graduate) students from the university of Žilina. In order to obtain data from other road users (T2), interviewers approached people on the streets. In addition to the survey, accident data for the time period of interest and a comparison period were obtained from the Slovakian police.

2.3. Questionnaires

In total, four questionnaires were used in this study to gather data from the groups of FBL drivers T_{12} (T1 & T2), FBL drivers T2, and other road users (T2). All questionnaires can be found in the online supplement to this report (<https://doi.org/10.17605/OSF.IO/6ZFRV>). For every participant, demographic variables like name, sex, and year of birth were requested, and a short description of the basic function of the FBL was given. If the participant was a driver of an FBL vehicle, the approximate number of kilometers driven with the FBL was recorded at T2 as well. Further questions concerned the participants' knowledge, expectations, and experience with the FBL, as well as safety effects of the FBL (expected safety effects at T1 and experienced safety at T2). Based on Monzel et al. (2021), six items on safety effects were summarized into the Safety Effects Scale. For FBL drivers T_{12} , Cronbach's α of this scale was .92 at T1 ($n = 286$) and .87 at T2 ($n = 210$). The last section of the questionnaires dealt with eight items on attitudes towards the FBL. Again, the items were summarized to a scale (Attitudes Scale) with Cronbach's α for FBL drivers T_{12} at T1 being .89 ($n = 278$) and at T2 .86 ($n = 210$).

In the T2 versions of the questionnaires, additional questions referred to the actual experience and impressions with the FBL as well as the number of conflicts, misunderstandings, and accidents associated with it. In this context, participants were also asked about the occurrence of "dangerous traffic situations". Since no definition of dangerous traffic situations was provided, participants were asked to describe the specific situations if they reported any. Both the Safety Effects and Attitudes Scales were used again at T2, but additional items were added to enable differentiation between different traffic situations and specific attitudes about the FBL.

Two different versions of the questionnaire for FBL drivers at T2 (V1 and V2) were used, differing in the answer format of six questions. V1 used an open-ended answer format or categorical options allowing for a more precise quantification of frequencies, whereas V2 used Likert-type options allowing for a more subjective approach to estimate frequency perception. Each of the questionnaires used for the different groups in this study differed slightly from each other.

3. Results

All three groups considered in this study were analyzed separately and are reported separately. The focus of the analysis is on a descriptive evaluation of experiences with and attitudes towards the FBL, and the design in one of the groups allowed for a direct analysis of changes due to the introduction of the FBL. Initial results using the same data samples but focused on certain subgroups of road users under special circumstances have been published previously (Poliak et al., 2024, 2025a,b).

3.1. FBL drivers T_{12}

3.1.1. T1

A total of 311 drivers who later drove FBL vehicles participated in the survey at T1. Of the 311, 90.0% reported that they had already heard about the FBL, mostly at their work place (39.2%) and/or via TV (35%). All in all, 72.3% of the sample reported feeling well informed about the FBL at the beginning of the field trial. The first survey began before the first study-related FBL vehicles drove on the roads, but continued for a few days after their introduction. At this data collection, 12.5% of the sample stated they had seen such vehicles *often* or *very often*.

The average ratings on the Safety Effects Scale, its items, one additional item that was not included in the scale, as well as correlation with previous contact with the FBL, are shown in table 3. Per these data, participants anticipated safety effects of the FBL even before it was in use.

Descriptive statistics and correlations for the Attitudes Scale can be found in table 4. Apart from the significant positive correlation between the overall scale and previous experience with the FBL, significant negative correlations were found between two of the three

Table 2
Number of FBL vehicles.

	Passenger Car	Delivery	Taxi	Driving School	Local Bus	Regional Bus	Truck	Total
Number of vehicles	1513	161	43	19	127	665	544	3072

Table 3

Mean values for the Safety Effects Scale and correlations with previous FBL experiences (T1).

Item	<i>M</i>	<i>SD</i>	$\rho_{\text{experience}}^a$
In case of crossing traffic between vehicles and pedestrians?	3.92	1.26	.12*
In case of crossing traffic between several vehicles?	3.74	1.17	.15*
At zebra crossings?	4.10	1.32	.14*
When turning left with oncoming vehicles?	3.78	1.22	.07
When changing lanes on the motorway?	3.37	1.23	.04
When approaching the end of a traffic jam?	3.84	1.20	.06
Safety Effects Scale	3.79	1.04	.10
Additional item:			
When overtaking? ^{ab}	3.31	1.24	.03 ^c

Note. $n = 286$. 1 = *much less safe* to 5 = *much safer*.

^a $n = 285$.

^b Item is not included in the Safety Effects Scale.

^c $n = 284$.

* $p < .05$.

reverse-coded items and experience. Results were generally in line with our expectations. Also as expected, the majority of participants (77.7%) reported being in favor of the general introduction of the FBL ($n = 287$). The vote did not correlate significantly with previous experience with the FBL ($\rho = .11$, $p = .057$).

3.1.2. T2

From the 311 drivers who participated at T1, 210 answered the questionnaire at T2 again (67.5%). Of the 210 who responded during both data collection periods, 111 participants answered V1 of the questionnaire and 99 answered V2. Of the total sample at T2, 45.2% had their private car equipped with the FBL, 17.6% a truck (long range/transport), 13.3% a truck for short ranges (e.g., delivery), 11.4% a bus, 10.0% a taxi, 1.9% used another vehicle, and one person drove a transporter/van. Per their reports, 27.6% of the sample used their FBL vehicle only in urban traffic, and 5.2% used it exclusively in rural traffic, and a majority of 67.1% used it in both environments. Since all drivers drove at least 1000 km with the FBL, it was assumed that all had sufficient driving experience with the FBL.

Another indicator of experience with the FBL is how often other vehicles equipped with FBLs were seen during the test period. In version 1 of the questionnaire ($n = 111$), 80.2% of participants reported having seen an FBL in traffic action on another car *several times a week*, 15.3% *once a week*, 3.6% at least *once a month*, and only one person (0.9%) reported to have *never* seen another FBL on a vehicle in traffic action. In version 2 of the questionnaire ($n = 99$), only one person (1.0%) indicated having seen other FBL-equipped vehicles *very often*, 48.5% *often*, 28.3% *occasionally*, and 22.2% *rarely*. None of the interviewees in version 2 selected the option *never*. Regarding accidents, only one was reported in the questionnaire (V1 & V2). However, according to the description, it was not related to the FBL.

Average ratings of the items of the Safety Effects Scale as well as additional items and the respective correlations to the experience with other FBL-equipped vehicles are depicted in table 5. Mean ratings indicated an increase in perceived traffic safety for all items listed.

With the exception of one, every item of the Safety Effects Scale had a significant correlation with the item assessing experience with FBLs on the V2 questionnaire. Only the item, "In case of crossing traffic between several vehicles?" did not show a substantial relationship. For V1 of the questionnaire, only the total score of the scale showed a significant correlation with the item assessing experience with FBLs. Two of the three additional items that were not included at T1 had highly significant correlations to experience with the FBL (V2).

Comparing the average Safety Effects Score at T1 and T2, the difference was significant ($t(209) = -2.37$, $p = .019$). That is,

Table 4

Mean values for the Attitudes Scale and correlations with previous FBL experiences (T1).

Item	<i>M</i>	<i>SD</i>	$\rho_{\text{experience}}^a$
The Front Brake Light is a good idea.	3.83	1.15	.21**
The Front Brake Light would have more disadvantages than advantages in the long run. (–)	2.92	1.29	–.12*
The Front Brake Light can make road traffic safer.	3.91	1.08	.18**
The Front Brake Light can prevent accidents.	3.76	1.15	.17**
The Front Brake Light is unnecessary. (–)	2.56	1.25	–.13*
The Front Brake Light can cause accidents. (–)	2.68	1.23	–.09
The Front Brake Light increases the safety of pedestrians.	3.94	1.15	.15*
The Front Brake Light can make road traffic more fluid.	3.56	1.09	.11
Attitudes Scale	3.60	0.89	.20**

Note. $n = 278$. 1 = *strongly disagree*, 2 = *disagree*, 3 = *neither agree nor disagree*, 4 = *agree*, 5 = *strongly agree*.

^a $n = 277$.

* $p < .05$.

** $p < .01$.

Table 5Mean values for the Safety Effects Scale and correlations with previous FBL experiences (FBL drivers T₁₂).

