

Reminding Child Cyclists about Safety Gestures

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ABSTRACT

Cycling safety gestures, such as hand signals and shoulder checks, are an essential part of safe manoeuvring on the road. Child cyclists, in particular, might have difficulties performing safety gestures on the road or even forget about them, given the lack of cycling experience, road distractions and differences in motor and perceptual-motor abilities compared with adults. To support them, we designed two methods to remind about safety gestures while cycling. The first method employs an icon-based reminder in heads-up display (HUD) glasses and the second combines vibration on the handlebar and ambient light in the helmet. We investigated the performance of both methods in a controlled test-track experiment with 18 children using a mid-size tricycle, augmented with a set of sensors to recognize children's behavior in real time. We found that both systems are successful in reminding children about safety gestures and have their unique advantages and disadvantages.

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

Author Keywords

Safety gestures; HUD glasses; child cyclists; cycling safety.

INTRODUCTION

Looking over the shoulder and performing hand signals are an essential part of cycling and safe manoeuvring on the road [7, 1, 2]. Even though safety gestures are not mandatory road regulations in some countries, cyclists are expected to obey road rules that are in place for everyone's safety. This is particularly important for child cyclists, given their still developing motor and perceptual-motor skills, lack of cycling experience and knowledge of traffic rules. One possible way of improving children's literacy on the road is through cycling courses that help children practice cycling over an extended period of time. However, the disadvantage of this approach is that children tend to forget what they learnt, especially when they cycle irregularly. Occasionally, many children still need to be

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Figure 1. Participants wearing a helmet (left) and HUD glasses (right) for the controlled test-track experiment using a mid-size tricycle.

reminded about the right sequence of actions by their parents before performing a turn, namely looking over the appropriate shoulder and showing hand signals.

To address this issue, we explore ways of reminding child cyclists about safety gestures using technological augmentation of cycling accessories. This is illustrated by the following scenario: a 9-year old Liam has not performed a shoulder check and/or a hand signal at the particular junction on his way to school over the last two days. His bicycle logs this behavior and activates a reminder system that recommends the appropriate safety gestures next time he is at this junction. With this, we aim to remind children about safety gestures on demand, and not before every manoeuvre.

To assist cyclists, researchers have previously augmented cycling accessories with vibrotactile, visual and auditory feedback [16, 15, 6, 12, 14]. Recent commercial products, such as EverySight¹ and helmet SKULLY AR-1², introduced head-up displays integrated into helmets and glasses to show important information for cyclists. Due to the lack of empirical evaluation of these systems with child cyclists, we explore both multimodal systems and head-up displays in this paper. Particularly, we investigate how icon-based and multimodal feedback integrated into a helmet, bicycle and heads-up display (HUD) glasses can be used as reminders about safety gestures for children. We focus on multimodal feedback, because of its success with child cyclists for warning signals [12],

¹<https://eversight.com/>

²<https://skullytechnologies.com/fenix-ar/>

navigation [14] and lane keeping cues [13], and on the head-up displays due to their granular presentation of information. To compare these methods, we designed multimodal and icon-based reminders and conducted an experiment on an outdoor practice test track using a mid-size tricycle (Figure 1). We found that both methods are successful in reminding children about safety gestures and have their unique advantages and disadvantages. In this paper, we contribute an empirical evaluation of reminders about safety gestures for child cyclists and a technical bicycle setup to facilitate cyclists' assistance.

RELATED WORK

While warning signals [12] and navigation cues [14] have been previously investigated with child cyclists, the systems with safety recommendations remain unexplored. In the following subsections we outline previous works within these three dimensions.

Warning signals

Bicycles and helmets have been previously augmented with visual feedback to warn cyclists about upcoming danger. For instance, Garmin Varia Rearview radar³ warns the rider about vehicles approaching from behind using an on-screen visual notification mounted on the handlebar. Other warning systems for cyclists [9] and motorcyclists [8] employed a buzzer, beeper, or lighted bulb to warn about approaching vehicles and possible collisions. Massey [11] introduced technology for tracking location and motion of multiple vehicles, which warns drivers about possible collisions at the same time.

