Which signal modalities do cyclists prefer based on experiences in road traffic?

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**ABSTRACT**

**Objective:** On-bike systems warning cyclists about critical situations are a promising approach to improve safety. The chosen warning modality might strongly influence whether the cyclist accepts the system. So far, cyclists' warning preferences have not been analyzed based on field data. They were only analyzed through web-based surveys or a simulator study without including the three most promising signal types (i.e., visual, auditory and vibro-tactile). This study aims to evaluate the signal preferences for transmitting information to cyclists based on experience of the signals in the field.

**Method:** We conducted a field study where participants received signals of different signal types, i.e., visual, auditory and vibro-tactile signals, while cycling. After completing the course, all participants answered a questionnaire on their subjective experiences of the signals. The participants separately cycled a 10 km long route in road traffic. All participants received 12 signals per modality on predefined GPS coordinates. The course covered different environmental conditions like loud ambient noise, gravel roads or high visual load.

**Results:** The data of 55 participants was analyzed. The participants chose the auditory and vibro-tactile signal over the visual signal. When asked, they significantly preferred an auditory warning to the other two signal types. The participants rated the auditory signal as most urgent and frequently associated it with warnings. Participants reported the visual signal as distracting from the cycling task and the vibro-tactile signals as difficult to distinguish from surface related vibrations.

**Conclusion:** The advantages of different signal modalities can be applied to develop information transmission systems in the cycling context. Our results show that the signal types have inherent qualities which may fit into different areas of application. This study highlights that the choice of a warning modality needs to be balanced on a combination of noticeability, criticality and personal preference.

**Introduction**

The number of bicycle crashes is continuously increasing (Statistisches Bundesamt 2019). There are different approaches to improve cyclists’ safety. Aside from adapting the infrastructure (Pucher and Buehler 2016) intelligent transportation systems (ITS) have gained importance for different types of road users (Jamson et al. 2013). Research has only recently focused on cyclists (Prati et al. 2018). On-bike warning system reach high acceptance among cyclists and have an impact on cycling behavior (Engbers et al. 2016; Prati et al. 2018). However, there is limited data on preferences of warning signals in a realistic setting.

There are two available studies on cyclists’ modality preference. Both are online-based surveys (De Angelis et al. 2018; Institut für Mobilität und Verkehr 2017). Overall, the results of the two web-based studies are contradictory. While the results from one survey showed no clear preference between audio-visual and vibro-tactile warnings (De Angelis et al. 2018), the other found user preferences for the visual warning followed by the vibro-tactile and the auditory warning (Institut für Mobilität und Verkehr 2017). A further study tested a rearview assistant in a simulator that offered two different warning conditions: visual and vibro-tactile (Engbers et al. 2016). Practicality and satisfaction of the two warning conditions was compared in the simulator study, but the signal preference was not.

Our goal was to investigate the warning modality preference of cyclists’ in a real-life setting. We conducted a field study in which we presented visual, auditory and vibro-tactile signals to participants while they cycled in road traffic. The participants received each signal type in different environment conditions that were supposed to interfere to a different extent with the different signal types. The signals did not contain any informative content. This field study aimed to answer two questions: (1) how frequently are the different signal types noticed by the participant while cycling and (2) after...
experiencing the different signals in different environment conditions, which signal type do cyclists prefer as warnings.

The results related to the first question were recently published (Erdei et al. 2020). On average, the participants responded to 83.2% of the signals. The response rate was not equally distributed across the three modalities. The participants noticed 65.1% of the visual, 97.4% of the auditory and 87.2% of the vibro-tactile signals.

Following completion of the course, the participants completed a questionnaire on their experience with the presented signals. They rated the signals and weighed the advantages and disadvantages of the different modalities. To our knowledge, this is the first study to present cyclists’ signal preference based on field experience.

