Text Me if You Can: Investigating Text Input Methods for Cyclists

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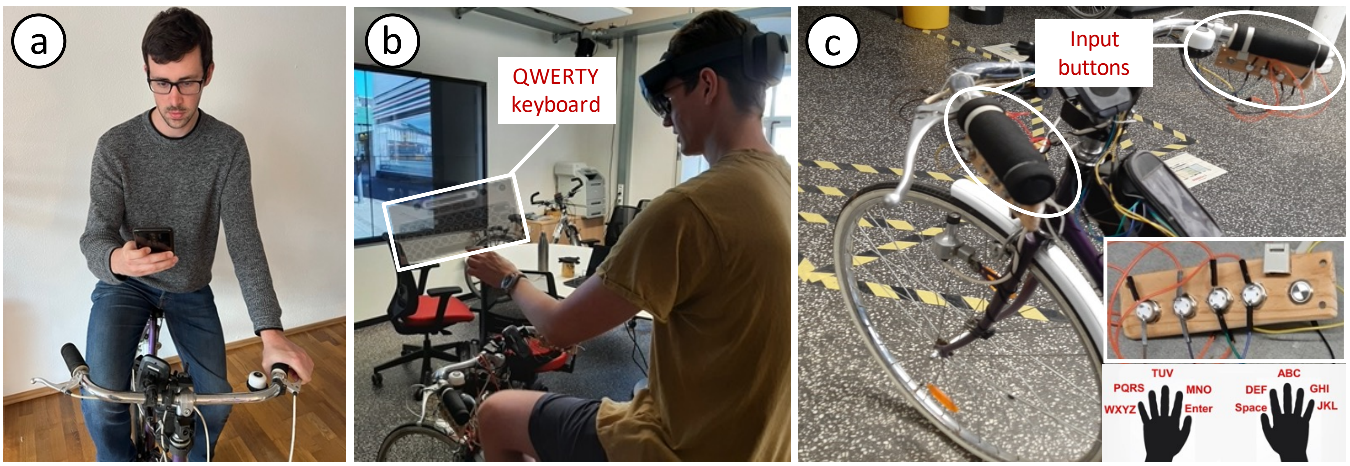

Figure 1: We compared three text input methods for cyclists: (a) touch input using smartphones, (b) midair input on a qwerty keyboard using a Microsoft Hololens 2, and (c) a set of ten physical buttons placed on both sides of the handlebar.

ABSTRACT

Cycling is emerging as a relevant alternative to cars. However, the more people commute by bicycle, the higher the number of cyclists who use their smartphones on the go and endanger road safety. To better understand input while cycling, in this paper, we present the design and evaluation of three text input methods for cyclists: (1) touch input using smartphones, (2) midair input using a Microsoft Hololens 2, and (3) a set of ten physical buttons placed on both sides of the handlebar. We conducted a controlled indoor experiment (N = 12) on a bicycle simulator to evaluate these input methods. We found that text input via touch input was faster and less mentally demanding than input with midair gestures and physical buttons. However, the midair gestures were the least error-prone, and the physical buttons facilitated keeping both hands on the handlebars and were more intuitive and less distracting.

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CCS CONCEPTS

• **Human-centered computing** → **Text input**; **Interactive systems and tools**; **Mixed / augmented reality**.

KEYWORDS

cycling, mobile interaction, text input, smartphone

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1 INTRODUCTION

The number of cycling commuters increases all around the world [6, 8] since it positively affects people's health and turns cities into more liveable and sustainable environments [30]. This increase in cyclists strongly correlates with the use of technology on the go. The most common technology used on the go are smartphones that facilitate navigation, listening to music, answering calls, or even texting [25]. Texting, in particular, puts cyclists in danger because it requires removing at least one hand off the handlebar, adds distractions to the cycling [10], and puts them in danger of possible accidents [12]. Given the increasing number of accidents connected to texting on smartphones while cycling [5, 12], there is a need to explore alternative and safe text input methods for cyclists.