Schopp et al. [17] integrated a bone conductive speaker into a helmet to warn cyclists about approaching, out-of-view vehicles. The cyclists showed increased situational awareness and were better able to identify dangerous situations. Jones et al. [10] augmented a cyclist's helmet with both input and output methods. They tracked head tilts and utilized them to indicate turn signals on the back of a helmet. Similarly, a commercial product, Blink Helmet, utilized manual buttons on the sides of the helmet to indicate stop and turn signals. Another safety helmet made a step further and combined internal and external inflatable pads, which are activated prior to impact, depending on the calculated speed, distance, and direction of the upcoming object [3]. More recently, Matviienko et al. [12] investigated multimodal feedback to represent warning signals for child cyclists. They showed that a combination of vibration, light, and sound on both handlebar and helmet can efficiently warn cyclists about upcoming hazards.

Navigation cues

Navigation cues have been previously integrated on the handlebar, in a helmet, projected on the road or in front of a cyclist's eyes. One of the earlier works in on-bicycle systems was TactiCycle [16, 15], which integrated vibration motors in the handlebar for turn-by-turn navigation. This idea was commercialized and SmartGrips⁴ released two vibrotactile grips that could be easily integrated in the handlebar for navigation. Smarthalo⁵ is another on-handlebar LED-based navigation

product, which indicates distance and direction via different light patterns. Hammerhead⁶ is a bike accessory that also can be fixed to the handlebar and indicates turn-by-turn navigation cues through directional LEDs. These navigation devices, however, require pairing with a smartphone to receive routing information.

Tseng et al. [19] utilized peripheral light cues located inside the helmet, above the eyes, to navigate riders without introducing additional distraction. Matviienko et al. [14] further explored this idea and showed through the lab and test-track evaluations that navigation cues presented with ambient light integrated into a helmet were applicable for children. Dancu et al. [6] augmented a bicycle with a map projection in front of the bicycle to show navigational cues and projected turn signals at the back to show the turn intentions to other road users.

Safety recommendations

Recommendations for safe behavior on the road have been previously presented using head-up displays and projected interfaces in different commercial products. For example, a newly introduced helmet SKULLY AR-1⁷ shows detailed information about speed, navigation, and nearby vehicles in the corner of a helmet's visor. More recent glasses by EverySight⁸ employs a similar idea and displays navigation information in front of a cyclist's eyes using OLED technology. Both products display instructions without blocking the view, in a subtle and non-distracting way. This technology inspired us to create HUD glasses and explore it with children for icon-based representation of safety gestures. Another example is the Livemap helmet⁹, which augments the environment with routing information, speed and safety features. However, it is unclear whether helmets with HUDs or augmented reality can enhance safe cycling and successfully remind children about safety gestures.

Other commercial systems have explored possibilities for obstacle detection on the road, such as potholes¹⁰, or to indicate visibility via a projected bicycle sign in the front¹¹. A similar idea with projection on the road was introduced by Flashy Blinky Lights to increase the visibility of cyclists in the dark and assist car drivers in keeping a safe distance¹². Previously, researchers have also discovered that projected surfaces were harder to use and perceived as less safer than head-up displays [6]. However, from the perspective of child cyclists it is valuable to have a system which can be usable in both day and nighttime. Therefore, in our evaluations we investigated both a head-up-display and a multimodal system to support child cyclists with safety gestures.

⁶<https://www.dragoninnovation.com/customer-projects/hammer-head>

⁷<https://skullytechnologies.com/fenix-ar/>

⁸<https://everysight.com/>

⁹<https://livemap.info/>

¹⁰<https://newatlas.com/lumigrids-led-projector/27691/>

¹¹<https://thexfire.com/products-page/lighting-system/bike-lane-safety-light>

¹²<https://www.youtube.com/watch?v=6cstdEpmKLM>

³<https://buy.garmin.com/en-GB/GB/p/518151>

⁴<http://smrtgrips.com/>

⁵<https://www.smarthalo.bike>



Figure 2. Overview of animations for HUD glasses. A shoulder look animation consisted of two images: looking straight and looking aside (left). A hand gesture animation consisted of three images: looking aside, stretching a hand 45° and stretching a hand 90° to the body (right). The images appeared in HUD glasses in yellow color as a single monochromatic option available by the hardware.

SAFETY GESTURES SIGNAL DESIGN

Shoulder checks and hand signals are an essential part of safe manoeuvring while navigating on the road [7, 1, 2]. While not mandatory in some countries, they help to increase awareness and alert other road users of cyclists' intentions, and therefore increase safety on the road. Normally children learn about safety gestures from cycling courses or their parents, however, sometimes they might forget about them. Therefore, within the scope of our work we explore methods of reminding child cyclists about safety gestures. Based on the assisting cues presented in the related work [12, 14], we designed two types of reminders for safety gestures: icon-based and multimodal.