Methods

Study design

Prior to the study the participants signed a consent form. The Ethics Committee of the Technische Universität Dresden approved the study (running number by the Ethics Committee EK 360072019). We demonstrated all signal types to the participants to familiarize them with the signals and reduce the startling effect. After individual completion of a 10.2 km long route in road traffic using an e-bike with support of up to 25 km/h, during which they received 36 signals in total, the participants filled in the questionnaire. We used a complete within-subjects design and presented visual, auditory and vibro-tactile signals each three times in each of the four environments split into three segments per environment: a baseline condition without sensory interference and three sensory interference conditions (visual, acoustic and haptic) matching the three signal types respectively. The baseline condition was a road segment without interference by noise, visual distraction or surface related vibrations (e.g., gravel, cobblestones). The sensory interference conditions are conditions, which cyclists are likely to meet in real life settings. Each condition mainly interfered with one sense. Cycling through a town with increased amount of road users represented visual interference. Cycling next to a highway caused acoustic interference and cycling on gravel haptic interference. The location of the signal transmission was predefined but designed to seem random. The order in which the signal types were presented within an environment segment was permuted. The participants were instructed to press a button on the handlebar when they noticed a signal. Exposing participants to critical situations in road traffic in order to transmit realistic warnings is currently not feasible due to safety concerns. Warnings without a reason however might also bias the results. Thus, we instructed the participants that the signals contained no information.

We expected the environment and the noticeability of the signals to influence signal preference. Therefore, we wanted to answer the following questions: Which signal type do participants rate as the best signal after experiencing all signals in the field? Which signal type do participants prefer as warnings? Does the comfort rating differ between signal types? Is the subjective rating of signal types related to the signal preference? Do participants’ characteristics and their performance in the field when responding to the different types of signals predict signal preference? We expected that the visual signal was least favored both in general and as a warning. We hypothesized that there would be a relation between the subjective rating of signal types and the signal preference. We also expected the response rates and participant characteristics (age, gender, trip distance, cycling frequency and regular route characteristics) to affect signal preference.

Signal design

The participants obtained the signals through a self-implemented Android app and a smartphone. We equipped the bicycle with a phone centrally mounted on the handlebars, external speakers below the handlebars and vibrating handles. As it is important to compare signals across modalities, comparable signal intensities were chosen based on feedback from several user experience experts (Baldwin and Lewis 2014; Lewis and Baldwin 2012). The visual signal was a red full screen pop-up illuminating the phone three times (twice for 400 ms each followed by a pause of 400 ms and a final illumination of 2,400 ms) for a total duration of 4 s. For the auditory signal, the participant received two beeps at an intensity of 75 dB with a frequency of 780 Hz (both for 650 ms interrupted by a pause of 20 ms). The vibro-tactile signal consisted of two vibrations with a frequency of 120 Hz (both for 250 ms interrupted by a pause of 400 ms) transmitted using the prototypical handles. The vibrations appear somewhat longer due to a superposition of the vibrations on the handles.

Questionnaire

The questionnaire consisted of two sections. The first covered socio-demographic background and bicycle usage. The second part contained questions related to the participants’ experience with the different signals and the three signal types as answer options, see Table 1 for details. In addition, the participants had the opportunity to give an explanation to their preference.

The participants were queried whether they thought they had noticed a certain signal more often than the others, whether one was noticed faster and whether they felt distracted by a signal. They were asked about signal urgency. Subsequently, the participants were questioned which signal type they expected to perceive on their regular routes. Additionally, the participants stated which signal type they preferred.

For future implementation of a warning system, the participants were asked which modality they would wish to obtain warnings in (Question 2b). Finally, the participants answered whether it was uncomfortable or embarrassing if their own bicycle transmitted a certain type of signal. Additionally, the participants rated each signal type
Regarding comfort on a scale from one (comfortable) to six (uncomfortable; Question 2c).

### Results

#### Evaluation of signal types

The subjective advantages and disadvantages as experienced by the participants were evaluated based on several questions. See Table 1 for participant answers. Almost half of the participants experienced the visual signal as distracting. The participants reported the auditory signals as particularly urgent. Most of the participants stated that they expect to notice the auditory (85.5%) and the vibro-tactile signal (83.6%) on their regular routes. In contrast, only 12.7% of the participants thought that they would perceive the visual signal.