Item	M	SD	$\rho_{\text{experienceV1}}$ ^b	$\rho_{\text{experienceV2}}$ ^c
In case of crossing traffic between vehicles and pedestrians?	4.18	1.04	.10	.53**
In case of crossing traffic between several vehicles?	3.93	0.94	.15	.13
At zebra crossings?	4.28	1.05	.15	.49**
When turning left with oncoming vehicles?	4.04	1.04	.15	.39**
When changing lanes on the motorway?	3.70	0.94	.17	.39**
When approaching the end of a traffic jam?	3.84	0.90	.13	.25*
Safety Effects Scale	4.00	0.77	.19*	.46**
Additional items:				
When you are the last car in a traffic jam? ^a	3.82	1.01	.14	.17
When you have right of way but another car is in a position such that it could violate your right? ^a	4.16	1.07	.14	.35**
When an oncoming car is in overtaking manoeuvre and fast approaching in your lane to see if action might be aborted? ^a	4.13	1.03	.16	.43**

Note. $n = 210$. 1 = *much less safe* to 5 = *much safer*. $\rho_{\text{experience}}$ = correlation with frequency of seeing other FBL vehicles (V1 1 = *never*, 2 = *once*, 3 = *once a month*, 4 = *once a week*, 5 = *several times per week*; V2 1 = *never*, 2 = *rarely*, 3 = *occasionally*, 4 = *often*, 5 = *very often*).

^a Item is not included in the Safety Effects Scale.

^b $n = 111$.

^c $n = 99$.

* $p < .05$.

** $p < .01$.

participants perceived FBLs as more likely to improve safety once they had more experience with it.

The majority of drivers (74.8%) reported that the FBL facilitated traffic situations for them at least *occasionally*, 19.5% reported that the FBL facilitated traffic situations *rarely*, and 5.7% reported they did not experience a facilitation at all. Dangerous traffic situations caused by an FBL on another vehicle were reported on average 0.57 times ($SD = 0.19$; $Md = 0.00$; interquartile range (IQR): 0–0; $n = 106$) in V1. In questionnaire V2, 8.1% of participants indicated that the FBL led *occasionally* or *often* to a dangerous traffic situation. No one chose the option *very often*. In almost all of the dangerous situations described by the drivers ($n = 8$), there was a reported misunderstanding of whether the FBL was a signal of stopping. This misunderstanding was also emphasized by the finding that 13.8% experienced such a situation at least once (V1; $Md = 0.00$; IQR : 0–0; $n_{V1} = 94$) and 44.5% reported having experienced it at least *occasionally* (V2).

On the other hand, 52% of the drivers reported that they experienced situations in which the FBL minimized or prevented dangerous traffic situations at least *occasionally*. In questionnaire V2 50.5% of the sample reported being able to recognize stopping of other vehicles more quickly due to the FBL *often* or *very often*, and an additional 28.3% at least *occasionally*. In the open answer format of V1, 50.1% reported at least one occasion in which that was true ($Md = 0.50$; IQR : 0–10; $n_{V1} = 60$).

A comparison of the mean answers for positive (facilitation of traffic situations, minimization of dangerous situations, and faster detection of braking) and negative items (leads to dangerous situations and misinterpretation of braking signal) of the questionnaire showed a significant difference ($t(98) = 16.15$, $p < .001$) for V2 of the questionnaire. Positive situations with the FBL occurred significantly more often than negative ones. Correlational analyses revealed a substantial relationship of experience (V2) with positive items ($\rho = .57$, $p < .001$) but not with negative ones ($\rho = .19$, $p = .05$).

Concerning consequences for the traffic, half of the answers (50.0%) in the V1 questionnaire (only 58 persons answered this question) indicated at least two situations in which traffic flow was improved by the FBL ($Md = 1.00$; IQR : 0–10), and 51.5% answering the V2 questionnaire reported to have *often* or *very often* experienced such situations. Of the 58 participants answering this question in V1 of the questionnaire ($Md = 3.50$; IQR : 0–10), 58.6% reported to have had the experience that the FBL on their car helped other road users predicting their next driving maneuvers at least once (53.5% chose *often* or *very often* in V2).

Information on the comprehensibility of the FBL can be found in table 6. Drivers were in favor of a preliminary explanation of the idea of the FBL, even if they seemed to have understood the idea themselves quite quickly. All in all, the concept of the FBL was rated as rather easy to understand.

In table 7 descriptive statistics for and correlations of the Attitudes Scale with experience with the FBL are presented. All items that indicate a positive attitude towards the FBL tended to be endorsed or agreed with, but negative statements tended to be disagreed with. In this respect, answers were in line with expectations. Regarding experience with the FBL, only some answers from V2 of the questionnaires showed significant correlations with the attitude statements. The total score of the Attitudes Scale was also significantly

Table 6Mean values for comprehensibility of the FBL (FBL drivers T₁₂).

Item	M	SD
The idea of a Front Brake Light is easy to understand for everyone.	3.72	0.90
The idea of the Front Brake Light needs explanation upfront when introducing widely to public traffic.	4.15	0.91
It took me some time to understand the Front Brake Light.	2.15	1.02
During the time vehicles with Front Brake Lights participated in road traffic a technical and administrative hotline was important.	2.83	0.88

Note. $n = 210$. 1 = *strongly disagree*, 2 = *disagree*, 3 = *neither agree nor disagree*, 4 = *agree*, 5 = *strongly agree*.

Table 7Mean values for the Attitudes Scale and correlations with previous FBL experiences (FBL drivers T₁₂).

Item	<i>M</i>	<i>SD</i>	$\rho_{\text{experienceV1}}$ ^b	$\rho_{\text{experienceV2}}$ ^c
The Front Brake Light is a good idea.	3.99	1.02	.16	.32**
The Front Brake Light would have more disadvantages than advantages in the long run. (–)	2.60	1.23	.02	–.13
The Front Brake Light can make road traffic safer.	4.05	0.94	.11	.32**
The Front Brake Light can prevent accidents.	3.95	0.93	.04	.35**
The Front Brake Light is unnecessary. (–)	2.30	1.14	–.04	–.30**
The Front Brake Light can cause accidents. (–)	2.78	1.01	.02	–.11
The Front Brake Light increases the safety of pedestrians.	3.95	1.01	.10	.33**
The Front Brake Light can make road traffic more fluid.	3.71	1.06	.10	.25*
Attitudes Scale	3.75	0.74	.07	.37**
Additional items:				
The Front Brake Light would reduce the level of stress in road traffic. ^a	3.37	1.02	.12	.27**
If I see a Front Brake Light lit, I take it for sure that the driver is braking. ^a	3.90	0.95	.07	.40**
If I see a Front Brake Light lit, I take it for sure that the vehicle will stop. ^a	2.76	1.20	.09	–.11
I would like to keep a Front Brake Light on my car. ^a	3.48	1.15	.18	.24*
I would buy a Front Brake Light for my (private) car as a retrofit, even if it is not mandatory. ^a	3.17	1.12	.13	.22*
The Front Brake Light is a means of traffic comfort. ^a	3.35	1.07	.16	.13
The Front Brake Light is a means of traffic safety. ^a	3.98	0.97	.08	.22*

Note. *n* = 210. 1 = *strongly disagree*, 2 = *disagree*, 3 = *neither agree nor disagree*, 4 = *agree*, 5 = *strongly agree*. $r_{\text{experience}}$ = correlation with frequency of seeing other FBL vehicles (V1 1 = *never*, 2 = *once*, 3 = *once a month*, 4 = *once a week*, 5 = *several times per week*; V2 1 = *never*, 2 = *rarely*, 3 = *occasionally*, 4 = *often*, 5 = *very often*).

^a Item is not included in the Attitudes Scale.

^b *n* = 111.

^c *n* = 99.

* *p* < .05.

** *p* < .01.

correlated to the experience measure of V2. All in all, drivers seemed to evaluate the FBL rather positively, regardless of their actual amount of experience with it. Agreement with the positive statements of the Attitudes Scale was significantly stronger compared to the negative ones ($t(209) = 13.44$, $p < .001$).

The difference between responses to the Attitudes Scale at T1 and T2, for which only a subsample of 208 drivers was available due to missing data, was not significant ($t(207) = -1.53$, $p = .128$). Descriptively, the attitudes towards the FBL at T2 ($M = 3.75$) were slightly more positive than at T1 ($M = 3.63$). However, the correlation between T1 and T2 was significant ($r = 0.16$, $p = .02$). The scores on the Safety Effects Scale and the Attitudes Scale correlated significantly with each other for both test times ($r_{T1} = .73$, $p < .001$; $r_{T2} = .52$, $p < .001$).

Furthermore, it was tested whether the relationship between the T1 and T2 score on the Attitudes Scale was potentially moderated by the experience the drivers had with seeing other FBL vehicles in traffic. Since experience was assessed differently in V1 and V2 of the questionnaire, two moderation analyses were calculated. Using the V1 variant, the interaction-term did not contribute significantly to the regression model ($\beta = -0.16$, $p = .113$). That was true for the V2 variant of the question as well ($\beta = -0.08$, $p = .45$). Therefore, experience with other FBL vehicles did not play a significant role in the change of attitudes towards the FBL.

At 82.9%, a clear majority of the drivers supported a general introduction of the FBL after using it for about six to eleven months. There was no significant correlation between the vote and experience with the FBL on other vehicles (V1 & V2). Changes in the final vote between T1 and T2 can be found in [table 8](#). Note that five drivers did not cast a vote at T1, so that the comparison could only be analyzed with the 205 participants who responded at both data collection points. By means of a χ^2 -test, it was tested whether the distribution of votes at T2 differed significantly from the expectations that were inferred from votes at T1. Although descriptively there was a slight shift towards more endorsement, the χ^2 -test did not result in a significant change between T1 and T2 ($\chi^2(1) = 3.22$, $p = .073$).

