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Identification of Potential Warning Signals for a Smartphone-Based Bicyclist Assistant System

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ABSTRACT

Bicycle-vehicle crashes are common and often result in severe outcomes for bicyclists. Assistive technologies may help mitigate bicycle-vehicle crashes; however, these technologies applied to bicycles are understudied. This paper summarizes a preliminary study to identify effective warning signals for a smartphone-based application. This application alerts bicyclists to an imminent collision with a vehicle using a warning signal and gives them additional time to avoid the collision. The signal, however, must be designed to be informative and not otherwise distracting. This work analyzes discussions from experts and stakeholders on the modality and design of warning signals, as well as the efficacy of the mobile application. The experts were presented with visual, audible, and haptic signal options. Text analysis of the focus group transcript shows that flashing visual signals, high pitch auditory tones, and speech messages were most favored by participants.

Keywords: Focus-group, Assistive technology, Mobile application, Heuristics

INTRODUCTION

Bicycling has always been a cost effective and convenient mode of transportation. According to the United States Census Bureau in 2019, roughly 870,000 people in the U.S. commuted by bicycle (Burrows, 2019). Despite having many health and environmental benefits, bicycling on-street with vehicles is often unsafe in a transportation system designed primarily for vehicular travel. Bicyclists are considered to be vulnerable road users (VRUs) as they are not protected and are thus more prone to severe outcomes during crashes (Alvarez et al., 2019).

Unfortunately, bicycle crashes have increased in recent years (National Center for Statistics and Analysis, 2020). In 2018, the United States Consumer Product Safety Commission reported 424,350 bicycle-related injuries that had to be treated by the emergency department (National Center for Statistics and Analysis, 2020). The unsafe biking conditions in the transportation system diminishes travelers' motivation toward cycling, which dampens the potential public health and environmental benefits that could manifest if more people biked.

In order to promote safe cycling, changes should be made in policies, infrastructure, and enforcement of traffic laws. These changes take time and resources; however, technological advancements could be implemented more quickly. For example, existing technologies that assist motor vehicle drivers, such as Advanced Drivers Assistance System (ADAS) (Zahabi, et al., 2019), can mitigate potential collisions by controlling certain operations and providing warning for drivers. Similarly, the Motorcyclists Safety Assistant Application (MSAA) assists motorcyclists by detecting their speed in real time and alerting riders when they exceed speed limits (Fernando et al., 2020).

Unlike the technological advancements for motor vehicle drivers, comparable assistive technology does not yet exist for bicyclists, and there is limited research to support these developments. This study contributes to this research gap and aims to support the development of a smartphone-based bicyclist assistance system (BAS) by identifying the most effective warning systems for bicyclists in potential crash scenarios. BAS is a smartphone app that uses commercial off-the-shelf (COTS) portable speaker to emit imperceptible high-frequency acoustic signals and a smartphone for reflected signal reception and analysis. Based on received acoustic signals, BAS applies advanced acoustic ranging techniques to characterize and detect hazardous traffic conditions surrounding cyclists and provide them with alerts. These real-time alerts ensure that cyclists have sufficient time to react, apply braking, and eventually avoid the hazard (Jin et al., 2021).

LITERATURE REVIEW

Warning Signal Design

Warning systems can be classified into two types-*unimodal,* which only provides either visual, auditory, or haptic signals and *multimodal,* which provides a combination of two or more unimodal signals (Zuki & Sulaiman, 2016). Previous research on in-vehicle warning signal design shows multimodal signals to be more effective than unimodal signals, as they can lower the visual workload and can convey warnings using multiple channels (Dettmann & Bullinger, 2017; Yun & Yang, 2020). The researchers found multimodal warnings combining auditory and tactile cues useful when visual perception is busy, impaired, or nonexistent.

Several studies tested warning systems implementation in vehicles. Geitner et al. (2019) investigated the efficiency of different warning signals and found the shortest reaction time from multimodal warnings, comprising auditory and vibro-tactile signals, and unimodal warnings, comprising auditory signals. In a similar study, audio and haptic systems were found to be the most suitable and easily implementable for in-vehicle warning systems (Zuki & Sulaiman, 2016). Similarly, in a study to incorporate overtaking requests in a conditionally automated driving scenario, a combination of visual, auditory and haptic warnings resulted in the best performance, whereas unimodal signals, especially the visual warning signals, resulted in the worst performance (Yun & Yang, 2020).