For the icon-based representation, we used HUD glasses with a projected animation in front of the eyes. This animation consists of an upper part of a cyclist on a bicycle, who is turning his head to the left and right to indicate a shoulder check or stretching his arm to the left or right to indicate a hand gesture. We used a two-image animation for a shoulder check (looking forward - looking aside) and a three-image animation for a hand gesture (looking aside - a hand is 45° to the body - a hand is 90° to the body). For each signal, an animation consisted of three repetitions, i.e., a projected cyclist turned his head three times or stretched his arm three times to a side. The visual overview of both signals is shown in Figure 2.

For the multimodal representation, we combined an LED helmet with vibration on the handlebar grips. We used peripheral visual feedback placed in the helmet's visor to remind about a shoulder look. A pulsing green light on the left or right side of the helmet indicated the direction, in which children had to perform a shoulder check. To remind kids about hand signals, we employed vibrotactile feedback integrated in the left and right grips of the handlebar. Vibration in a corresponding grip indicated the direction in which children had to show a hand signal. Similar to the icon-based representation, each light and vibration signal consisted of three repetitions, i.e., a handlebar grip vibrated three times and the helmet pulsed three times.

According to cycling rules, the reminders were represented sequentially: a shoulder check was followed by a hand signal. We created two experimental conditions, based on each type of reminder.

SAFETY BICYCLE

To evaluate both types of reminders, we used a mid-size tricycle augmented with cameras and sensors to recognize cyclists' behavior. The tricycle was equipped with five RGB-D cameras,

perceptual pedals, GPS-module, an odometry system, and an on-board computer placed in the rear cargo box (Figure 4). In the following we outline each component in detail.

Recognition cameras. RGB-D cameras belong to the type of cameras, which provide both color (RGB) and depth (D) information for every pixel in the image. We equipped the tricycle with five stereo based RGB-D cameras (Intel RealSense D435¹³): three facing a cyclist to recognize cyclist behavior and two pointing to the front for environment recognition. Two of the behavior recognition cameras were placed on the left and right side of the handlebar and the third one on the bicycle frame. The environment recognition cameras were mounted above the wheel in front of the bicycle. All cameras were connected to the on-board computer via a USB-hub and powered by a lithium-ion battery (16000mAh) placed in the rear cargo box.

To recognize cyclist behavior, such as shoulder look and hand gestures, we used the open source OpenPose library, normally used for real-time multi-person keypoint detection for body, face, hands, and foot estimation¹⁴. We used this library due to its previous success in research projects of hand keypoint detection in single images [18] and real-time multi-person 2D pose estimation [4, 5]. The library ensures real-time recognition of arm joints and head movements necessary for safety gesture reminders (Figure 3). The environment recognition cameras have a total view angle of approximately 120° and are designed to recognize other road users, road obstacles, and traffic signs.



Figure 3. Recognition of head movement (left) and hand gestures (right) of cyclists using the OpenPose library.

Pedals and Tilting. We augmented the pedals with inertial measurement units (IMU) and strain gauges to measure accel-

¹³<https://www.intelrealsense.com/depth-camera-d435/>

¹⁴<https://github.com/CMU-Perceptual-Computing-Lab/openpose>

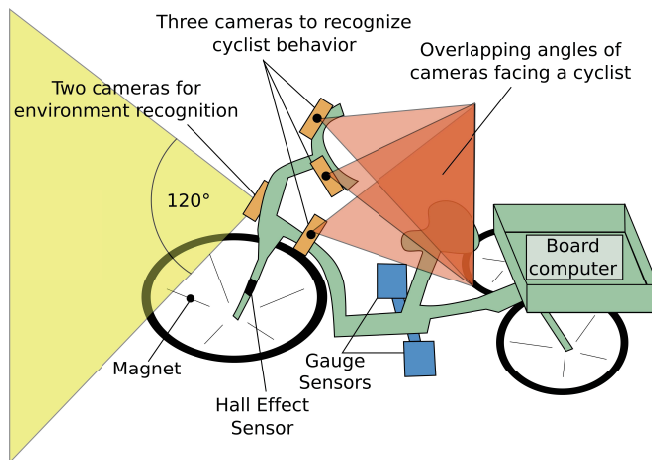


Figure 4. Schematic representation of the tricycle.

eration and pressure on the pedals. Each pedal contained a single point load cell with precision of 50 kg and NodeMCU 8266 directly connected to the strain gauge sensor. This allows us to measure a weight distribution between the left and right pedals while cycling and use it as an additional measure for cyclist behavior, e.g., cycling while standing.