3.2. FBL drivers T2

In total, data from 2476 FBL drivers who did not take part at T1 were available for analyses. At T2, questionnaire V1 was answered by 1046 and V2 was answered by 1430 drivers. Most (91.1%) of the drivers had more than 1000 km of driving experience with the FBL.

Table 8

Comparison of votes on the general introduction of an FBL.

		T2	
		...opposed to it	...in favor
T1	...opposed to it	17	31
	...in favor	18	139
		35	170
			205

Of the same sample, 22.6% reported to have driven in urban traffic and 11.6% to have driven in rural traffic exclusively. A majority of 65.8% drove the FBL vehicle in both environments.

Asked for the quantity of encounters in V1 of the questionnaire, 1.4% of participants at T2 indicated they had *never* seen other FBL vehicles, 2.7% *once*, 4.9% *once a month*, 11.0% *once a week*, and 80.0% *several times a week*. In response to V2 at T2, 1.5% of drivers reported to have *never* seen an FBL on another vehicle, 16.6% reported having seen one *rarely*, 25.7% *occasionally*, 17.8% *often*, and 38.5% *very often*. It can be concluded that most drivers had seen other FBL vehicles several times a week and, thus, had experience with the FBL in traffic action.

Data from the Safety Effects Scale and additional items again showed an average rating above the neutral option of 3 for all items (table 9). The situation in which the drivers felt that the FBL made the greatest contribution to safety was as a pedestrian at a zebra crossing. For both V1 and V2 of the questionnaire, every single correlation between the items and experience with other FBL vehicles was highly significant. The more experience the drivers had with the FBL on other vehicles, the higher they rated its safety effects. In general, correlations were higher in the V2 compared to the V1 answer format.

A majority of the drivers reported experiencing FBL-facilitated traffic situations at least occasionally (68.5%). Only 12.7% *never* experienced a facilitation by the FBL. Nearly three quarters of the sample (73.6%) who responded to V2 of the questionnaire had never experienced a dangerous traffic situation caused by the FBL, and only 5.8% of respondents reported experiencing a dangerous traffic situation related to the FBL *often* or *very often*. In V1, more than 90% of respondents stated that they had never experienced such a situation ($Md = 0.00$; $IQR: 0-0$). The highest number of situations was reported by a single person who reported experiencing 300 dangerous traffic situations related to the FBL. However, in total less than 5% reported more than two situations and only three persons reported 100 or more situations (including the participant who reported 300). Note that 4.1% of the sample responding to V1 of the questionnaire did not respond to the item.

More specific reports of the dangerous situations were also taken into account. The reports revealed that interaction with pedestrians partly caused problematic situations, e.g., pedestrians taking the signal of FBL as a sign to be given the right of way. Others reported that they had concerns about the braking distance at crossings, especially for heavier vehicles, or that the FBL could be blinding for other road users at night.

In contrast to the perceived dangerous situations, 44.6% of the sample witnessed at least occasionally situations in which the FBL did not cause but reduced or even prevented dangerous traffic situations. Over a third (37.3%) never experienced situations in which danger was reduced by the FBL. Asked for a description of situations in which the FBL minimized or prevented dangerous scenarios, situations with pedestrians who can safely cross the street at crossings were named most often. The FBL was also used to communicate with other motorized road users to clarify right of way constellations at e.g., roundabouts, junctions, or urban traffic in general.

Misunderstandings caused by FBL on other vehicles were not experienced often by 89.4% of the FBL drivers, according to responses to V2 of the questionnaire. In the open-ended responses reported in V1, 80.4% stated to have never mistakenly assumed that another vehicle was stopping ($Md = 0.00$; $IQR: 0-0$). Less than 10% experienced this kind of misunderstanding at least 10 times. The highest number reported by one person again was 300. Note that only 90.15% of the V1 sample answered the question.

In contrast to misunderstandings, more than 61.8% of the drivers had at least *often* been quicker to recognize that another FBL vehicle was braking (V2). Only 7.7% had never experienced such situations. On average, participants in the V1 group reported 16.55 ($SD = 89.2$; $Md = 0.00$; $IQR: 0-4$) situations in which the FBL helped them to more quickly recognize other drivers' braking. Numbers ranged from 0 to 1000. About 20% named at least six situations. Note that only 78.68% of the V1 sample answered this question.

Positive items (facilitation of traffic situations, minimization of dangerous situations, and faster detection of braking) were

Table 9

Mean values for the Safety Effects Scale and correlations with previous FBL experiences (FBL drivers T2).

Item	<i>M</i>	<i>SD</i>	$\rho_{\text{experienceV1}}$ ^c	$\rho_{\text{experienceV2}}$ ^d
In case of crossing traffic between vehicles and pedestrians?	3.85	1.17	.15**	.31**
In case of crossing traffic between several vehicles?	3.71	1.11	.11**	.33**
At zebra crossings (when you are the driver)? ^a	3.77	1.18	.10**	.31**
At zebra crossings (when you are a pedestrian)? ^a	3.99	1.16	.12**	.31**
When turning left with oncoming vehicles?	3.67	1.09	.13**	.28**
When changing lanes on the motorway?	3.41	1.09	.18**	.25**
When approaching the end of a traffic jam?	3.51	1.11	.15**	.23**
Safety Effects Scale	3.70	0.96	.16**	.34**
Additional items:				
When you are the last car in a traffic jam? ^b	3.51	1.12	.14**	.21**
When you have right of way but another car is in a position such that it could violate your right? ^b	3.69	1.16	.19**	.28**
When an oncoming car is in overtaking manoeuvre and fast approaching in your lane to see if action might be aborted? ^b	3.74	1.15	.20**	.30**

Note. $n = 2476$. 1 = *much less safe* to 5 = *much safer*. $r_{\text{experience}}$ = correlation with frequency of seeing other FBL vehicles (V1 1 = *never*, 2 = *once*, 3 = *once a month*, 4 = *once a week*, 5 = *several times per week*; V2 1 = *never*, 2 = *rarely*, 3 = *occasionally*, 4 = *often*, 5 = *very often*).

^a Items correspond to the original item, "At zebra crossings?"

^b Item is not included in the Safety Effects Scale.

^c $n = 1046$.

^d $n = 1430$.

** $p < .01$.

answered on average with 3.07 ($SD = 0.98$) and negative items (leads to dangerous situations and misinterpretation of braking signal) with 1.71 ($SD = 0.85$; both items were rated on a 5-point Likert scale). The difference was statistically significant ($t(1\ 429) = 36.53, p < .001$; Fig. 3). Accordingly, positive situations were experienced significantly more often than negative ones.

Correlations between positive items (V2) and experience with the FBL on other vehicles revealed similar results to the previous analyses of FBL drivers T₁₂. Spearman's Rho of .44 was highly significant ($p < .001$). In contrast to the previous analysis, negative items (V2) had a significant correlation with experience, too ($\rho = -.18, p < .001$). That is, drivers who had seen the FBL more often on other vehicles reported more positive and less negative experiences with it.

Overall, FBL drivers stated they had been involved in 134 accidents while driving an FBL-equipped vehicle ($Md = 0.00$; IQR: 0–0). Of note, 95 of those accidents were reported by 40 drivers; 39 drivers reported one accident, 25 reported two accidents, and 15 drivers reported three accidents. Asked for the relevance of the FBL, 14 respondents stated that the FBL played a role in one of the accidents, 21 stated that for two, and 13 for three accidents. Surprisingly, 14 drivers claimed that the FBL played a role in more than three of their accidents. This, however, is implausible since no one initially reported to have had more than three accidents. Overall, at least 48 of the reported 134 accidents can plausibly be associated with the FBL.

The kind of damage was reported for 92 accidents. In 41 cases *light (property) damage* was reported, in 24 *heavy (property) damage*, in 22 *light personal injury*, and in 5 *heavy personal injury*. Accidents in which the FBL played a role were mostly based on the misconception that a car would stop if the FBL lit up. In one case, however, a participant described a situation in which no FBL was present, but the driver would have wished for one on the other vehicle so that the accident could have been avoided.

Numbers concerning the improvement of traffic flow due to the FBL ranged from 0 to 1000 (V1; $Md = 0.00$; IQR: 0–5). Although nearly 60% of the sample reported to have never experienced an improvement of traffic flow due to the FBL, more than 15% experienced it ten times or more. Note that only 79.83% of the V1 sample answered the question. In response to V2 of the questionnaire, only 10.8% indicated they had never experienced improved traffic flow due to FBL. In contrast, 33.0% reported they did experience it *often* and 16.9% even *very often*. More than three-quarters of the drivers who responded to V2 of the questionnaire reported that the FBL at least *occasionally* improved traffic flow.