The participants were asked which signal they preferred (Question 2a). Cochran’s Q test for repeated measures data with a binary dependent variable revealed significant differences in the signal preferences among participants, \( \chi^2(2) = 27.3, p < .001, R = .234 \). We performed pairwise McNemar’s tests with Bonferroni correction to compare signal preferences among participants. The preferences are significantly different between the visual and the auditory signal, \( \chi^2(1) = 29.12, p < .001, \) and the visual and the tactile signal, \( \chi^2(1) = 19.17, p < .001 \). There is no significant difference in the preference of auditory and vibro-tactile signals, \( \chi^2(1) = 1.85, p = .521 \).

When specifying their signal choice for warnings (Question 2b), most participants preferred the auditory signal. Cochran’s Q test revealed significant differences in the preference of warning modalities, \( \chi^2(2) = 59.7, p < .001, R = .476 \). Pairwise comparisons with the McNemar test with Bonferroni correction showed that the auditory signal is preferred as a warning over the visual signal, \( \chi^2(1) = 46, p < .001 \), the vibro-tactile signal is preferred over the visual signal, \( \chi^2(1) = 16.2, p < .001 \), and the auditory signal is preferred over the vibro-tactile signal, \( \chi^2(1) = 18.67, p < .001 \).

When presented with a “multiple choice option” 41 participants chose only a single warning as their warning signal of choice (34 auditory, 7 vibro-tactile). A single participant chose all three signal types, one chose visual and auditory and 12 auditory and vibro-tactile. Four participants explicitly mentioned that they would like to have a combination of signals in the case of warnings.

More than one third of the participants expected to feel uncomfortable if the auditory signal was transmitted by their bike (Question 2c). Out of these twenty persons 14 preferred mostly other signal types (combining answers to 2a and 2c).

### Statistics

Signal preferences were analyzed (Question 2a) by comparing the binary coded preference levels (visual, auditory, vibro-tactile) using Cochran’s Q test and reported the effect size using a chance-correlated measure R (Berry et al. 2007). Pairwise McNemar’s test with Bonferroni correction was used to analyze which signal types were preferred. The warning preferences (Question 2b) were evaluated correspondingly. We used Friedman’s ANOVA to compare the comfort rating of the signal types (Table 2) and Wilcoxon signed rank tests for post hoc comparisons.

We calculated Kendall’s \( \tau \) correlation coefficients for Questions 1a-1e per signal type in relation to Question 2a in Table 1. For instance, we calculated whether choosing that signal, \( \chi^2(1) = 8.39, p < .001, R = .41 \).

Logistic regression was used to predict signal preference with response rates for all signal types and gender, age, trip distance, cycling frequency and regular route characteristics as predictors (see Table A1, Supplementary material).

### Participants

In total, 56 participants took part in the field study. We recruited voluntary participants within the company Bosch. One person was excluded due to technical difficulties with the vibrating handles. All other participants reported that they noticed signals of all three modalities during the cycling part of the experiment. The participants’ characteristics are displayed in Table A1, Supplementary material.

#### Table 1. Questionnaire and answers.

| Perception related | Visual signal | Auditory signal | Vibro-tactile signal | None |
|--------------------|---------------|-----------------|----------------------|------|
| 1a Did you perceive any signal more frequently during the cycling course? | 4 | 31 | 21 | 16 |
| 1b Did you perceive some signal faster than others? | 0 | 51 | 29 | 2 |
| 1c Is any signal type experienced as distracting? | 4 | 1 | 5 | 28 |
| 1d Did you experience some signals as being particularly urgent? | 3 | 39 | 16 | 6 |
| 1e Which signals would you perceive when cycling on your regularly cycled routes? | 7 | 47 | 46 | 0 |

#### Table 2. Comfort rating of the signals.

| Signal | 1 – comfortable | 2 | 3 | 4 | 5 | 6 – uncomfortable | Mdn |
|--------|-----------------|---|---|---|---|------------------|-----|
| Visual | 4 | 10 | 15 | 20 | 5 | 1 | 3 |
| Auditory | 16 | 20 | 7 | 5 | 6 | 1 | 2 |
| Vibro-tactile | 15 | 22 | 8 | 7 | 3 | 0 | 2 |

Answers to questions related to perception of different signals during the cycling and to preferences of signal types in particular as warnings. *Only one answer possible.*
When it came to choosing a signal as a warning, 30% of the twenty participants preferred an auditory warning (combining answers to 2b and 2c).