Previous research has explored many input methods of interacting with technology while and after cycling. Particularly, researchers investigated midair gestures to indicate a direction of movement on the go [3, 19], systematically explored on-body locations for tapping input [33], used speech-based input to provide traffic reports [29], employed a button- and rotation-based smartphone controllers placed on the sides of the handlebar [36], and midair gestures using Augmented Reality glasses [14]. Although these approaches have shown promising results in facilitating safety and efficiency while interacting with technology, they have not explored alternatives methods for texting, which has a more significant negative impact on cycling performance than calling or listening to music [5, 12]. Moreover, existing input methods for cyclists do not go beyond a single input, e.g., to confirm a notification or play/pause a song, which leaves us questioning which input method can be effectively used over a long time, e.g., for texting. Therefore, in this work, we build on the success of the previous input methods for cyclists and aim to answer an open question of whether alternative text input methods can be used for cycling and, if yes, how effective they are. By this, we do not aim to promote texting while cycling and explore alternatives for interaction on the go using texting as an example.

In this paper, we investigate text input methods for cyclists to facilitate safe interaction on the go. For this, we conducted an indoor experiment (N = 12) in a screen-based stationary bicycle simulator to examine the effectiveness of the proposed text input methods: (1) touch input using a smartphone as a baseline, (2) midair input using a Microsoft Hololens 2, and (3) physical buttons attached to both sides of the handlebar (Figure 1). Our results indicate that text input via touch input was faster and less mentally demanding than input with midair gestures and physical buttons. However, midair gestures were the least error-prone, and physical buttons made it easier to keep both hands on the handlebars and were more intuitive and less distracting. With this work, we contribute an empirical evaluation of text input methods for cyclists on the go.

2 RELATED WORK

Although researchers have not previously focused on alternative methods for text input to facilitate safe interaction for cyclists, they explored various methods to make cycling more interactive. This section outlines previous work about (1) interactive cycling and (2) input while cycling.

2.1 Interactive Cycling

A vast body of previous work in HCI for cyclists focused on providing effective output. For instance, Poppinga et al. [26] integrated tactile feedback into a handlebar for communicating directional cues and found that cyclists process signals communicated through the handlebars with medium accuracy. Other researchers explored on-body vibrotactile feedback while cycling. For example, Huxtable et al. [11] proposed moving the vibration motors to the user's wrists, and Steltenpohl et al. [32] designed and developed a vibrotactile belt placed around the waist. The results showed that on-body vibrotactile feedback leads to fewer navigation errors than a handlebar-mounted smartphone. For the visual output, Dancu et al. [2] employed projected surfaces for navigation. Matviienko et al. [16–18] have further explored multimodal feedback for child cyclists and found the benefit of using multiple modalities to notify about hazards, and provide navigation and behavior correction cues. Carton [1] proposed a smart glove for added directional safety, resulting in additional visibility.

Another research direction focused on collecting sensor data to assess road situations or increase awareness of cyclists. For example, a project called BikeSafe [7] showed that smartphones could effectively detect dangerous bicycling behavior and, thus, prevent dangerous traffic accidents. Rowland et al. [28] have further underlined the importance of contextual interactions and considered the qualitative experience of bicycle rides. Several systems emphasized the social experience of cycling and highlighted the role of the cyclist as part of a larger community of road users. For instance, Biketastic [27] investigated the annotation of routes and their friendliness for cyclists. E-bikes were augmented to help cyclists to catch "green waves" at the traffic lights. Walmink et al. [34] built a helmet that reflected the rider's heart rate and shared it with others. As previous work on transportation research provides empirical evidence on which behaviors are unsafe [4], the challenge for HCI is to design input methods to prevent such unsafe behaviors, which lies in the focus of this work. We outline the main challenges and overview of input while cycling in the following subsection.

2.2 Input while Cycling

Although smartphone interaction on bicycles is a dangerous activity [5], cyclists still do it [15]. To better reflect on this phenomenon, Marshall et al. [15] introduced a taxonomy for interaction in motion, and cycling falls into a highly constrained activity within it due to the necessity of using hands and feet for operating a bicycle. Previous work has addressed the limitations for interaction in motion for pedestrians by improving direct interaction with an interface, e.g., by introducing larger GUI elements [13]. Other researchers explored the possibilities of turning cyclists' bodies into an input space [33] or augmenting bicycles with additional physical buttons [36]. For example, Vechev et al. [33] investigated the suitability of on-body locations on the go while cycling. However, researchers cannot directly transfer these solutions to cyclists, given that they prefer input techniques that do not require them to remove their hands off the handlebar [3]. Woźniak et al. [36] augmented the bicycle's handlebar with additional physical controls that facilitate smartphone input by pressing buttons or rotating parts. Their results show that such control might be suitable for answering calls and controlling music. Alternatively, researchers explored speech-based interaction methods [29]. However, their main disadvantage is that the environmental noise can interfere with input commands and requires wearing headphones that might reduce the auditory perception of other road users [28, 31]. Researchers have also investigated implicit input methods, such as hand gestures and head movements [3, 19]. Dancu et al. [3] employed hand gestures to provide an additional projected indication of cyclists' maneuvering. Matviienko et al. [19] explored the same idea for reminding child cyclists about showing safety gestures. More recent work by Kosch et al. [14] investigated techniques for different notification selections in augmented reality. Their results have shown that combining a button press with an eye gaze selection leads to faster interaction and lower mental load.