The numbers of situations in which the FBL seemed to have helped other road users to predict driving maneuvers again ranged from 0 to 1000 in V1 ($Md = 0.00$; IQR: 0–8). More than a fifth (21.13%) of the sample who responded to V1 of the questionnaire did not answer this question. In the responses, 57.3% percent reported no such situations and around 15% reported at least ten. In response to V2, 79% stated they had experienced it *occasionally*, *often*, or *very often*. Only 8% reported they had never experienced it.

Drivers affirmed that the FBL is easy to understand for everyone ($M = 3.73, SD = 1.10$; 5-point Likert scale, 1 = *strongly disagree*, 5 = *strongly agree*). However, with a mean of 3.94 ($SD = 1.00$) they also indicated that some upfront explanation is needed, although the concept is rather quick to understand ($M = 2.04, SD = 1.01$).

Means, standard deviations, and correlations of the two measures of experience with other FBLs of the Attitudes Scale and additional items can be found in table 10. Regarding the means, a clear pattern can be observed that positive statements regarding the FBL were endorsed more than negative ones ($t(2\ 475) = 39.32, p < .001$), with mean agreement of 3.88 ($SD = 0.98$) for the positive and 2.49 ($SD = 0.98$) for the negative ones.

Every item of the Attitudes Scale and the additional ones had a highly significant relationship to the V2 measure of experience with other FBL vehicles. In accordance with expectations, negative items correlated negatively and positive items positively with experience. Even though weaker, most of the correlations with V1 of the questionnaire were significant, too. Only three items did not reach significance.

A large majority of 77.4% of the drivers assessed at T2 were in favor of a general introduction of the FBL. Both measures of experience with other FBLs correlated significantly and positively with the voting ($\rho_{V1} = .16, p < .001$; $\rho_{V2} = .32, p < .001$). The more experience the drivers had with the FBL, the more likely they were to vote in favor of a general introduction of the FBL. Effect sizes, however, were rather small to medium.

3.3. Other road users

In addition to the drivers of FBL-equipped vehicles, 621 other road users were included in the study. A total of 308 responded to V1 of the questionnaire, and 313 to V2 of the questionnaire. Asked for the frequency of situations in which they, as pedestrians, are unsure whether crossing traffic is braking, more than half of the sample (54.5%) reported experiencing this type of situation *often* or *very often*, while 22.5% reported experiencing it *occasionally*, 17.7% *rarely*, and only 5.3% reported to have never experienced it at all.

Regarding their contact with FBLs, in response to V1 of the questionnaire, 5.8% of participants reported to have *never* seen an FBL in traffic action, 4.9% to have only seen it *once*, 16.2% to have seen it *once a month*, and 21.1% *once a week*. Just over half of respondents, however, reported having seen FBLs *several times per week* (51.9%). The same question in V2 was answered as follows: 4.2% *never*, 31.6% *rarely*, 33.9% *occasionally*, 23.3% *often*, and 7.0% *very often*. This leads to the conclusion that FBLs were regularly noticed in the test regions by people who did not drive such vehicles, too.

Results of the Safety Effects Scale for the group of other road users can be found in table 11. As observed in previous groups, the highest potential for an increase of traffic safety due to the FBL was attributed to the situation of a pedestrian at a zebra crossing. Correlations with the amount of contact with FBL-equipped vehicles, however, differed from the previous findings for other groups. Although responses to V1 of the questionnaire showed no significant correlations, for V2 four items as well as the total score of the Safety Effects Scale reached significance among other road users. Cronbach's α for the scale in the given subsample was .87 for V1 of the questionnaire and .91 for V2 of the questionnaire. Fig. 4 shows a comparison of the mean ratings on the Safety Effects Scale (+ additional items) between the groups of other road users and FBL drivers at T2. Statistically significant differences (Bonferroni-

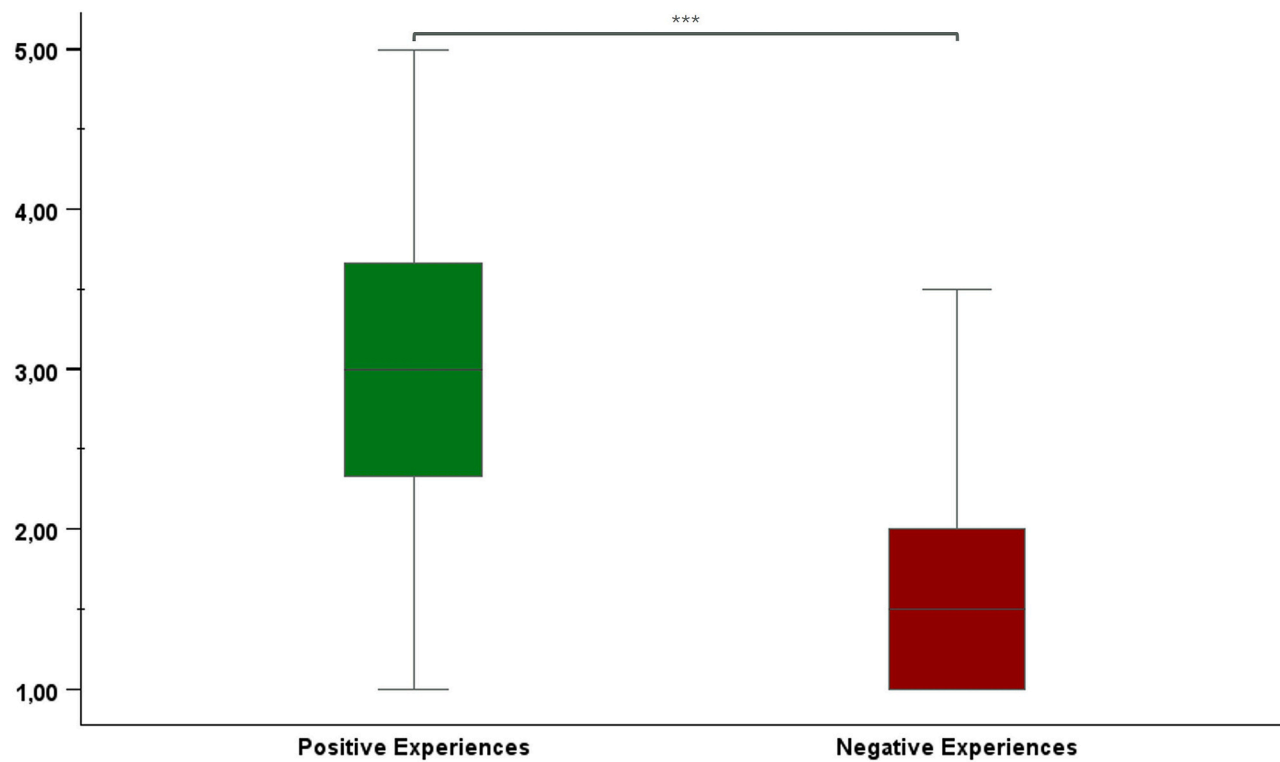


Fig. 3. Comparison of positive and negative experiences with the FBL (FBL drivers T2).
Note. $n = 1430$. 1 = *never*, 2 = *rarely*, 3 = *occasionally*, 4 = *often*, 5 = *very often*.

Table 10

Mean values for the Attitudes Scale and correlations with previous FBL experiences (FBL drivers T2).

Item	M	SD	$\rho_{\text{experienceV1}}$ ^b	$\rho_{\text{experienceV2}}$ ^c
The Front Brake Light is a good idea.	3.95	1.20	.13**	.37**
The Front Brake Light would have more disadvantages than advantages in the long run. (–)	2.55	1.34	.01	–.24**
The Front Brake Light can make road traffic safer.	3.95	1.10	.16**	.35**
The Front Brake Light can prevent accidents.	3.82	1.09	.12**	.32**
The Front Brake Light is unnecessary. (–)	2.31	1.20	–.08	–.30**
The Front Brake Light can cause accidents. (–)	2.62	1.16	–.02	–.19**
The Front Brake Light increases the safety of pedestrians.	3.93	1.11	.16**	.30**
The Front Brake Light can make road traffic more fluid.	3.75	1.06	.17**	.31**
Attitudes Scale	3.74	0.88	.15**	.38**
Additional items:				
The Front Brake Light would reduce the level of stress in road traffic. ^a	3.45	1.06	.18**	.29**
If I see a Front Brake Light lit, I take it for sure that the driver is braking. ^a	3.68	1.11	.08**	.28**
If I see a Front Brake Light lit, I take it for sure that the vehicle will stop. ^a	3.01	1.13	.04	.22**
I would like to keep a Front Brake Light on my car. ^a	3.66	1.25	.14**	.42**
I would buy a Front Brake Light for my (private) car as a retrofit, even if it is not mandatory. ^a	3.25	1.26	.12**	.38**
The Front Brake Light is a means of traffic comfort. ^a	3.52	1.10	.16**	.30**
The Front Brake Light is a means of traffic safety. ^a	3.79	1.11	.19**	.33**

Note. $n = 2476$. 1 = *strongly disagree*, 2 = *disagree*, 3 = *neither agree nor disagree*, 4 = *agree*, 5 = *strongly agree*. $r_{\text{experience}}$ = correlation with frequency of seeing other FBL vehicles (V1 1 = *never*, 2 = *once*, 3 = *once a month*, 4 = *once a week*, 5 = *several times per week*; V2 1 = *never*, 2 = *rarely*, 3 = *occasionally*, 4 = *often*, 5 = *very often*).