The rating of the different signal types is depicted in Table 2. Friedman’s test was carried out to analyze the rating differences among the signal types. The signal types were rated differently, χ²(2) = 15.6, p < .001, W_{Kendall} = .142. Pairwise Wilcoxon signed rank tests with Bonferroni correction were applied for post hoc comparisons. The rating of the visual and auditory signal, p = .007, and the rating of the visual and vibro-tactile signal, p < .001, differed significantly. The ratings between the auditory and vibro-tactile signal are not significantly different, p = 1.0.

After most questions, the participants had the possibility to outline their answers in writing. The given answers were summarized regarding content-related similarities, see Appendix B.

**Relation of signal preference to rating of signals**

In the previous section we described the subjective experiences of the signals. In this section, we present the relation of signal qualities perceived by the participants to their signal preference. As only one participant preferred the visual signal, we excluded this participant from the analysis. Persons who stated to have perceived the auditory signal faster were more likely to prefer the auditory signal, τ = −.34, p = .013. In contrast, persons who rated the auditory signal as uncomfortable preferred the vibro-tactile signal, τ = .42, p = .003. Subjective experiences are coded as “No − 0” and “Yes − 1”; the signal preference variable is coded with “auditory − 0”, “vibro-tactile − 1”.

**Relation of rating of the signals and response rate while cycling**

In previous two sections, the subjective experiences with the different signals were described and analyzed. In contrast, this section combines the subjective answers with objective response rates to these signals. How well can the subjective modality preference be predicted by demographic characteristics and the objective response rate in a logistic regression? A reduced number of data sets is available for this subsection as the response rates of only 52 participants were available due to technical issues.

Table 3 shows the relation between objective response rate, perceived perception frequency and signal preference. The response rate describes to which signal modality the participants responded most often while completing the cycling course. Participants who claimed that they had perceived more visual signals actually had not responded to more visual signals compared to other signals. Most persons, who stated to have perceived more auditory signals, actually had responded to auditory signals the most.

While cycling, 30 persons had responded most to the auditory signal. About half of them preferred this signal modality, the other half the vibro-tactile modality. The majority of persons, who responded equally to both the auditory and the vibro-tactile signal, preferred the auditory signal.

We evaluated whether the response rate and participant characteristics predicted the modality preference. As only one participant preferred the visual signal to the other signals, we excluded this participant from the following analysis and included only participants preferring either auditory or vibro-tactile signals. In Table 4, the results of the logistic regression related to choosing either the auditory or the vibro-tactile signal as the preferred signal are displayed. An odds ratio (OR) greater than one indicates that a participant was more likely to choose a vibro-tactile over an auditory signal when asked for the preferred signal type. Persons with a high response rate to auditory signals are more likely to prefer the auditory signal, b = −.18, p = .024. Female participants preferred the auditory signal to the vibro-tactile signal, b = −2.06, p = .048. We observed that gender appears to function as a so-called suppressor variable (MacKinnon et al. 2000) for the response rate to auditory signals. If the gender was included in the logistic regression, the predictive value of the auditory signal was increased.

**Discussion**

The objective of this paper was to evaluate cyclists’ signal preferences based on testing them in road traffic. We aimed to derive accepted warning modalities from these results.