As seen from previous work, input methods for cyclists have advantages and disadvantages. However, we ask ourselves whether we can introduce alternative text input methods that encapsulate the successes and failures of previous work to facilitate safe and efficient interaction. With this, we aim to explore an interaction that goes beyond a single input, e.g., to confirm a notification or play/pause a song, and allows us to understand an input over a more extended time. Therefore, we designed and developed three text input techniques based on the touch input using smartphones as a baseline, midair gestures using Augmented Reality based on the success of previous work [14, 22], and physical buttons attached to the sides of the handlebar as introduced by Woźniak et al. [36]. Within the scope of this work, we exclusively focused on the hand-based text input methods as a first step and see an evaluation of them to hands-free methods, e.g., speech input, as future work. We evaluated these text input methods in a controlled experiment described in the following section.

3 EVALUATION

We conducted a controlled indoor experiment on the bicycle simulator to investigate three types of text input for cyclists. We aimed to assess text input efficiency and find a safer alternative for interaction on the go. Therefore, for this experiment, we had the following research question: *How can we improve text input methods for cyclists?*

3.1 Participants

We recruited twelve participants aged between 20 and 25 ($M = 21.6, SD = 1.5$). Seven cycle less than once a week, one – once a week, and the remaining five 3-4 times a week. Four participants regularly use their smartphones while cycling by holding them in their hands (N = 3) or placing them on the handlebar (N = 1). Participants did not receive any compensation for their participation.

3.2 Study Design

The study was designed to be within-subject with two independent variables: (1) *text input method* and (2) *text length*. The text input method contained three levels and reflected three experimental conditions, which included (1) *touch input* – texting on a smartphone held in hand as a baseline, (2) *midair input* – texting on the midair keyboard using gestures, and (3) *physical buttons* – texting with hardware buttons placed on both sides of the handlebar. For the touch input, participants had to use the thumb of their dominant hand to enter text on the soft qwerty keyboard. We chose this method as a baseline since many cyclists use one hand to enter text while cycling [25]. For the midair input, cyclists had to use their dominant hand to provide input using a soft qwerty keyboard from the Microsoft Hololens 2. This input method was selected based on the success of using Augmented Reality on the go for confirming pop-up notifications, as shown by Kosch et al. [14]. Finally, for the physical buttons, cyclists used fingers on both hands to provide input, with ten buttons placed under each of their fingers on both sides of the handlebar. The buttons were integrated into the boards placed on both sides of the handlebar, with buttons for thumbs at the bottom and the remaining ones on the top (Figure 1 c). The number of presses on each button determines the selection of a letter, similar to text inputs on Nokia phones, e.g., model 3310. For example, if a cyclist wants to enter the letter "N", she would press a button under her pointing finger on the left hand twice, and in the case of the letter "D", one press with a pointing finger on the right hand is sufficient. The buttons under the thumbs were designed to provide Enter (left thumb) and Space (right thumb). The layout for the input with buttons is shown in Figure 1 c. We chose the buttons-based input method based on the work by Woźniak et al. [36] who showed that augmenting bicycle handlebars with physical input controllers to facilitate safety. All three text input methods mimic different input modalities (touch, midair, and physical buttons), allowing us to understand better which can improve text input on the go. The participants' task was to type three messages of different lengths while cycling on the indoor bicycle simulator and paying attention to the road. These messages included: (1) *"On my way"* (short text: 7 characters and two spaces), (2) *"Just left from home"* (medium text: 16 characters and three spaces), and (3) *"I will be there in five minutes"* (long text: 25 characters and six spaces). For all the conditions, if participants made a mistake while typing, they did not have a possibility to correct their message and had to continue typing a correct character after a mistake. We counterbalanced the order of the conditions and types of messages using a Balanced Latin Square.