Warning Systems for Bicyclists

Although limited research has been conducted to design warning signals for bicyclists, few simulator and field studies investigated whether or not children noticed warning signals while cycling (Matviienko et al., 2018; Matviienko et al., 2019; Erdei et al., 2020). In a simulator study, cyclists ages 6-13 years were warned about critical situations and their reaction time to the warnings were calculated. The researchers revealed that a combination of visual, auditory and haptic signals resulted in the shortest reaction time (Matviienko et al., 2018). Another field study with children using tricycles investigated auditory instructions for navigation with auditory distractions (Matviienko et al., 2019). They found that even with distractions, auditory navigational cues were easily understandable and least prone to errors. It is important to note that these studies did not involve cyclists of all ages, and they did not measure the application of warnings to avoid a crash. This work thus contributes to a clear gap in the research.

Additionally relevant to warning systems for bicyclists is the context in which the warnings are received (Erdei et al., 2020). In this study, visual signals were frequently missed by bicyclists as the cyclist was visually engaged in cycling while observing traffic. However, when there were vibrations from bumpy roads, visual signals were the most preferred in terms of their reaction times. Although, this field study measured reaction times for participants recognizing these signals as they appeared (visual), sounded (auditory), or acted (tactile), again these results do not address participants' exposures to hazard scenarios or reaction times to control the speed of bicycles. Therefore, these results need to be validated in different contexts.

Engaging Stakeholders in Signal Design

Stakeholder involvement is crucial at the planning stage of any transportation related innovation. Previous studies in this area show that addressing and managing stakeholders' interests and concerns can be significantly effective to successfully implement and sustain a new transportation technology (Mok et al., 2015; Wei et al., 2016). Social and behavioral science researchers often rely on focus groups to simultaneously collect data from multiple individuals including direct user populations or experts (Wei et al., 2016). This setting provides an opportunity for participants to discuss and comment on one another's views, which enhance diversity and quality of ideas and feedback to the researcher.

In summary, the literature review shows that additional research should be conducted to identify potential warning signals and successfully implement assistance for bicyclists of all types and ages. Therefore, this research involved expert stakeholders from City and State level administrations, non-benefit organizations for bicyclist safety, and transportation research communities to find a potential lists of warning signals in order to assist bicyclists avoiding hazards in traffic environments.

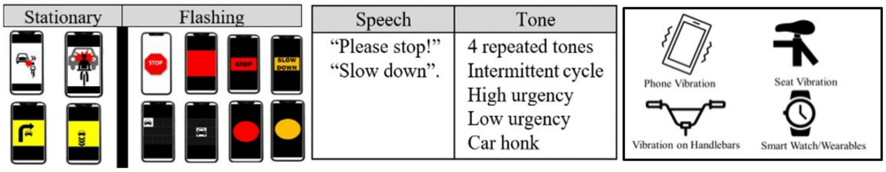

Figure 1: Warning signals included in the study.

METHOD

Study Design

The research team designed and facilitated a virtual focus group study with experts including researchers, policymakers, and stakeholders to direct development of a bicyclist warning system for different road hazards. The study was approved by the Institutional Review Board (IRB) at the University of Texas at Arlington (UTA). Focus group facilitators presented stakeholders with different warning signals, and participants were invited to discuss the perceived effectiveness of the signals based on their expertise and cycling experience. At the end of the focus group, participants were asked to complete an online survey in which they rated each warning system on a 7-point Likert scale. The entire focus group was one hour long.

Warning Signal Selection

From crash data analysis and previously published reports, researchers identified two critical vehicle-bicyclist collision scenarios to be deployed in BAS for its initial development: collision with right turning vehicle and collision with front vehicle nearing. Based on past literature designing warning signals for VRUs and considering the design principles (heuristics) for warnings, a list of signals were created for the focus group discussion. These signals were first divided into *unimodal* and *multimodal* (bi- and tri-modal). The unimodal signals were classified as *visual*, *auditory*, and *haptic* signals. *Visual* and *auditory* signals were further divided in to two groups: *stationary* and *flashing* for *visual* and *speech* and *tone* for *auditory.* The list of signals shown to the participants is presented in Figure 1. These signals were presented to the invited stakeholders using a PowerPoint presentation.

Participants

Researchers reached out to eleven potential stakeholders chosen for their involvement in the cycling advocacy and design community. Interested participants were provided with IRB approved consent forms to describe the study procedure. In the email, they were given an introduction about the prototype BAS app and the need for effective warning signals for the app. Out of eleven invited participants, nine stakeholders showed interest, and ultimately seven stakeholders (four males and three females) participated in the focus group. These stakeholders included representatives from Atlanta

Regional Commission, People for Bikes, Verizon, City of Portland, Georgia Department of Transportation (GDOT), Bike Dallas-Fort Worth, and transportation researcher in the field of smart-phone app technology.

Focus Group Protocol

At the start of the focus group, detailed instructions about the study protocol were provided to ensure consistent participation. One of the researchers led the discussion session while others contributed when participants had questions regarding BAS, study procedure, or designs.