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**Table 3. Response rates and signal preference.**

|                  | Visual (n = 2) | Auditory (n = 30) | Vibro-tactile (n = 5) | Visual and auditory (n = 2) | Auditory and vibro-tactile (n = 13) |
|------------------|----------------|-------------------|-----------------------|-----------------------------|-----------------------------------|
| 1a Did you perceive any signal more frequently? (subjective) | Visual (n = 3) | 0                 | 1                     | 0                           | 1                                 |
|                  | Auditory (n = 13) | 1                 | 11                    | 0                           | 0                                 |
|                  | Vibro-tactile (n = 5) | 0                 | 1                     | 1                           | 2                                 |
|                  | Auditory and vibro-tactile (n = 16) | 1                 | 9                     | 2                           | 4                                 |
|                  | None perceived more frequent (n = 15) | 0                 | 8                     | 2                           | 0                                 |
| 2a Which signal is the best signal? | Visual (n = 1) | 1                 | 0                     | 0                           | 0                                 |
|                  | Auditory (n = 29) | 1                 | 17                    | 0                           | 2                                 |
|                  | Vibro-tactile (n = 22) | 0                 | 13                    | 5                           | 0                                 |

Answers to questionnaire about subjective perception frequency and best signal choice in relation to the objective response rate. Matches of response rate and subjective perception frequency or preference are printed bold.
Considering the response rates of the different signal types, the signal preferences are not surprising. The auditory and the vibro-tactile signal, which the participants noticed the most (Erdei et al. 2020), were also the preferred signals. Contrary to our expectation, only the response rate to auditory signals and gender significantly predicted the choice of the preferred signal type. Response rates to the visual and vibro-tactile signals and age, cycling frequency, trip distance and regular route characteristics did not predict signal preference.

The participants clearly favored the auditory signal as a warning over the visual and the vibro-tactile signal. Our results do not reflect the preferred modalities described in the aforementioned web-based surveys. De Angelis et al. (2018) found no significant differences in the preference of an audio-visual to a vibro-tactile warning. This is a contrast to our results where we found large differences related to the modalities. The other survey reported that pedelec users prefer having the warning element on the bicycle instead of on themselves (Institut für Mobilität und Verkehr 2017). The study also reported that 66% of their participants would like to have a visual warning, 38% an auditory and 44% a vibro-tactile warning. Our results, especially related to the visual signal, strongly differ from the results of the online study. We assume that experiencing the signals while cycling in the field strongly influenced the rating of the different signals. While persons in an online study can often base their decision only on theory, the participants in our study experienced examples of all signal types while cycling.

In contrast to the two web-based studies, Engbers et al. (2016) reported that older participants prefer vibro-tactile signals to visual signal. In general, older cyclists with potentially reduced hearing abilities are prone to be involved in accidents (Hagemeister and Tegen-Klebingat 2012). Unfortunately, we were only able to recruit few participants older than 55 years.

Auditory and vibro-tactile signals fulfill characteristics of warnings, appearing urgent, being faster to perceive or being easy to perceive on the daily routes. Whether a person perceives the auditory signal faster than other signals correlates with signal preference. The same is true if the participant expects the transmission of the auditory signal to be uncomfortable. We cannot differentiate whether the participants felt embarrassed because others might have heard the signals or were concerned about disturbing others based on the given answers.

Summarizing the participants’ remarks, signal type dependent differences were revealed. The visual signal was mainly associated with negative aspects. As a result, it is not surprising that the visual signal was not preferred over the other signal modalities. Based on this feedback, we would suggest to only rarely use unimodal visual signals. In contrast, both auditory and vibro-tactile signals attract the cyclists’ attention. However, the difficulty to distinguish vibrating handles from road surface vibrations may be a drawback of the vibro-tactile signal. The discomfort of many participants with the auditory signal indicates that the use of auditory signals should be selected carefully. A balance must be found between reliable perceptibility and signal related annoyance. We suggest that the balance is based on the urgency and criticality of the situation in order to be well accepted in the long term. Similar difficulties of balancing noticeability and negative associations related to the signal were published in a motorcycle HMI study (Song et al. 2017). Participants in that study rated the multimodal HMI as most beneficial, but pointed out that its leading benefit, the noticeability, is also the biggest drawback due to being overwhelming.

