Supporting Cyclists through Hazard Notification Systems: Insights from the Evaluation of Notification Modalities with a Head-mounted Wearable System

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ABSTRACT

Bicyclists belong to vulnerable road users (VRUs) and are increasingly involved in accidents. As accidents pose a significant risk to their safety due to the lack of protection from the bike or clothing, there is a need for effective measures to enhance bicyclists' safety. While road infrastructure improvements can play a role, they are often challenging to implement and costly. In this paper, we propose the use of smart wearables as a solution for providing hazard notifications to cyclists. Specifically, we focus on the application of different systems, including augmented reality (HoloLens) and virtual reality (VR headset, CAVE), and present preliminary results from evaluations conducted on real roads, including closed test tracks. In this workshop, we will present our findings and progress to date in using these technologies to improve cyclist safety. We believe that using smart wearables, cyclists are better able to recognize and manage hazardous situations, leading to a reduction in accidents and improved safety outcomes.

KEYWORDS

Cyclist safety, Hazard notification systems, Smart helmets, Connected traffic.

1 INTRODUCTION

Micromobility is a topic that is being discussed with growing interest. In particular, the bicycle is often the most important means of transportation in this context. In recent years, the number of cyclists has increased, as have efforts to make cycling more attractive and to convince non-cyclists to use bicycles instead of cars for short trips or commuting to work. However, since cyclists are among the more vulnerable road users, measures must also be taken to make cycling safer. To reach a higher number of cyclists, measures are discussed and implemented to make cycling more attractive and safer, e.g., support for cycling itself, for exploring areas or for safer interaction with smartphones while cycling (see section 2) or even through hazard alerts for cyclists (see section 3).

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In our view, in particular hazard notifications could contribute to increased road safety. However, the way in which this information is provided to cyclists may affect its effectiveness. We hypothesize that providing such information on the head (using smart glasses or feedback integrated into helmets) could be a viable way to reduce the distraction from the road that is given, compared to when cyclists have to access information via handlebar-mounted smartphones. In addition to the benefits offered by such wearables, there are still outstanding challenges, which are described below (see section 4).

2 SUPPORT FOR CYCLISTS

Infrastructural measures can contribute a lot to making cycling as a mode of transport more accessible, safer and more convenient. However, the implementation of suitable infrastructures is often cost-intensive and cannot be implemented everywhere at the same time in the short to medium term; it also requires good planning and research in advance to find good and pragmatic solutions.

But it’s not just providing good infrastructure that could benefit cyclists. In many ways, systems integrated into bicycles or wearables for cyclists could contribute to greater comfort and safety when cycling. Such support for cyclists can take many forms. To support older cyclists in particular, Dubbeldam et al. [1] studied the effect of cycling with SOFIE (N=9), a prototype bicycle that 1) has an auto-adjusting saddle size that allows for lower entry into the bicycle and adjusts to the rider as they begin cycling, and that 2) is self-stabilizing at lower speeds so that the rider needs to exert less balance effort, and that 3) was electrically assisted and has a starting aid. They concluded that getting on/off the bike was safer and that cyclists swayed less than when cycling with a standard low-entry bike.

To make navigating while cycling safer and more intuitive, researchers are studying how best to display navigation information to cyclists. Pielot et al. [9] introduced the Tacticycle for exploratory cycling trips, which provides information about points of interest near the cyclist by using a smartphone that displays potential destinations and guides the cyclist in the general direction of those destinations through vibrations on the handlebars. Also in this context, Krauß et al. proposed a vibrotactile compass for cyclists that provides tactile feedback on the head via a headband, enabling the cyclist to set a destination, explore an area, and learn the direction of the set destination upon request.
As cyclists are among the vulnerable road users, there is increasing research on possible measures to improve their safety on the road. Improving interaction with bicycle-mounted devices may reduce the risk of self-inflicted crashes due to distraction from traffic when interacting with them. Savino et al. [11] investigated how best to report traffic incidents while bicycling; currently, this is accomplished through touch inputs from the bicyclist and requires 1) looking at the handlebar-mounted smartphone and 2) removing one hand from the steering wheel, which is not necessarily safe. They proposed guidelines on how best to integrate voice assistance to ensure safer interaction. In terms of general smartphone interaction, Woźniak et al. [19] proposed two concepts, using either grip rotation as input (Brotate) or three buttons (Tribike).

The aforementioned support systems could 1) assist older people with bicycling, 2) enable exploratory cycling, and 3) enable interaction with electronic devices while bicycling. As a result, they could help reduce self-inflicted crashes. However, cyclist accidents are not only self-inflicted. Often, other road users, especially motorized vehicles, are also involved; therefore, providing hazard information seems to be a viable way to reduce the number of such accidents.