The lead researcher presented the design of the BAS and its operation using a video-based demonstration. Following this, researchers presented unimodal warning signals by visual, auditory, and haptic classes. For each class, signals were presented one at a time and then grouped together at the end of each class presentation. Once signals from each class were presented with its basic description, the participants were asked to discuss pros and cons of each signal and pick the one they found most feasible to be included in BAS. At the end of the discussion session for visual signals, participants were asked whether stationary or flashing signals would be easier to recognize. Similarly, they were asked whether they would prefer speech or tone for auditory signals.

At the end of the focus group discussion, a QuestionPro survey link was sent to the stakeholders. The survey contained questions regarding Likert scale ratings for each of the unimodal signals, and question about potential combinations of multimodal signals. The rating was conducted on a 7-point Likert scale with ‘1’ being the ‘least useful’ and ‘7’ being the ‘most useful’.

Data Analysis

A heuristic evaluation was performed to measure the usability of warning signals to successfully assist bicyclists in hazardous situations. Heuristic evaluation is one of the popular methods in research to investigate usability problems in user interface designs. In this method, a small set of expert evaluators test potential interface design and judge its compliance with recognized usability principles, the “heuristics” (Nielsen, 1992). In this study, researchers used established interface design heuristics by Lee, et al. (2017) and revealed insights useful to enhance usability from the early stage of BAS development. Transcription from the meeting discussion was recorded along with notes taken by the researchers. Once the data was cleaned, word frequencies were obtained for each heuristic. Survey ratings were analyzed to further validate outcomes of the discussion and explore stakeholder’s design preference for multimodal signals. Participants’ perceptions on multimodal signals are summarized.

RESULTS AND DISCUSSIONS

Factors Influencing Experts’ Choice of Signals

Each participant’s comments were recorded onto one Excel file separating each class of designs. All comments regarding potential designs were coded

Table 1. Factors influencing experts' perception of signal design for BAS

Heuristics (Percentage)	Definition	Example of Verbiage
Compatibility (34%)	Signals being perceived to be consistent with user's expectation and conventions	"My first reaction was we don't want to distract bicyclists"
Visibility (29%)	The degree to which signals will attract bicyclist's attention.	"I like flashing something - that catches your attention"
Explicitness (18%)	The clarity of signals and their timely and useful enactment	"I should be able to differentiate between signals when a crash is coming up"
Consistency (8%)	Extent to which the appearance and enactment of signals match standardized traffic warnings	"I think the use of standardized signals is really important"
User control (8%)	Users being able to easily use and control features of the app	"I would like to control speech or tone mode as my auditory signal"
Error prevention (3%)	To what extent the signals can minimize user error	"There is a lot of errors that could happen"

based on the heuristics hypothesized to be influential. The percentage of factor usage and examples of verbiage are presented in Table 1.

Compatibility, *visibility*, and *explicitness* were the top heuristics mentioned by the experts (Table 1), as these three would ensure the warning system is designed for the bicyclists and would not interfere with riding. These heuristics will be essential to conduct the usability testing of the warning system and the application itself to find errors and defects.

Warning System Features

Results from the survey showed that participants preferred visual and audible signals over haptic signals, especially flashing visual signals (86%), high pitch audible signals (57%), and tone audible signals (71%). This differs somewhat from the literature review as experiments have shown audible and haptic to be preferable (Geitner et al., 2019, Zuki & Sulaiman, 2016, Erdei et al., 2020). Specifically, participants noted that vibration warnings would be harder to distinguish from text notifications with haptic stimuli. They also mentioned handlebar vibration can disrupt a person's control over the bike. When asked whether they would prefer multimodal vs unimodal signals on the survey, all respondents agreed on multimodal signaling. This finding aligns with previous literature, which has shown that multimodal signaling can lower visual overload and conveying messages via multiple channels (Dettmann & Bullinger, 2017; Yun & Yang, 2020).

Regarding multimodal signal combinations, participants responded that a combination of flashing visual signal and a high-pitch tone or speech will be effective. These results were also evident from the focus group results as experts selected flashing signal and high-pitch tone. Participants stated "I really like the idea of audible" and "I like flashing something that catches your attention". Participants also noted the value in providing the user the ability to select their own combination of the warning system based on their preferences.

CONCLUSION

This paper is a preliminary study for a Bicycle Assistance System application in which a focus group study was conducted to determine the appropriate warning signals to help bicyclists recognize potential crashes. Experts in this field were invited to discuss the feasibility of different modes of signal. Multimodal signals with a combination of visual and auditory warnings were identified to be the ideal warning system. Participants preferred flashing visual signals and high-pitch tones for auditory signals, and they did not prefer haptic signals. Factors affecting the choice of warnings included compatibility, visibility, and explicitness. Experts acknowledged the benefit of such warnings on a smartphone-based application for improving bicyclist safety. Future research will further test the prototype BAS and the signal warning systems with simulated and naturalistic experiments.

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