3.3 Apparatus

The study setup consisted of an indoor bicycle that included a bicycle (28-inch wheel size) fixed on a cycling platform with lateral suspension Kinetic Rock and Roll[1] and a video wall consisting of six 4K displays (2×3 arrangement) (Figure 2). The setup allows cyclists to rotate the handlebar to the left and right due to its increased usability and higher realism in bicycle simulators [23]. The video wall showed a prerecorded video from the first-person cycling perspective in an inner-city street environment to simulate the normal day-to-day cycling[2]. To avoid the endangerment of participants during outdoor cycling, we aimed to improve the experiment's internal validity and create safe cycling conditions. Moreover, we excluded Virtual Reality bicycle simulators to facilitate the visibility of real-world text inputs and avoid unwanted effects of motion sickness [20, 23, 24, 35]. The cycling route consisted of a straight road with slight curves, comparable to a real-world cycling scenario. We instructed participants to follow the simulation, adjust their cycling speed, and turn the handlebar in the direction of the simulation. To reflect a realistic cycling scenario, we have selected a part of the video where the scene was busy, including intersections, other cyclists, pedestrians, and approaching cars. Throughout the simulation, we showed no special occasions, such as accidents or abrupt events.

For the midair input method, we used a Microsoft Hololens 2, and for the smartphone input, we employed a Samsung Galaxy A50.

[1] www.kurtkinetic.com/trainers-products/rock-and-roll-smart-2
[2] The tour was an excerpt of a biking tour through Amsterdam: www.youtube.com/watch?v=PcKXjFCC2f0

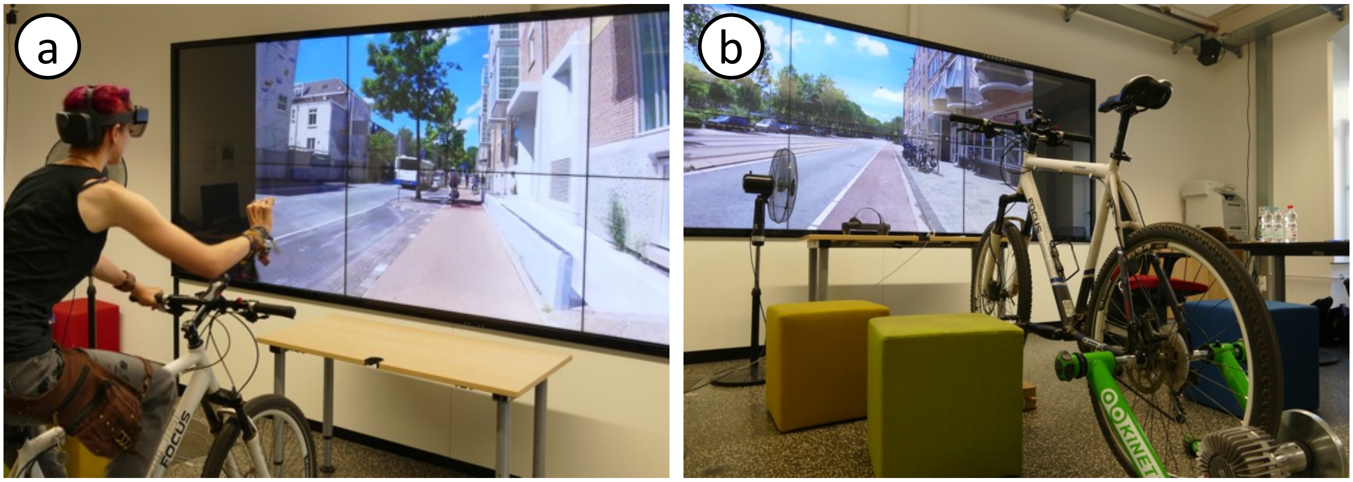

Figure 2: We employed a stationary indoor bicycle simulator to mimic cycling under safe conditions. The bicycle was placed on a fixed platform in front of a video wall comprising six screens (a). Participants entered text while cycling in this bicycle simulator (b).