3 HAZARD NOTIFICATIONS FOR CYCLISTS

Recent research and also cycling devices suggest how cyclists can be notified of hazards. For notification of approaching vehicles in traffic, cyclists could use a Garmin Varia RTL 516 [4], which visually and audibly notifies cyclists of vehicles approaching from behind using a radar mounted on the bicycle. Another approach proposed by Jin et al. [6] is CycleGuard, that uses acoustic ranging to alert cyclists of potential "right-hook" accidents (vehicles turning right and hitting an intersecting cyclist).

Kreißig et al. [7] investigated ways to inform cyclists of potential hazards by providing general direction on a smartphone while using auditory and vibrotactile cues (all devices attached to handlebars). To assist child cyclists, Matviienko et al. [8] studied warnings using multimodal feedback (tactile and visual on handlebars, auditory on helmet) to increase cyclists’ hazard awareness when participants encounter randomly appearing vehicles from the side as the cyclists are approaching an intersection or vehicles pulling out of a hidden parking space. They concluded that unimodal cues were most effective for encoding directional information, whereas multimodal cues resulted in shorter reaction times and were most appropriate when immediate action (braking hard or swerving) was required. Also in the context of hazard notifications, von Sawitzky et al. [16] investigated how bicyclists can be notified of potential “dooring” accidents (opening vehicle doors colliding with passing bicyclists) by using visual and/or auditory feedback on smart glasses.

While some of the above concepts [4, 6–8] provide hazard notifications via handlebar-mounted devices, Matviienko et al. [8] and von Sawitzky et al. [16] also used feedback at the head. Vo et al. [15] also suggested the use of tactile feedback on the head that could be integrated with hazard notifications.

4 SMART WEARABLES FOR CYCLISTS TO PROVIDE HAZARD NOTIFICATIONS

There have been recent introductions of cycling glasses such as the Raptor [3] or Engo glasses [2], which allow cyclists to receive information in their direct field of view. This information is provided via a smartphone connected to the device via Bluetooth and currently includes non-safety critical information such as navigation instructions, calories burned, ride time, etc. Current research [12, 16] is exploring how such devices could also be used to provide safety-critical information, such as hazard alerts, without distracting cyclists and posing an additional risk to themselves and others in traffic.

In our research [16–18], we investigate how hazard messages can be presented to cyclists on head-mounted devices in an intuitive and non-distracting manner and how this effects their cycling behavior. Our research is based on the assumption, that connected traffic systems are in place which can detect potential hazards for cyclists and that this information can be shared with them. Based on our studies, we come to the following conclusions regarding hazard presentation for cyclists:

4.1 Representing Hazard Notifications to Cyclists

As mentioned earlier, notifications for cyclists are currently often provided via output devices on the handlebars of the bicycle (see warnings of approaching vehicles with the Garmin Varia [4] or navigation instructions or notifications of traffic accidents [10] via a smartphone). Our focus is on the use of wearables in the form of head/helmet displays, inspired by smart glasses for cyclists [2, 3].

In three user studies (N=77; two of them in a mixed reality bicycle simulator in a CAVE automatic virtual environment (CAVE, a 3m×3m×3m cube with four projection sides on the left, right, bottom, and back) and one on a test track, see ??), we investigated the effect of different feedback modalities (visual only, visual + speech, visual + auditory icons, visual + tactile). We assumed that displaying relevant information in a visual way is the easiest option for the user to obtain information, compared to using solely other modalities (e.g., auditory or tactile only). However, to take notice of an incoming message, other modalities then visual should be considered to catch the cyclists attention and provide information about nearing a potentially hazardous situation. These cues were then used to guide the user by indicating that a hazard was approaching or the cyclist was approaching a hazard while a notification was active (indicating that the hazard is about 6 and then 3 seconds away). This was done with the intention of minimizing potential distraction by repeatedly checking the elapsed time in the visual cue, thus this information was presented redundantly on another modality. The visual cue is representing 1) the type of hazard to expect, 2) its direction relative to the cyclist and 3) the elapsed time (allowing the cyclist to estimate when the hazard will be close), see Figure 2b.

As a mock-up for a head-worn wearable, we used a HoloLens 2 (visual and auditory cues) and a self-built tactile headband (tactile cues), as shown in Figure 2a, to provide cues about potential hazards on the road (potential hazards: dooring, vehicles that will overtake the cyclist).

In the three studies, the participants evaluated their cycling experiences with the hazard notifications provided on the wearable and without any hazard notifications. In post-ride questionnaires, they
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(a) Dooring Study in MR.  
(b) Overtaking Study in MR.  
(c) Dooring Study on a test track.

Figure 1: An overview of the three user studies conducted in the scope of this research context: dooring 1a and overtaking 1b situations in a MR (CAVE) environment and dooring situations 1c on a test track.

(a) The mock-up used in our user studies consisted of a Microsoft HoloLens 2, providing visual and auditory cues to the user, and a self-built headband providing tactile cues on the head.