To calculate bicycle tilting, we used an Arduino Primo board, which receives data from two NodeMCU boards placed in the front and in the back of the bicycle. We calculated the tilt using IMUs placed in the front and in the back of the bicycle and connected to the NodeMCU boards. Even though the tilting of tricycle is smaller in comparison to the two-wheeled bicycle, with this set of sensors we were able to measure the tilting while cycling on the curve.

GPS and Odometry System. To measure the position of the bicycle at any point in time we used a ROS-based (Robot Operating system) odometry system and a GPS module (NaviLock 62531). We augmented the front and two rear wheels with a set of magnets and added reed switches on the frame of a bicycle. We used the odometry system and IMUs in the pedals to calculate the velocity of the bicycle.

Board computer. We placed an on-board computer and a power supply in the rear cargo box. For the on-board computer we used NUC INTEL 8 (16 GB RAM, 1 TB storage) with Ubuntu operating system (16.04 LTS) running ROS server for real-time processing of video and logging data from the pedals, GPS coordinates, speed and tilting. The on-board computer was also used as a Wi-Fi and Bluetooth access point to connect the different peripheral components, such as helmets, handlebar grips, HUD glasses, and the experimenter's tablet for the Wizard-of-Oz signal activation during the experiment. The schematic overview of the bicycle is shown in Figure 4.

CONTROLLED TEST-TRACK EXPERIMENT

The goal of the controlled test-track experiment was to investigate the efficacy of the two reminding methods for showing safety gestures. From an experimental perspective, running the study in real-world traffic conditions would have been

ideal. However, due to safety concerns this would not have been possible (or approved) by our institutional review board (IRB). Therefore, we aimed for an approximation with an outdoor test track. This marks a gradual shift towards ecological validity. Moreover, we had to use a tricycle instead of a regular bicycle to address any safety concerns due to balance and coordination issues based on recommendations from the IRB. Although not ideal, children still had to ride on a regular paved road, steer and maneuver the bicycle at intersections, and experience multisensory perception of the environment.

Participants

We recruited 18 children (5 female) aged between six and thirteen ($M = 10.11$, $SD = 2.05$) years. They had between two to ten years of cycling experience ($M = 6.33$, $SD = 2.11$). All of the participants had normal or corrected vision without color blindness. Majority of participants (14 out of 18) knew that one has to perform a shoulder look and a hand signal before making a turn. However, only 11 of them knew that a shoulder look must be followed by a hand signal, and other seven participants thought that a cyclist should first signal and then look.

Apparatus

For this evaluation, we used a mid-size tricycle, described in previous section, to prevent falls (Figure 5). To represent vibrotactile reminders, we fitted a tricycle with the vibration motors on the left and right grips of the handlebar. The vibromotors were directly connected to an Arduino Uno microcontroller. All reminding cues were activated by experimenter using an Android application via WiFi communication five meters before a turn. To observe the behavior and focus of the participants, a GoPro camera was placed in the middle of the handlebar facing the rider.



Figure 5. The tricycle used in the experiment on the outdoor test track.

We used a helmet with a visor and integrated the LED strips on the sides of the visor (Figure 7). The LED strips were directly connected to a NodeMCU 8266 and powered by a lithium ion (LiPo) battery. Both vibrotactile and visual signals were activated via Wi-Fi by the experimenter using an Android application.

For the HUD glasses, we used microoled's MDP05DK microcontroller directly connected to a mini projector and powered by a lithium ion (LiPo) battery. The HUD glasses are based on

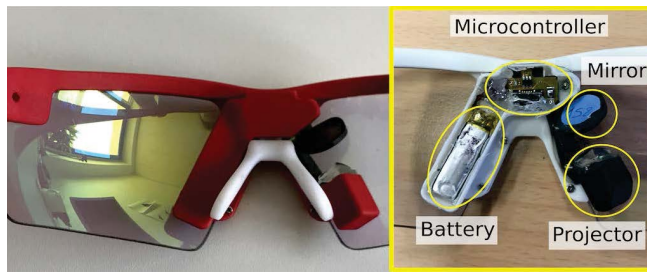


Figure 6. The HUD glasses and its components. The microcontroller is powered by the battery and connected to a projector. The projection is reflected by the mirror and seen in the front.

the ActiveLook technology¹⁵, which includes a miniaturized, light and powerful display module with ultra high brightness and very low power consumption. Cyclist images stored on the microcontroller were activated via Bluetooth by the experimenter using an Android application and projected in front of cyclist's eyes reflected by a mirror (Figure 6). An overview of the animations is shown in Figure 2.