^a Item is not included in the Attitudes Scale.

^b $n = 1046$.

^c $n = 1430$.

** $p < .01$.

Table 11

Mean values for the Safety Effects Scale and correlations with previous FBL experiences (other road users).

Item	M	SD	$\rho_{\text{experienceV1}}$ ^c	$\rho_{\text{experienceV2}}$ ^d
In case of crossing traffic between vehicles and pedestrians?	4.03	1.04	.05	.14*
In case of crossing traffic between several vehicles?	3.88	1.03	.07	.08
At zebra crossings (when you are the driver)? ^a	3.85	1.07	.07	.13*
At zebra crossings (when you are a pedestrian)? ^a	4.31	0.98	.10	.13*
When turning left with oncoming vehicles?	3.66	1.13	.06	.14*
When changing lanes on the motorway?	3.51	1.16	–.04	.10
When approaching the end of a traffic jam?	3.65	1.18	–.00	.07
Safety Effects Scale	3.84	0.84	.07	.13*
Additional items:				
When you are the last car in a traffic jam? ^b	3.49	1.17	–.00	.00
When you have right of way but another car is in a position such that it could violate your right? ^b	3.94	1.10	.02	.06
When an oncoming car is in overtaking manoeuvre and fast approaching in your lane to see if action might be aborted? ^b	4.10	1.04	.08	.06

Note. $n = 621$. 1 = *much less safe* to 5 = *much safer*. $r_{\text{experience}}$ = correlation with frequency of seeing other FBL vehicles (V1 1 = *never*, 2 = *once*, 3 = *once a month*, 4 = *once a week*, 5 = *several times per week*; V2 1 = *never*, 2 = *rarely*, 3 = *occasionally*, 4 = *often*, 5 = *very often*).

^a Items correspond to the original item “At zebra crossings?”

^b Item is not included in the Safety Effects Scale.

^c $n = 308$.

^d $n = 313$.

* $p < .05$.

corrected $\alpha = .005$) between the two groups were found for items 1 (Welch $t(1049.52) = -3.82$, $p < .001$), 2 (Welch $t(1014.89) = -3.56$, $p < .001$), 4 (Welch $t(1099.27) = -7.02$, $p < .001$), 9 (Welch $t(998.05) = -4.88$, $p < .001$), and 10 (Welch $t(1037.04) = -7.49$, $p < .001$; order as shown in table 11). However, all effect sizes can be classified as small (Cohen's d between -0.15 and -0.32). For all five items where a significant difference was observed, the group of other road users reported a slightly greater impact on perceived safety compared to the drivers.

More than half of the sample of other road users reported that the FBL facilitated traffic situations at least *occasionally*, with 25.1% stating that it is *often* and 9.3% even *very often* the case. Dangerous traffic situations caused by the FBL were only experienced *often* (2.6%) or *very often* (1.6%) by a small number of persons who received the V2 questions. However, 76.7% had never experienced dangerous situations in which the FBL played a major role. Similarly, in the V1 questionnaire responses, 94.4% reported zero dangerous situations ($Md = 0.00$; $IQR: 0-0$). Note that only 301 valid answers were available for this question. Ten or more of these situations were only experienced by 1.9% (i.e., 6 persons in total). Two respondents reported ten such situations, while one respondent each reported 12, 15, and 100 situations. The highest number was reported by one respondent, who indicated having personally

Based on your experience with the FBL, how would you evaluate the effect of the FBL in the following traffic situations?

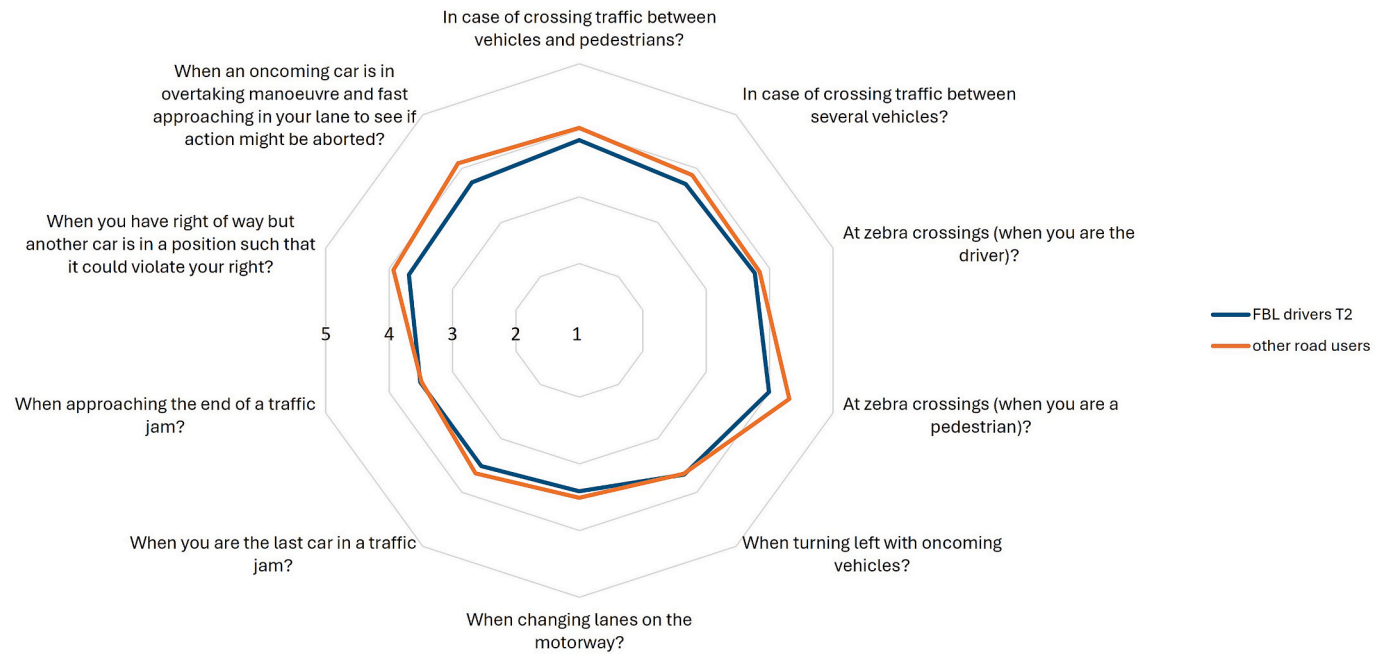


Fig. 4. Comparison of mean ratings on the Safety Effects Scale between FBL drivers T2 and other road users.

Note. 1 = much less safe to 5 = much safer.

experienced 1641 occasions in which the FBL led to dangerous traffic situations. Although this value differs substantially from all other reported numbers, it indicates that this person perceived dangerous situations far more frequently than all other participants. In the detailed reports of dangerous situations, it was most often mentioned that vehicles braked but did not stop. Moreover, it was mentioned that the FBL was sometimes blinding other road users.

Situations in which the FBL minimized or prevented dangerous situations, on the other hand, were not experienced at all by 38.7% of the sample. Still, 47.4% of the respondents had at least *occasionally*, and 13.9% *rarely* experienced such preventive effects of the FBL (one person did not answer this question). Interactions at crosswalks or roundabouts were the most often listed when respondents were asked to give detailed reports of the FBL minimizing or preventing accidents. Additionally, it was stressed that the communication of driving maneuvers in general was facilitated by the FBL.

In the open report of misunderstandings of the FBL (questionnaire V1), numbers ranged from 0 (74.8%) to 1000 (0.4%). However, the wide range of the reported numbers was largely driven by a single respondent who reported 1000 misunderstandings ($Md = 0.00$; $IQR: 0-1$). The next highest reported numbers were 20, 13, and 12, each reported by a single respondent. The majority (95.0%) of the other road users reported having a maximum of five misunderstandings involving an FBL during the test period. Note that only 278 valid answers were available for this question. The results from the V2 questionnaire pointed in the same direction, with 38.0% *never* and 28.8% *rarely* experiencing misunderstandings involving FBLs.

In contrast, a majority of the respondents witnessed situations in which the FBL helped them to more quickly recognize the braking of another vehicle. In response to the V1 questionnaire, reported numbers ranged from 0 to 1000 ($n = 210$; $Md = 4.00$; $IQR: 0-10$). Once again, the wide range was driven by a single respondent. The next highest value was 100, reported by two respondents. Over one-third (35.2%) did not report recognizing braking faster due to the FBL. Nearly the same number of respondents (38.9%), on the other hand, experienced it at least 10 times. Contrasting the responses to the V1 and V2 of the questionnaire, only 8.9% of the V2 respondents stated they had never been quicker to recognize braking because of the FBL, whereas 48.3% reported such situations to occur *often* or *even very often*.