(b) The visual representation which was continuously displayed when a potential hazard was detected. It informed cyclists of 1) the type of hazard (in form of icons), 2) its direction relative to the cyclist, and 3) a time indicator to inform the cyclist of the approach to a potential hazard (indicating the elapsed time and color-coding the closing in from green-yellow-orange).

Figure 2: The mock-up used in the user studies 2a and the visual representation 2b which was accompanied by supporting cues intended to guide the cyclist with an additional cue to reduce potential visual distraction.

(a) The mock-up used in our user studies consisted of a Microsoft HoloLens 2, providing visual and auditory cues to the user, and a self-built headband providing tactile cues on the head.

(b) The visual representation which was continuously displayed when a potential hazard was detected. It informed cyclists of 1) the type of hazard (in form of icons), 2) its direction relative to the cyclist, and 3) a time indicator to inform the cyclist of the approach to a potential hazard (indicating the elapsed time and color-coding the closing in from green-yellow-orange).

provided feedback in terms of workload (NASA-TLX [5]), user experience [13], intuitiveness of hazard detection [14] and perceived safety [17]. In addition, in the final semi-structured interviews, we asked how the participants perceived the cues and what their attitude toward them was, what suggestions they had for improvement, and where they saw potential challenges.

Based on the results, we concluded that displays with visual cues and auditory icons or visual cues with tactile feedback were best perceived by our participants. Overall, receiving information about potential hazards increased perceived safety while cycling and was found to be very useful.

In addition to the many benefits of using a wearable device for cyclists to indicate potential hazards (see subsection 4.2, there are still some challenges that need to be accounted for (see subsection 4.3):

4.2 Advantages

Visual Cues. Displaying content on devices attached to the bike is a distraction from the road, which can be a danger to the cyclist themselves and a danger to others. When using wearables on the head to provide information to cyclists (safety related or others alike), the distraction of checking incoming notifications should be much less. In particular, for providing visual cues, head-up displays (HUDs) seem to be a convincing solution that could reduce distraction from road traffic and bring all the benefits already known for in-vehicle HUDs. In addition, cyclists could, for example, perceive hazard alerts from their peripheral vision, as they are informed by clear color coding in the display that they are approaching a potential hazard, which can then be perceived even when not focusing on the display, which is not given by handlebar-mounted devices.

Tactile Cues. In addition, tactile feedback at the head is decoupled from vibrations caused by ground conditions, such as when using vibrations on the handlebars. In addition, this feedback can be perceived at all times, which is not the case with handlebar feedback, as it requires the hands to be on the grips, which is not always the case (e.g., when giving hand signals or riding the bike hands-free).

Auditory Cues. The use of audible signals from a handlebar-mounted device also requires the sound to be audible at all times,
which may not be possible due to varying ambient noise levels or due to the volume settings of the device. The user may also not want to ride the bike and emit sounds that are audible to everyone nearby. If the acoustic feedback were moved closer to the head, either directional speakers or bone-conducted headphones could be used.

4.3 Challenges

The usage of such wearables as well as current devices, however, still come with some challenges.

Usage of Head-Mounted Wearables.
- It is not yet clear which impact looking at a display from such a short range impacts the cyclist.
- Not everyone feels comfortable wearing a helmet or glasses while cycling.
- The devices need to be lightweight to be wearable over longer time periods.

Technological Restrictions.
- The displaying area is quite limited with the current technological advances.
- The content is moving “up and down” due to ground conditions, due to active movement of the cyclists and the device being able to slightly move as it is not rigidly fixed to the users which could lead to perception issues/annoyance of the user.
- Brightness and contrast levels are not yet sufficient in an see-through augmented reality context outdoors.
- The detection of hazards and the transfer of this information to the cyclist (connected traffic information) needs to be reliable.

However, considering the use of contact lenses, which in the future could also be equipped with some kind of projection technology, some of these problems (weight, stable content representation, displaying area) could be solved.

Information Content.
- It is yet unclear how much information should be even displayed in the cyclists field of view as too much content could easily distract the cyclists and obstruct the view.
- Future work needs to investigate how to best arrange different content types.

5 CONCLUSION

Wearables for cyclists in the form of devices that attach to the head or helmet could make cycling safer by 1) providing hazard information and 2) relocating feedback/visual content, i.e., speedometers and smartphones, both of which are now necessarily attached to handlebars, to reduce visual distraction from the road by requiring less time to look (similar to HUDs in vehicles). Although there are many benefits to using the proposed type of wearable to provide hazard messages and notifications to bicyclists in general, there are some technological challenges that need to be addressed. Further, consideration needs to be given to how the information can be displayed in a way that does not obstruct the user’s field of view and allows them to quickly obtain desired information.

REFERENCES