Additionally, the possibility of adapting the intensity to the present ambient noise might help to increase the situations where an auditory signal can be used comfortably. Interestingly, several participants mentioned that the auditory signal interfered with their desire to listen to music or talk to other cyclists. In fact, a negative influence of listening to music on perceiving auditory signals was reported in the cycling context (De Waard et al. 2011).

While our study offers new insights into how cyclists experience signals of different modalities during the cycling task, it has some limitations. Due to safety concerns, we did not link the signal to a warning or transmission of information. However, the intended purpose of a signal might influence its rating. Furthermore, having a signal modality dependent response rate might bias how the participants experience the signals. A person who notices less signals of a certain modality might not prefer that modality. At the same time, the differences in the response rate based on environment condition reflect how well cyclists perceive the signals in a realistic setting. We therefore consider the outlined weaknesses to reflect the realistic difficulties of the signal types.

Another limitation to the study is that all results are dependent on the implementation of the particular signal type. We specifically chose easy to mount solutions (Erdei et al. 2020).

### Table 4. Results of logistic regression.

| Response rate to visual signal [%] | B(SE) | OR | 95% CI |
|-----------------------------------|-------|----|-------|
| Response rate to auditory signals [%] | −0.00 (0.01) | .998 | .968–1.027 |
| Response rate to vibro-tactile signals [%] | −0.18 (0.08)* | .832 | .690–.957 |
| Gender (0 – male, 1 – female) | 0.01 (0.03) | 1.010 | .951–1.079 |
| Age groups (0 – 18–25 years, … , 5 – 56–65 years) | −2.96 (1.04)* | 1.128 | .012–.799 |
| Trip distance (0 – 0–5km, … , 5 – more than 30 km) | −0.59 (0.35) | .555 | .260–1.056 |
| Cycling frequency (0 – daily, … , 4 – 1–3 days per month) | 0.32 (0.30) | 1.373 | .763–2.535 |
| Regular route characteristics (0 – none, 1 – traffic, 2 – loud, 3 – bumpy, 4 – traffic and bumpy, 5 – traffic and loud, 6 – all) | 0.19 (0.19) | 1.210 | .845–1.791 |

Odds ratio (OR) and confidence interval (CI) for choice of preferred signal between auditory (baseline in logistic regression) and vibro-tactile signal predicted by response rate and participant characteristics. Significance codes: p ≤ .05.
et al. 2020). Both the objective response rates and the signal preferences are mostly valid for our setup and used signals.

The location of the signals is likely to influence how participants experience them. For instance, having a visual signal in the visual focus (e.g., smart glasses) might lead to a higher perception rate, and thus the signal might be experienced as more reliable. The difficulty to distinguish the vibro-tactile signal from road surface related vibrations might be minimized by using a vibration pattern not resembling the rattling of the road.

Since the course started at the same location for all participants, sequence effects might be present. To limit the sequence effects to a certain extent, the order of the three signal types was permuted within an environment segment. However, the order of the environment segments might still influence the perception of the signals.

Regarding further research signals need to be linked to cycling related content. It would be interesting to analyze modality preferences once signals transmit certain information (e.g., warnings). It could be a further indication to use a specific modality to transmit warnings, if cyclists react faster to a specific modality, are less startled and manage the critical situation more safely.

Our study sheds light on modal preferences of cyclists based on their experience with them in road traffic. We found that while both auditory and vibro-tactile signals are preferred over the visual signal, auditory signals are preferred as warnings. Furthermore, our results indicate that unimodal visual signals are not suitable for warnings. While auditory signals are preferred as warnings, they seem to have disadvantages compared to vibro-tactile signals. Further research is required to compare both signal types in actual warning scenarios.

Disclosure statement
In accordance with Taylor & Francis policy and my ethical obligation as a researcher, I am reporting that I, Elke-Henriette Erdei, as well as Dr. Jochen Steinmann are employed by the Robert Bosch GmbH. Prof. Dr. Carmen Hagemeister, in accordance with Taylor & Francis policy and her ethical obligation as a researcher states, that she does have nothing to disclose and did not receive any funding for this project.

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Data availability statement
We do not have permission to share research data.