We utilized the E.161 standardized layout to design our ten-finger hardware keyboard. Eight buttons were assigned for each finger, with the thumbs placed above the Space and Enter buttons. For the order of assignment to each finger, we looked at the frequency of letters in the English language. Then, we looked for the letter with the highest frequency for each button and arranged the buttons to the highest frequencies.

3.4 Measurements

To compare the text input methods, we measured the following dependent variables:

- **Task completion time (in sec)**: for each input method and text length, we measured the time participants needed to enter the text, starting the timer when the first character was entered and stopping it when they pressed enter.
- **Error Rate**: for each input method and text length, we counted the number of mistakes participants made while entering the text. We counted the number of mistakes after the text was submitted.
- **Perceived workload**: for each input method, we asked participants to specify the perceived workload using the NASA Task Load Index, which covers the workload in terms of mental demand, physical demand, temporal demand, overall performance, effort, and frustration level [9].

3.5 Procedure

After obtaining informed consent, we collected participants' demographic data and provided a brief overview of the text input methods and the task. Participants familiarized themselves with a bicycle simulator and text input methods in the test trial. Once the participants felt comfortable, we started the experiment, in which they had to enter a message given to them and press an enter button when they were done while cycling in the simulator with a focus on the road. At the end of the study, we interviewed the participants about their preferences for the text input methods. The riding part of the study took about half an hour, and the entire study lasted approximately one hour.

4 RESULTS

We discovered that entering text with touch input was faster and less mentally demanding compared to midair input and physical buttons. However, midair gestures were the least error-prone compared to the other two methods. Finally, cyclists expressed their preferences for the input with physical buttons because they facilitate keeping both hands on the handlebar the whole time and are intuitive and less distracting interaction.

4.1 Task completion time

We discovered that cyclists were the fastest in entering text using the touch input ($M = 14sec, SD = 7$), followed by the midair ($M = 48sec, SD = 23$) and physical buttons ($M = 84sec, SD = 38$). A statistically significant main effect confirmed this finding for the *text input method* ($F(2, 22) = 110, p < 0.001, \eta^2 = 0.91$). The post-hoc analysis has further shown that entering text using touch was statistically faster than with the midair gestures ($p < 0.001$) and physical buttons ($p < 0.001$). Moreover, text input with the midair gestures is faster than with physical buttons ($p < 0.001$).

As for the text difficulty, we found that it took the shortest amount of time for cyclists to enter the shortest text ($M = 34sec, SD = 25$), followed by medium ($M = 48sec, SD = 37$) and longest ($M = 64sec, SD = 46$). A statistically significant main effect confirmed this finding for the *text difficulty* ($F(2, 22) = 27, p < 0.001, \eta^2 = 0.71$) and all statistically significant pairwise comparisons ($p < 0.001$).

As for the statistically significant interaction effect for input method and text difficulty ($F(4, 44) = 14, p < 0.001, \eta^2 = 0.56$), we discovered that cyclists were slower entering the long text using buttons than the touch input ($p < 0.05$) and midair gestures ($p <$