Differentiating between positive (facilitation of traffic situations, minimization of dangerous situations, and faster detection of braking) and negative items (leads to dangerous situations & misinterpretation of braking signal) for the V2 questionnaires, mean answers for positive items ($M = 2.78$, $SD = 0.90$) were significantly higher than for negative ones ($M = 1.77$, $SD = 0.82$; $t(312) = 15.79$, $p < .001$; Fig. 5). Thus, positive effects of the FBL were experienced more often than negative effects. Furthermore, a positive correlation of $\rho = .41$ ($p < .001$) was observed between contact with FBL vehicles and the frequency of positive experiences with it. There was no significant correlation between FBL contact and negative experiences. The more often people saw vehicles with FBLs, the more advantages but not disadvantages they experienced.

In total for the other road users respondent group, 49 accidents with vehicles equipped with an FBL ($Md = 0.00$; $IQR: 0-0$) were reported by 34 persons, in at least 28 of which the FBL was reported to play a role. Twenty respondents reported *light (property) damage*, 7 *heavy (property) damage*, in 6 cases *light personal injury*, and in one case *heavy personal injury* was reported.

To ask impressions of the FBL, questions for other road users were adapted in a dichotomous answer format (*yes/no*). Regarding the traffic flow, 78.4% of the sample indicated a positive effect of the FBL. A facilitation of anticipation of driving maneuvers due to the FBL was confirmed by 87.8% of other road users.

Since this group did not receive any information in advance, their view on the comprehensibility of the FBL was of special interest. The basic idea of the FBL seemed to be rather easy to understand (table 12). However, upfront information on the FBL seemed to be desired.

Descriptive statistics and correlations with contact to FBL vehicles for the Attitudes Scale and additional items can be found in table 13. Cronbach's α for the Attitudes Scale was .87 for V1 and .86 for V2 of the questionnaire. Other road users on average were not in favor of voluntarily buying an FBL for their own vehicle, although the FBL itself was perceived positively. The more contact respondents had with FBLs, the more willing they were to buy an FBL, according to V2 of the questionnaire. Only perceptions of the FBL being a good idea (positive) and the FBL having more disadvantages than advantages (negative) correlated substantially with both versions (V1 and V2) of the contact question. There were no significant correlations that violated our assumptions.

Comparison of the mean rates of agreement of positive and negative items of the Attitudes Scale revealed a significant difference ($t(620) = 29.48$, $p < .001$). Positive statements reached a mean agreement of 4.09 ($SD = 0.77$) compared to a mean of 2.29 ($SD = 0.91$) for negative statements.

Asked for a vote on the general introduction of the FBL, a large majority of other road users (86.2%) were in favor of this measure. A significant correlation between contact with the FBL and a positive voting was not observed.

3.4. Accident data

Besides the questionnaires, accident data from the Slovakian police were obtained for further analyses as a cautious estimate of objective effects of the FBL. Accident data from the test period were compared to data from the same months and same region in 2019. Table 14 shows the descriptive changes in accident numbers between the test and the comparison period for the main FBL counties (Trenčín and Žilina) as well as the rest of Slovakia. The decrease of accident numbers according to police data was larger for the major FBL counties than for the rest of Slovakia. However, it needs to be considered that police recordings only include accidents with a damage >3990 € and percentage changes are strongly influenced by the base rates of accidents. Especially bus accidents in the counties of Trenčín and Žilina were very rare in both time periods, which causes larger percentage changes.

Since a Poisson model showed clear evidence of overdispersion ($\chi^2/df = 3.26$), a negative binomial regression was conducted to test whether changes in accident rates between 2019 and 2023 differed between the counties of Trenčín & Žilina and the rest of Slovakia,

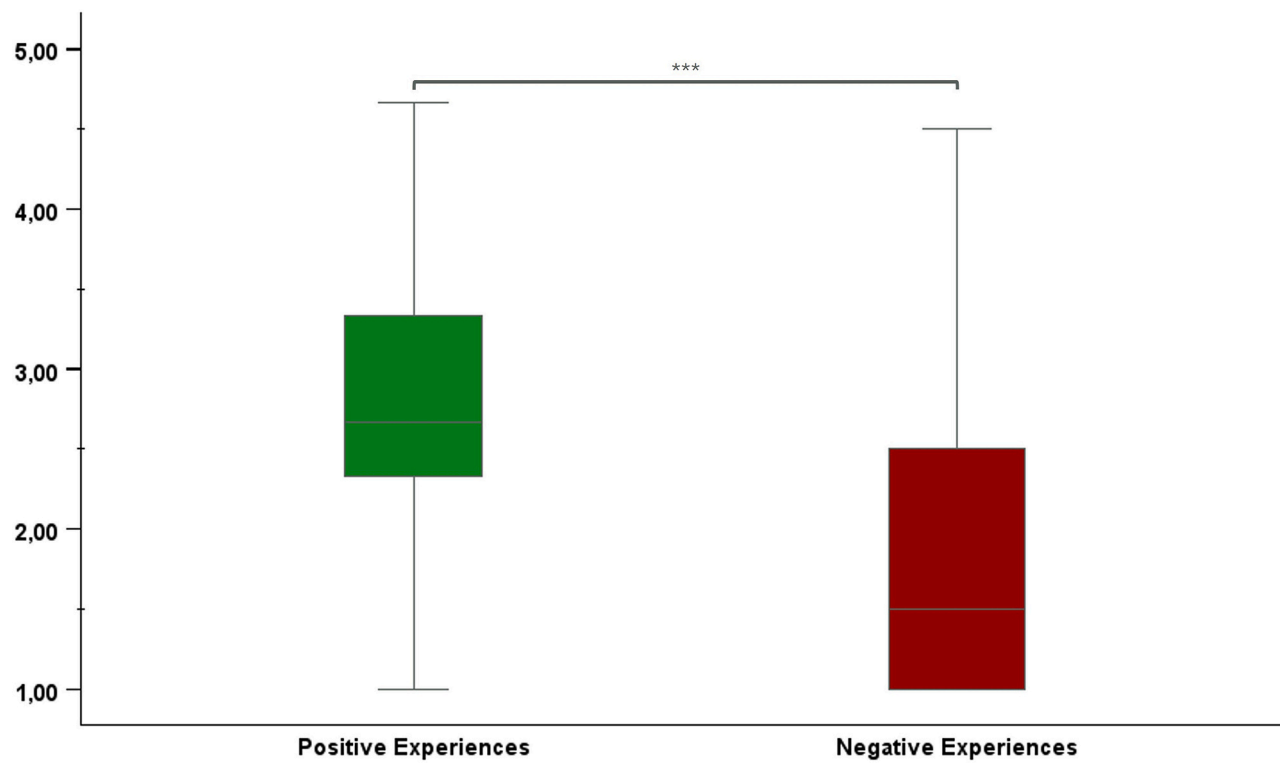


Fig. 5. Comparison of positive and negative experiences with the FBL (other road users).
Note. $n = 313$. 1 = never, 2 = rarely, 3 = occasionally, 4 = often, 5 = very often.

Table 12

Mean values for comprehensibility of the FBL (other road users).

Item	M	SD
The idea of a Front Brake Light is easy to understand for everyone.	3.86	1.03
The idea of the Front Brake Light needs explanation upfront when introducing widely to public traffic.	3.79	0.97
It took me some time to understand the Front Brake Light.	2.31	1.18
During the time vehicles with Front Brake Lights participated in road traffic a technical and administrative hotline was important.	3.08	0.73

Note. $n = 621$. 1 = *strongly disagree*, 2 = *disagree*, 3 = *neither agree nor disagree*, 4 = *agree*, 5 = *strongly agree*.

Table 13

Mean values for the Attitudes Scale and correlations with previous FBL experiences (other road users).