Study Design

We conducted the controlled test-track experiment on an outdoor practice track in Germany, normally used as a training facility by novice car drivers. The test track consisted of a network of gravel roads with intersections, old stationary parked cars, traffic signs and lights. The roads on the test track did not have any cycling infrastructure. For safety reasons, no other traffic (except for parked cars) were presented during the experiment. The experiment was conducted over the course of six days: four of the days were sunny and other two were cloudy. Every participant had to cycle with both types of reminders for 15 minutes and was presented with a signal ten times per condition. The reminders were presented at intersections, where participants could turn left or right. The order of two conditions was counterbalanced. To activate the signals, the experimenter walked behind or next to the participant. The entire study was approved by the ethical review board of our university. Each child received €10 for participation.

Procedure

After obtaining informed consent from participants' parents, we collected children's demographic data. We then explained the reminding cues and provided a brief overview of the procedures. Children had a chance to familiarize themselves with the tricycle and the different types of the cues during a test ride. The experiment started when children felt comfortable.

The children's task was to cycle, do the shoulder look and hand gestures every time they saw a reminder. After performing safety gestures they had to turn left or right correspondingly. After each condition, children were asked to estimate the understandability (5 – very understandable) and the demand (5 – very demanding) of the reminders using a 5-point Likert scale. At the end of the study, we interviewed children about their preferences and the problems they experienced with safety gesture reminders. The entire study lasted about 40 minutes.

¹⁵<http://www.activelook.net/index.html>

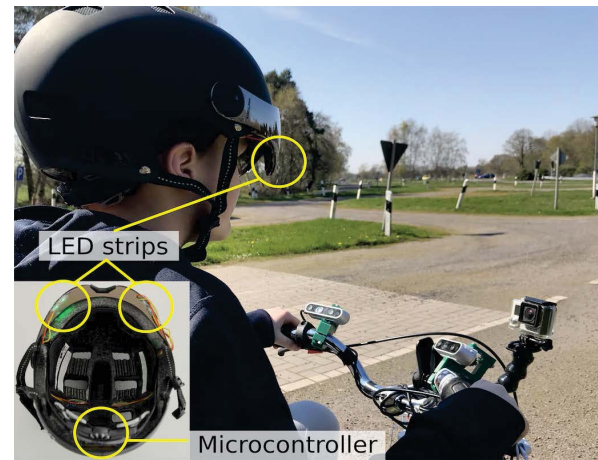


Figure 7. LED helmet with LED strips integrated into the visor for the ambient light cues.

Measures

To compare the types of reminders for child cyclists in the training area, we measured the following dependent variables:

Error rate: for each type of reminder, we counted the number of errors a child made when a reminder was presented. We counted an error, when children did not show a signal, showed it wrongly, or in the wrong sequence.

Understandability (5 - point Likert scale, 5 - most understandable): every participant estimated the understandability of each type of a reminder.

Demand (5 - point Likert scale, 5 - most demanding): every participant estimated the required mental load while cycling with a given type of a reminder.

RESULTS

Error Rate. All participants could always see and follow the instructions regarding a shoulder check and a hand signal. Despite the fact that not all of participants (only 11 out 18) knew the correct sequence of safety gestures, all of them performed the gestures in the correct order: a shoulder check followed by a hand signal.

Safety Gestures Recognition. We observed that head movement and hand gestures were recognized at 100% rate using Intel RealSense cameras in combination with OpenPose library in the real time.

Understandability and Demand. Understandability was comparable between multimodal system ($M = 4.33$, $Md = 5$, $IQR = 1$) and HUD glasses ($M = 4.28$, $Md = 4$, $IQR = 1$). Similarly, demand for both multimodal system ($M = 1.72$, $Md = 2$, $IQR = 1$) and HUD glasses ($M = 1.56$, $Md = 1$, $IQR = 1$) was comparably low. We did not observe statistically significant differences between both methods for both understandability ($Z = -0.28$, $p = 0.78$) and distraction ($Z = -0.69$, $p = 0.49$) using a Wilcoxon test.

Problems and Preferences. During the post-study interview, all children mentioned that they found the digital feedback useful and helpful, and would need them when they forgot to

show the safety gestures. With respect to the children's preferences for reminder types, we found that children preferred the HUD glasses marginally more ($n=10$) than a multimodal system ($n=8$).