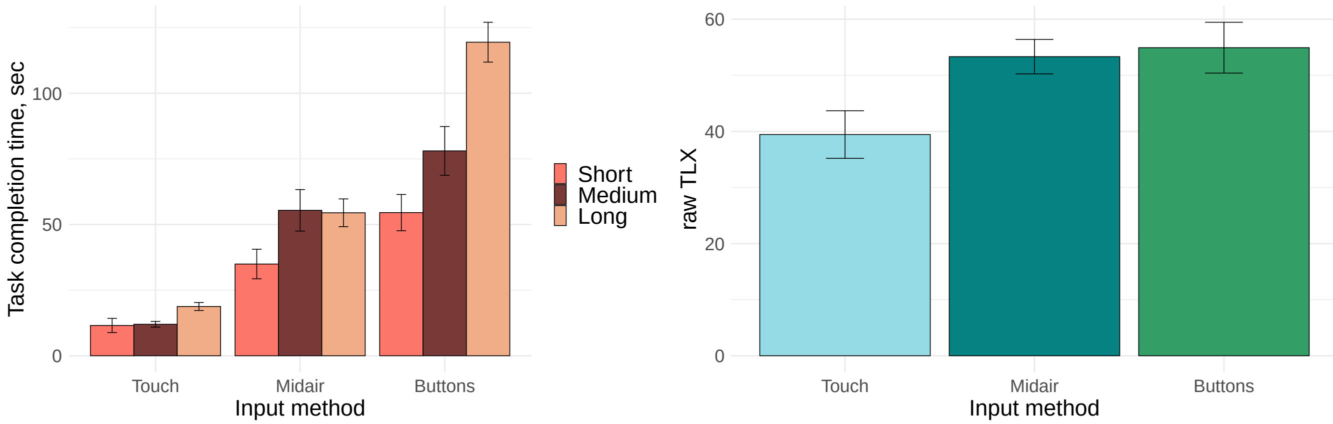

Figure 3: Overview of task completion times split by three text length (left) and raw TLX scores (right).

0.05). Moreover, entering long text using buttons takes longer than medium ($p < 0.01$) and short ($p < 0.01$) using physical buttons. We also discovered that cyclists were faster entering short text using touch input than long text using gestures ($p < 0.05$), short text using touch input ($p < 0.01$), and long text using touch input physical buttons ($p < 0.001$). Finally, we found that cyclists were faster at entering short text using touch input than medium text using physical buttons ($p < 0.05$). The remaining pairwise comparisons were not statistically significant ($p > 0.05$). The summary of results is shown in Figure 3 left.

4.2 Error Rate

We found that using touch input cyclists entered text faultlessly most of the time (N = 33) and entered it with 1 or 2 errors three times over all three types of text length. There were no mistakes for the shortest text, two for the medium, and one for the long text. Cyclists made no mistakes using midair input for all text difficulty levels. Finally, a few cyclists (N = 4) entered text perfectly using physical buttons. The majority made 1-2 errors (N = 15), could write an understandable text (N = 9), few participants (N = 2) wrote understandable words, and some (N = 6) cyclists wrote the unreadable text. Using buttons, two participants made no mistakes when entering a short text, one participant made no mistakes for a medium text, and none entered the text without mistakes for the long text.

4.3 Perceived Workload

As for the raw task load score, we found that entering text with touch input was the least mentally demanding activity ($M = 39, SD = 15$), followed by midair ($M = 53, SD = 11$) and physical buttons ($M = 55, SD = 16$) (Figure 3 right). Using Friedman's test, we discovered that this difference was statistically significant ($\chi^2(2) = 7.8, p < 0.05, \eta^2 = 0.33$). The post-hoc analysis has shown that the touch input was statistically less mentally demanding than midair gestures ($p < 0.01$) and physical buttons ($p < 0.01$). However, there was no statistically significant difference between the midair gestures and physical buttons ($p > 0.05$).

4.4 Qualitative Feedback

When asked about the ease of use, most of the participants (N = 10) mentioned that the touch input was the easiest, followed by midair (N = 1) and physical buttons (N = 1). Cyclists justified their ranking decisions for the touch input based on their experience. As one of the participants noted: *"It is very common to me for type on a smartphone, therefore easy to comprehend and use, even on a bike"* [P6]. However, participants also mentioned that they felt distracted by road traffic and did not like the occupation of one hand. For instance, some of them commented: *"One hand was occupied"* [P1] and *"Much time I am not looking on the road, because I had to look on the phone"* [P6].

As for the midair input, participants liked it because it was easy to use, looked at the road, and the keyboard was in a known layout. As some of the participants mentioned: *"[midair] uses the keyboard, known input because of daily use"* [P3], *"Cool idea [...], enables you to see traffic while typing"* [P6], and *"You have a full keyboard at your disposal"* [P8]. On the other side, cyclists disliked that midair input is mentally demanding and distracting, lacks accuracy, and is sometimes difficult to use. For example, some participants mentioned that *"Using it was unfamiliar to me, so I could not focus on the road the way I would have had to in a real situation."* [P4], *"The clanky controls of the Hololens and the onscreen keyboard, the keyboard would appear in a different location every time I had to type a new phrase so that I had to adjust it every time. Also, text input often would not be recognized, so I end up with a different phrase than I wanted."* [P6], and *"I could not concentrate on the road. In order to hit the keys, you have to move your fingers very precisely, which is impossible in an environment like the bike."* [P8].