Item	M	SD	$\rho_{\text{experienceV1}}$ ^b	$\rho_{\text{experienceV2}}$ ^c
The Front Brake Light is a good idea.	4.27	0.97	.14*	.18**
The Front Brake Light would have more disadvantages than advantages in the long run. (–)	2.14	1.23	–.17**	–.13*
The Front Brake Light can make road traffic safer.	4.14	0.88	.02	.09
The Front Brake Light can prevent accidents.	3.90	1.00	.01	.07
The Front Brake Light is unnecessary. (–)	2.08	1.10	.07	–.12*
The Front Brake Light can cause accidents. (–)	2.67	1.16	–.00	–.01
The Front Brake Light increases the safety of pedestrians.	4.21	0.92	–.07	.08
The Front Brake Light can make road traffic more fluid.	3.93	0.99	–.01	.13*
Attitudes Scale	3.95	0.75	.03	.13*
Additional items:				
The Front Brake Light would reduce the level of stress in road traffic. ^a	3.69	1.08	–.04	.07
If I see a Front Brake Light lit, I take it for sure that the driver is braking. ^a	3.89	1.08	.01	.06
If I see a Front Brake Light lit, I take it for sure that the vehicle will stop. ^a	3.25	1.17	–.06	–.04
I would buy a Front Brake Light for my (private) car as a retrofit, even if it is not mandatory. ^a	2.49	1.83	–.04	.15**
The Front Brake Light is a means of traffic comfort. ^a	3.72	1.09	.04	.19**
The Front Brake Light is a means of traffic safety. ^a	4.05	1.03	.10	.13*

Note. $n = 621$. 1 = *strongly disagree*, 2 = *disagree*, 3 = *neither agree nor disagree*, 4 = *agree*, 5 = *strongly agree*. $r_{\text{experience}}$ = correlation with frequency of seeing other FBL vehicles (V1 1 = *never*, 2 = *once*, 3 = *once a month*, 4 = *once a week*, 5 = *several times per week*; V2 1 = *never*, 2 = *rarely*, 3 = *occasionally*, 4 = *often*, 5 = *very often*).

^a Item is not included in the Attitudes Scale.

^b $n = 308$.

^c $n = 313$.

* $p < .05$.

** $p < .01$.

Table 14

Change in accident figures between comparison and FBL period.

		Passenger Car		Bus		Truck	
		Accidents (total vehicles registered)	%-Change	Accidents (total vehicles registered)	%-Change	Accidents (total vehicles registered)	%-Change
Counties Trenčín & Žilina (FBL)	Jan–Sept 2019	1277 (528736)	- 28.13	12 (2001)	- 34.79	257 (76945)	- 45.98
	Jan–Sept 2023	1005 (579002)		7 (1790)		147 (81470)	
	Jan–Sept 2019	3878 (1850213)	- 19.10	50 (7037)	+ 6.73	668 (263697)	- 29.72
Rest of Slovakia	Jan–Sept 2023	3473 (2048305)		51 (6789)		493 (276920)	

Note. % change is corrected for differences in total number of vehicles registered.

while accounting for the number of registered vehicles. The interaction between the region and the time period was not a significant predictor of changes in accident rates (Wald $\chi^2(1) = 0.07$, $p = .792$). Thus, the analysis provided no evidence that the FBL was associated with an increase or decrease in accident rates. However, it should be emphasized that the available accident data are not well suited for a reliable before-after comparison. Although there is no evidence to suggest an improvement or a deterioration in accident rates, the available data do not allow either possibility to be ruled out.

4. Discussion

In this field study, the perceived effects of an FBL in real traffic were assessed by means of different questionnaires administered to the drivers of FBL-equipped vehicles and other road users. Regardless of group, high levels of acceptance of the FBL were observed.

Even before people had any experience with the FBL, the general idea was favorably rated and the potential safety effects were perceived positively. This endorsement of the FBL was reflected above all in the fact that more than three-quarters of interviewees were in favor of such a device. As a result, there was relatively little room for further improving opinions on the FBL by actual road traffic experience.

Comparisons between T1 and T2 data revealed a significant increase in the perceived safety effects of the FBL. Attitudes towards the FBL and voting on a general introduction, however, did not change significantly between the two time points. It can be concluded that the high expectations towards the FBL at T1 were met or even exceeded by the actual use in everyday traffic.

The more contact people had with the FBL, the more they endorsed its Safety Effects and the more positive their attitude towards the FBL as assessed on the Attitudes Scale. More experience with the FBL, thus, only fosters positive evaluations of it. FBL contact did not moderate the relationship between T1 and T2 scores on the Attitudes Scale, which can arguably be attributed to restrictions in variance. Ratings on the Attitudes Scale were already high at T1 and, thus, could not increase sufficiently during the field trial.

Focusing on the 2476 FBL-equipped vehicle drivers who did not take part in the T1 survey, previous findings were supported. Concerning the Safety Effects Scale, there was great approval to the FBL effects on perceived traffic safety in different situations. Every item as well as the total score were positively related to both variants of the question on experience with other FBL vehicles. These results underscored that contact and real-world experience with FBLs boost the perception of positive impacts and outcomes. Moreover, it can be argued that individuals who have more contact with other FBL vehicles should be able to evaluate its effects more reliably than other people. Concerns about safety effects of the FBL, on the other hand, were more often expressed by drivers who did not have much experience with other FBL vehicles. Based on data from studies such as this one, it can be assumed that their concerns would have diminished over time. In the Attitudes Scale, stronger endorsement of positive statements about the FBL went along with having more contact with it, and negative statements were disagreed with more often.

For both groups of FBL drivers (T₁₂ and T₂), correlations between evaluations of the FBL and actual experience were higher in V2 of the questionnaire compared to V1. In V1, FBL contact was assessed using the categories *never*, *once*, *once a month*, *once a week*, and *several times per week*. In V2, the categories were *never*, *rarely*, *occasionally*, *often*, and *very often*. It can be argued that V2 is influenced by subjective perception since categories like *occasionally* or *often* can be interpreted differently. For example, *often* could be interpreted as occurring regularly once a week, or another interpretation could only classify something as *often* if it happens every day. The categories used in V1 are less ambiguous and, thus, more objective, but probably more difficult to answer. According to the patterns of correlations observed in this study, the subjective experience is more important for the overall attitude to the FBL than the more objective measure in V2. However, if the FBL was introduced for regular use, it can be expected that most of the population would objectively as well as subjectively gain more experience with it, which in the long run should positively influence their attitude towards it.

Although it could be argued that this effect can be attributed solely to the mere exposure effect (Zajonc, 1968), it should be taken into account that more experience means to actually witness more effects of the FBL. Therefore, we argue that positive effects of experience are likely to result from a combination of mere exposure and actually having more positive experiences with the FBL.

In the group of FBL drivers at T₂, influence of direct FBL experience was also shown in responses to questionnaire items on facilitation of traffic situations, minimization of dangerous traffic situations, faster detection of braking, potentially dangerous situations caused by the FBL, and misinterpretations of braking signals. There was a substantial positive relationship between experience and items indicating positive effects of the FBL, and also a negative correlation for items indicating negative effects.

All in all, drivers reported that the FBL is rather easy to understand and that they were able to understand it quickly. Nevertheless, there was also a great demand for upfront information before introducing it to public road traffic by drivers of FBL-equipped vehicles as well as other users.

Results for the group of other road users were largely comparable to those of drivers. However, using V1 of the questionnaire there was no significant correlation between experience with the FBL and the items of the Safety Effects Scale. Using V2, on the other hand, the total score as well as four of the scale's items showed substantial relationships to FBL experience. The single items and the total score indicated that even if people were not driving FBL vehicles themselves, they anticipated the potential effects on traffic safety the FBL could have.

Concerning the other road users' responses to the Attitudes Scale, the total score correlated with the other road users' experiences with the FBL (V2). Again, positive statements on the FBL were endorsed more strongly than negative ones. All in all, other road users seemed to be endorsing the idea of the FBL in a similar manner to drivers.

Results of the field study conducted in Slovakia replicated findings from the previous field study conducted at Tegel airport (Monzel et al., 2021) and even older ones (Post & Mortimer, 1971). Approval of a general introduction of the FBL was even higher in the current study. Since samples used in the current study were much larger than in the Tegel study, validity of previous results, which already indicated a positive perception of the FBL in real road traffic, was clearly demonstrated. Replicating these results in different countries only fosters the assumption of the FBL as a widely accepted measure that is evaluated positively by road users regardless of differing traffic cultures and conditions.

In addition to all the positive evaluations, some reports also pointed out that the FBL can be misunderstood. Seeing the FBL light up on a vehicle was misinterpreted by few road users as a sign that the vehicle was coming to a stop for them and that they were given right of way. However, the FBL can only indicate that the driver is braking. In some situations, e.g., at junctions with poor visibility, it is plausible to assume that many vehicles will slow down by braking (i.e., FBL lights up) but not completely stop. Concerns in this regard must be considered seriously for further steps on the FBL and were already identified in previous studies (e.g., Dey et al., 2020; Monzel et al., 2021).

It can be assumed that misunderstandings occur particularly frequently in situations in which the oncoming vehicle is expected to come to a stop even in the absence of an FBL (e.g., crosswalks). This type of situation also represents one of the most promising areas of

application for FBL – namely, facilitating pedestrians' decisions on whether to cross a road. However, if a vehicle is not stopping or letting pedestrians cross safely, misunderstandings are quite likely. In line with confirmation bias, the FBL would further reinforce the already existing expectation, and the perception that it is safe to cross the street would consequently become even more entrenched. If the vehicle, however, is not coming to a stop, the FBL would have contributed to a false sense of safety.