Despite the fact that eight children preferred the multimodal system, their decision was justified by the location of the signal (helmet over glasses) and not by its encoding. For example, P14 (7 years old, F) mentioned *"The helmet is quite fixed on my head, while the glasses can fall down."* or P11 (8 year old, F) commented *"The helmet can also hold better on my head."* Therefore, both children preferred the multimodal system, because it was integrated in the helmet, which they liked. Additionally, one child (P4, 12 years old, M) suggested to combine vibration with HUD, but when answering the question he decided for a multimodal system: *"I think the combination of glasses with vibration would be even better. One feels vibration very well and directly."* This makes a preference for the head-up display even higher.

The majority of children, who preferred the HUD glasses reported that it was very easy to see the projection in front of their eyes and it was clear to them what they had to do by mimicking the actions of a projected cyclist. *"I can see a human and I am also a human, so I just mimic his gestures"* [P6, 10 years old, M]. Another child also mentioned that it was a good reminder about what one has to do now: *"If one forgets or does not think about showing a hand signal, then a man reminds a cyclist about it very well."* [P8, 10 years old, M]. Other children mentioned good visibility during a sunny day and no problems with obscurity. *"In the beginning I thought it would block my way, but it was good and clear."* [P17, 13 years old, M]. *"I could always see it and it was also very good to see in the sun."* [P16, 11 years old, M]. Additionally, we found that children had difficulties feeling vibration on colder days. For example, one child mentioned: *"After some time it was harder to feel the vibration, because my hands became cold"* [P9, 8 years old, M].

DISCUSSION AND CONCLUSIONS

We evaluated two methods for displaying safety gestures reminders and presented one technical solution of a bicycle augmented with a set of sensors for recognition of environment and cyclist behavior. Based on the quantitative results from a controlled test-track evaluation, we have shown that both reminders about safety gestures were successful, and the difference between the systems is negligible. However, both systems have their unique advantages and disadvantages.

HUD glasses have advantages of intuitive icon-based representation and high visibility of icons on sunny days. Besides that, the head-up display was considered easy to understand, non-distracting, and effective for reminding children about safety gestures. This finding supports the previous research that shows that information should be presented in the close proximity to the normal line of sight [20]. Similarly to the results from previous work [6, 13] regarding the head-up displays to assist cyclists, our results have shown that the glasses with a head-up display perform comparable to the multimodal approach based on subjective measures. The head-up display in the previous work [6] was limited to night times, while the

OLED technology integrated in the glasses we used in our study showed that it also provides a high visibility of icons even on sunny days and, therefore, indicates a technological improvement. We assume that since the projection in the glasses was located in front of the eyes and not at the level of the handlebar, children also found it less distracting and easy to use. Moreover, HUD glasses has a smaller form factor compared to the system in the previous work [6], which can benefit from a better individual fit, i.e., the size of the glasses can be adjusted depending on the age.

The placement of the head-up display might be reconsidered even further in the future. We think that placement of the head-up display should be shifted to a helmet, given that some children felt more comfortable and safer with a helmet than with the glasses. Moreover, helmets are advisory and in some countries even mandatory cycling accessories. Similar to the glasses, the head-up display can be placed in the visor of a helmet. Unfortunately, due to the technical limitations we did not augment a helmet with a head-up display within the scope of this work.

We have shown that ambient light in the helmet and vibration on the handlebar is a valuable combination. Compared to HUD glasses, which require focal visual attention, vibration and ambient light cannot be simply missed on the busy streets. In this case, a multimodal system might be useful in the situations with heavy traffic situations, while HUD glasses might be more applicable for light traffic scenarios. The multimodal system can provide an efficient guidance for child cyclists, which is in line with previous work about navigation for child cyclists [14]. Similarly, vibration is a promising modality, but in our experiment we found that low outside temperature reduces hand sensitivity, which makes it difficult to perceive the signal (see P9 in Results). Alternatively, vibration feedback can be integrated in the gloves to avoid this limitation.

Within the scope of this test-track experiment, we focused primarily on the representation of reminder for safety gestures. However, we also showed that the current camera-based recognition system is sufficient to recognize the safety gestures in the real-time. Even though we have seen that gestures can be recognized without delays, we see the necessity in conducting an experiment with child cyclists in a more realistic scenario over a longer period of time, e.g., over one-two weeks during school period, and use all integrated sensors to observe cyclist's behavior and evaluate the robustness of the electronic components in real use, such as rough handling and bad weather conditions. Moreover, given that e-bicycles are becoming popular and have an energy source, it will be possible to supply power for all technical components.

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