As for the physical button input, cyclists liked it because one keeps the handlebar in the hands the whole time, it was intuitive and less distracting since one could feel the buttons without looking at them, and it was easy to learn. As some participants mentioned: *"It was fast to learn, you have both hands on the handlebars and you could concentrate on the road more."* [P8], *"You do not have to see which button you press"* [P11], and *"It was fun and straightforward to use"* [P7]. However, participants noted issues with latency, difficulty reaching the buttons, and difficulty using them without training.

For example, they commented that: *"slow reaction, button hard to reach"* [P1], *"requires some experience and memorization of the actual keyboard layout"* [P12], and *"Not used to it, therefore a bit frustrating"* [P3].

5 DISCUSSION AND FUTURE WORK

In general, we discovered that text input via touch input was faster and less mentally demanding than input from midair and via physical buttons. However, midair gestures were the least error-prone compared to the other two methods. Finally, cyclists indicated that they preferred physical button input because it made it easier to keep both hands on the handlebars the entire time and was an intuitive and less distracting interaction.

The data gathered from the experiment indicates a design opportunity to replace the direct touch input on a smartphone with additional (potentially indirect) text input methods. We assume that the biggest advantage of a touch input outperforming the other two methods in task completion time and mental load lies in the participants' higher familiarity with this input method and years of experience using it. Given the current design of the input methods, entering short messages using physical buttons takes a comparable amount of time using a midair keyboard for medium and long messages. Therefore, alternative text input methods for physical buttons should have prepared the most frequently used phrases or include an auto-complete function to improve the efficiency of text input future. This could reduce the number of clicks and ensure holding both hands on the handlebar. It is also important to note that buttons-based input had technical limitations that led to issues with latency and longer input times compared to other two methods. Although none of the participants had experience with using physical buttons attached to the handlebar for text input, they mentioned that they could easily learn the layout, which indicates that physical buttons can be an efficient alternative for input while cycling. As for the midair input, participants liked that they could use a familiar qwerty keyboard layout but it requires a long time to enter text. Therefore, similarly to physical buttons input, future designs should consider word-based rather letter-based input and offer an auto-complete function. Another advantage of the midair input lies on the fact that it increases awareness of other road users that cyclists' focus might be fully concentrated on the road.

All in all, our empirical evaluation provides a preliminary glimpse into the performance of alternative text input methods for cyclists. Furthermore, we provide a better understanding of hand-based text input methods in terms of task completion time, error rates, and perceived workload. It shows that midair and physical buttons can be employed with additional design considerations. Possible next steps for future work could be to explore word-based input rather than letter-based one or even utilize an auto-complete function. Within the scope of our experiment, we focused on the interaction under safe but artificial conditions in the indoor bicycle simulator. Therefore, going outdoors on tandem-based simulators [20, 21] would be a logical next step to facilitate safe but more realistic interaction conditions. Lastly, future work should consider running long-term in-the-wild studies with different age groups to understand cyclists' interaction under various traffic and weather conditions.

6 CONCLUSION

In this paper, we investigated text input methods for cyclists to facilitate safe interaction on the go. The results from our evaluation indicate that text input via touch input was faster and less mentally demanding than input with midair gestures and physical buttons. However, midair gestures were the least error-prone, and physical buttons made it easier to keep both hands on the handlebars and were more intuitive and less distracting. With this work, we contribute an empirical evaluation of text input methods for cyclists on the go.

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REFERENCES

[1] Anthony Carton. 2012. Design of a Context Aware Signal Glove for Bicycle and Motorcycle Riders. In *Proceedings of the 2012 ACM Conference on Ubiquitous Computing* (Pittsburgh, Pennsylvania) *(UbiComp '12)*. Association for Computing Machinery, New York, NY, USA, 635–636. https://doi.org/10.1145/2370216.2370341

[2] Alexandru Dancu, Zlatko Franjcic, and Morten Fjeld. 2014. Smart Flashlight: Map Navigation Using a Bike-Mounted Projector. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Toronto, Ontario, Canada) *(CHI '14)*. Association for Computing Machinery, New York, NY, USA, 3627–3630. https://doi.org/10.1145/2556288.2557289

[3] Alexandru Dancu, Velko Vechev, Adviye Ayça Ünlüer, Simon Nilson, Oscar Nygren, Simon Eliasson, Jean-Elie Barjonet, Joe Marshall, and Morten Fjeld. 2015. Gesture Bike: Examining Projection Surfaces and Turn Signal Systems for Urban Cycling. In *Proceedings of the 2015 International Conference on Interactive Tabletops & Surfaces* (Madeira, Portugal) *(ITS '15)*. Association for Computing Machinery, New York, NY, USA, 151–159. https://doi.org/10.1145/2817721.2817748