In situations where there is no expectation that oncoming vehicles should stop, potential misunderstandings could have at least less serious consequences in most cases, since expectations and the FBL would provide conflicting information, which in turn should lead to a re-evaluation of the situation. The re-evaluation could lead to more conservative decision-making regarding further actions.

Since many road users in our study indicated that upfront information on the FBL is necessary, even though the FBL itself is not difficult to understand, a promising approach to addressing misunderstandings could be an information campaign and public education initiative accompanying a general introduction of the FBL. The concept and functioning of the FBL should be communicated in a way that is accessible to everyone. In this context, informational materials specifically addressing children should be made available. Since the FBL provides identical information as the rear brake lights, it can be assumed that misunderstandings become more seldom if road users gain more experience with it (Weyde & Böck, 2021).

More technical ideas on how misunderstandings could potentially be mitigated already exist (see for example Eisele et al., 2024). Future studies should investigate whether characteristics of the FBL itself could be modified in such a way that it signals braking more clearly rather than stopping. To this end, it should be tested whether, for example, a flashing FBL could reduce the likelihood of misunderstandings. Another approach would be to link the light intensity of the FBL to the current braking force. The brake light would thus provide additional information to potentially prevent misunderstandings, as it signals that the braking force of the oncoming vehicle may change. This could additionally be accompanied by defining a threshold value for braking force above which the FBL would be activated. Very light braking, which primarily serves to slightly reduce speed rather than bring the vehicle to a stop, would therefore not activate the FBL at all. Further studies on ways to prevent misunderstandings should be conducted.

4.1. Accident numbers

In addition to subjective attitudes towards the FBL, the study also explored its potential effects on actual traffic accidents. Accident numbers from the self-reports were partly contradictory, making a reasonable interpretation virtually impossible. However, it can be concluded that accidents related to the FBL seem to have happened in some form. Police-recorded accident data were also analyzed, however, it should be noted that the Slovak police did not assess accident data separately for FBL vehicles and other vehicles, which prevented a more in-depth comparison. The absolute density of FBL vehicles in the counties of Trenčín and Žilina was too low to draw reliable conclusions from the overall accident data. Furthermore, police recordings include only accidents involving damages exceeding 3990 €. A negative binomial regression did not provide evidence for a change in accident rates in the counties of Trenčín and Žilina compared to the rest of Slovakia. However, it cannot be ruled out that the FBL leads to a decrease or an increase in accident rates. Overall, the accident data provided by the police did not allow for a reliable before-after comparison.

Nevertheless, previous accident analyses by Weyde and Böck (2021) and Tomasch et al. (2025) suggest that the FBL has the potential to reduce accident rates. In particular left-turn situations – in which the oncoming lane must be crossed – were identified as one of the most promising use cases of the FBL (Weyde & Böck, 2021). Further research on the actual effects of the FBL on accident numbers and severity, especially in the context of actual field studies, is needed.

4.2. Strengths and limitations

In contrast to previous studies, the current study improved the setting in which the FBL was tested. After first studies in a laboratory (e.g., Petzoldt et al., 2017) and a field trial in a closed traffic area at the airside of Berlin Tegel airport (Monzel et al., 2021), a field trial in everyday traffic was the logical continuation of the testing of the FBL.

Moreover, the duration of this field trial was more than doubled compared to the first field trial at Tegel airport. Drivers and other road users, therefore, were able to gain more experience with the FBL in real traffic and experience more situations in which positive or negative effects of the FBL could occur. Due to the longer period of testing, a more realistic picture was obtained on the perceived effects of the FBL. On the other hand, standardization is more difficult to guarantee the larger a study, especially a field trial, gets.

In addition to the realistic setting and longer testing phase, sample size increased, too, compared to the field trial at Tegel. Although the sample of the longitudinal design only increased slightly, the overall number of participants grew significantly. The number of vehicles equipped with the FBL increased drastically, with 3072 vehicles taking part in this study. The higher number of FBL-equipped vehicles, however, was also crucial for the study to reach a sufficient density of FBLs in everyday traffic. It has to be taken into account that the absolute density of FBL-equipped vehicles and the actual visibility of the devices in everyday traffic is nearly impossible to quantify.

A further strength of the study was the inclusion of different types of road users. Besides drivers, other road users were interviewed, too, to obtain different perspectives on the FBL. Since it can be assumed that an introduction of the FBL would only concern a rather small number of vehicles in the beginning, most people would be confronted with the FBL in the role of “other road users”. Results for this group indicate that endorsement of the FBL is high among all road users, no matter if they drive an FBL-equipped vehicle themselves or not.

Apart from the strengths, the study also has a number of limitations that must be taken into account. First of all, the study mostly relies on questionnaire data, which can only provide the subjective perception of the FBL rather than objective indicators of traffic safety. Questionnaire data are susceptible to various cognitive and perceptual biases. For example, confirmation bias implies that

people tend to search for information that are in line with their presumptions. If a participant in this study expected positive effects of the FBL upfront, it is highly likely that he or she in turn also perceived and reported more positive effects. However, the exact opposite would also be true: Having more negative expectations regarding the FBL should lead to more negative perceptions and reports of it. According to results from the first survey (T1), before the FBL was introduced to traffic, it can be expected that a majority of participants had rather positive expectations. Thus, the confirmation bias is likely to influence the results of this study in favor of the FBL. This influence may have been further amplified by social desirability, if participants assumed or inferred that expressing approval of the FBL was socially desirable. On the other hand, social desirability may also have had a negative influence if support for the FBL was seen as socially undesirable (e.g., due to safety concerns).

Another potentially relevant bias is recall bias (and its interaction with confirmation bias). When people are asked about the frequency of specific experiences (e.g., dangerous traffic situations with the FBL), their recollection of those memories may well be biased and therefore not objectively accurate. In the context of this study this applies arguably in particular to the open-ended questions in V1 of the questionnaires. It is unclear whether recall bias influenced the results in favor of or against the FBL – however, it must be taken into account that it may have had an influence.

Although biases are highly likely to be influential, we would argue that they do not undermine the key findings of this study. The study's main goal was to assess the subjective perception of the FBL by different groups of road users. Although the subjective perception is of course influenced by several biases, it remains the true participants' perception. The results clearly show a positive evaluation of the FBL by the participants. However, objective markers of actual reduction of different kinds of dangerous traffic situations due to FBL cannot be concluded from the questionnaire data collected here.

Another important limitation of the study lies in the real-world setting of the study, which makes it difficult to isolate the unique effects of the FBL. It cannot be ruled out that simply participating in the study or the exposure to some kind of traffic campaign led to a change in traffic awareness and behavior among drivers of FBL-equipped vehicles, which in turn may influence the results. Since there was no control group addressing the perception of drivers on non-FBL-equipped vehicles, it remains unclear whether the named factors were present in the study or not. However, even a control group would hardly allow for precise statistical control, since the questionnaires were designed specifically for the FBL and are therefore not applicable to other vehicles.

Moreover, since more than 60% of the drivers interviewed in this study indicated that they currently work or had previously worked as professional drivers, the sample does not necessarily represent the average driver. However, given their experience, professional drivers can be seen as experts regarding the driving task and are thus capable of evaluating the positive and negative effects of the FBL. Apart from their expertise, the remaining 40% of drivers without professional driving experience still constitute a substantial sample. The results, therefore, are arguably not representative of average drivers in a strict sense, but they still provide important insights into the evaluation of the FBL among the general driving public.

While the design of the study has limitations, it allows further insights into the perception of the FBL. To our knowledge the current study in Slovakia was the first field trial of FBLs in actual everyday traffic in the past 50 years and the largest one ever conducted.

5. Conclusion

In the present study the FBL was tested in a large-scale field trial in Slovakia with a focus on the counties of Trenčín and Žilina. Part of the study was a longitudinal design with individuals who drove a vehicle equipped with the FBL for six to eleven months. The longitudinal design was accompanied by a cross-sectional design in which more drivers of FBL-equipped vehicles as well as other road users were interviewed.

All in all, the results provide strong evidence that the FBL is suitable for improving subjective traffic safety and that it is relatively easy to understand. In addition, the concept is endorsed by a vast majority of traffic participants. Misunderstandings with the FBL occurring now and then can be assumed to be compensated by more experience with the FBL in the long term. An introduction of the FBL should be accompanied by an information campaign on the functionality and meaning of the FBL, so that misunderstandings and misconceptions can be more rapidly dispelled.

CRediT authorship contribution statement

Finn Rathgeber: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Bernhard Kirschbaum:** Writing – review & editing, Writing – original draft, Project administration, Conceptualization. **Wolfgang Schubert:** Writing – review & editing, Supervision, Project administration, Conceptualization. **Miloš Poliak:** Writing – review & editing, Data curation, Conceptualization. **Kristián Culík:** Writing – review & editing, Data curation. **Rainer Banse:** Writing – review & editing, Supervision, Methodology, Conceptualization.

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing

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Data availability

The data and questionnaires used in this study are publicly available on the Open Science Forum (OSF) at <https://doi.org/10.17605/OSF.IO/6ZFRV>.

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