References
Baldwin CL, Lewis BA. 2014. Perceived urgency mapping across modalities within a driving context. Appl Ergon. 45(5):1270–1277. doi:10.1016/j.apergo.2013.05.002
Berry KI, Johnston JE, Mielke PW, Jr. 2007. An alternative measure of effect size for Cochran’s q test for related proportions. Percept Mot Skills. 104(3 Pt 2):1236–1242. doi:10.2466/pms.104.4.1236-1242
De Angelis M, Fraboni F, Prati G, Giusino D, Depolo M, Zani B, Pietrantoni L, Shires J, Johnson D. 2018. Preferences of European cyclists towards passive and active systems with audio-visual and with handlebar vibration warnings. In: Proceedings of the Human Factors and Ergonomics Society Europe Chapter 2018 Annual Conference; October 8–10, Berlin, Germany.
De Waard D, Edlinger K, Brookhuis K. 2011. Effects of listening to music, and of using a handheld and handsfree telephone on cycling behaviour. Transp Res Part F Traffic Psychol Behav. 14(6):626–637. doi:10.1016/j.trf.2011.07.001
Engbers C, Dubbeldam R, Buurke JH, Schaake L, De Goede M, Rietman JS, De Waard D. 2016. The acceptance of a prototype rear-view assistant for older cyclists: two modalities of warnings compared. Int J Hum Factors Ergon. 4(3/4):264–281. doi:10.1504/IJHFE.2016.083520
Erdei E-H, Steinmann J, Hagemeister C. 2020. Comparing perception of signals in different modalities during the cycling task: a field study. Transp Res Part F Traffic Psychol Behav. 73:259–270. doi:10.1016/j.trf.2020.06.011
Hagemeister C, Tegen-Klebingat A. 2012. Cycling habits and accident risk of older cyclists in Germany. In Proceedings International Cycling Safety Conference; November 7–8, Helmond, Netherlands.
Institut für Mobilität und Verkehr. 2017. Sicherheitsorientierte Fahrerassistenzsysteme für Elektrofahrzeuge: Zusammenfassung der Ergebnisse der Nutzerstudie. [accessed 2020 Jan 30] https://www.bauing.uni-kl.de/fileadmin/imove/Bilder/projekte/SIFAFE/2017-07-11-Nutzerstudie_Ergebnisse.pdf
Jamson AH, Merat N, Carsten OMJ, Lai FCH. 2013. Behavioural changes in drivers experiencing highly-automated vehicle control in varying traffic conditions. Transp Res Part C Emerg Technol. 30:116–125. doi:10.1016/j.trc.2013.02.008
Lewis BA, Baldwin CL. 2012. Equating perceived urgency across auditory, visual, and tactile signals. Proc Hum Factors Ergon Soc Annu Meet. 56(1):1307–1311. doi:10.1177/1071181312516379
MacKinnon DP, Krull JL, Lockwood CM. 2000. Equivalence of the mediation, confounding and suppression effect. Prev Sci. 1(4):173–181. doi:10.1023/A:1026595011371
Prati G, Puchades VM, De Angelis M, Pietrantoni L, Fraboni F, Decarli N, Guerra A, Dardari D. 2018. Evaluation of user behavior and acceptance of an on-bike system. Transp Res Part F Traffic Psychol Behav. 58:145–155. doi:10.1016/j.trf.2018.06.005
Pucher J, Buehler R. 2016. Safer cycling through improved infrastructure. Am J Public Health. 106(12):2089–2091. doi:10.2105/AJPH.2016.303507
Song M, McLaughlin S, Doerzaph Z. 2017. An on-road evaluation of connected motorcycle crash warning interface with different motorcycle types. Transp Res Part C Emerg Technol. 74:34–50. doi:10.1016/j.trc.2016.11.005
Statistisches Bundesamt. 2019. Krafffah- und Fahrradunfälle im Straßenverkehr 2018. 2019. [accessed 2020 Jan 31], https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Verkehrsunfaelle/Publikationen/Downloads-Verkehrsunfaelle/unfaelle-zweirad-5462408187004.pdf?__blob=publicationFile.