[4] Dick De Waard, Ben Lewis-Evans, Bart Jelijs, Oliver Tucha, and Karel Brookhuis. 2014. The effects of operating a touch screen smartphone and other common activities performed while bicycling on cycling behaviour. *Transportation Research Part F: Traffic Psychology and Behaviour* 22 (2014), 196–206. https://doi.org/10.1016/j.trf.2013.12.003

[5] Dick de Waard, Paul Schepers, Wieke Ormel, and Karel Brookhuis. 2010. Mobile phone use while cycling: Incidence and effects on behaviour and safety. *Ergonomics* 53, 1 (2010), 30–42. https://doi.org/10.1080/00140130903381180 PMID: 20069479.

[6] Jennifer Dill and Theresa Carr. 2003. Bicycle Commuting and Facilities in Major U.S. Cities: If You Build Them, Commuters Will Use Them. *Transportation Research Record* 1828, 1 (2003), 116–123. https://doi.org/10.3141/1828-14 arXiv:https://doi.org/10.3141/1828-14

[7] Weixi Gu, Yunxin Liu, Yuxun Zhou, Zimu Zhou, Costas J. Spanos, and Lin Zhang. 2017. BikeSafe: Bicycle Behavior Monitoring via Smartphones. In *Proceedings of the 2017 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2017 ACM International Symposium on Wearable Computers* (Maui, Hawaii) *(UbiComp '17)*. Association for Computing Machinery, New York, NY, USA, 45–48. https://doi.org/10.1145/3123024.3123158

[8] Lucas Harms, Luca Bertolini, and Marco te Brömmelstroet. 2014. Spatial and social variations in cycling patterns in a mature cycling country exploring differences and trends. *Journal of Transport & Health* 1, 4 (2014), 232–242. https://doi.org/10.1016/j.jth.2014.09.012 Walking & Cycling: The contributions of health and transport geography.

[9] Sandra G Hart and Lowell E Staveland. 1988. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In *Advances in psychology*. Vol. 52. Elsevier, 139–183.

[10] Graeme Horsman and Lynne R. Conniss. 2015. Investigating evidence of mobile phone usage by drivers in road traffic accidents. *Digital Investigation* 12 (2015), S30–S37. https://doi.org/10.1016/j.diin.2015.01.008 DFRWS 2015 Europe.

[11] Brianna Jean Huxtable, Carlo Ka-Ho Lai, Johnson Wen Jun Zhu, Paulina Mun-Yee Lam, Yeseul Tracy Choi, Carman Neustaedter, and Greg J. Corness. 2014. Ziklo: Bicycle Navigation through Tactile Feedback. In *CHI '14 Extended Abstracts on Human Factors in Computing Systems* (Toronto, Ontario, Canada) *(CHI EA '14)*. Association for Computing Machinery, New York, NY, USA, 177–178. https://doi.org/10.1145/2559206.2579481

[12] Kang Jiang, Zhiwei Yang, Zhongxiang Feng, N.N. Sze, Zhenhua Yu, Zhipeng Huang, and Jiajia Chen. 2021. Effects of using mobile phones while cycling: A study from the perspectives of manipulation and visual strategies. *Transportation*

Research Part F: Traffic Psychology and Behaviour 83 (2021), 291–303. https://doi.org/10.1016/j.trf.2021.10.010

[13] Shaun K. Kane, Jacob O. Wobbrock, and Ian E. Smith. 2008. Getting off the Treadmill: Evaluating Walking User Interfaces for Mobile Devices in Public Spaces. In *Proceedings of the 10th International Conference on Human Computer Interaction with Mobile Devices and Services* (Amsterdam, The Netherlands) *(MobileHCI '08)*. Association for Computing Machinery, New York, NY, USA, 109–118. https://doi.org/10.1145/1409240.1409253

[14] Thomas Kosch, Andrii Matviienko, Florian Müller, Jessica Bersch, Christopher Katins, Dominik Schön, and Max Mühlhäuser. 2022. NotiBike: Assessing Target Selection Techniques for Cyclist Notifications in Augmented Reality. *Proc. ACM Hum.-Comput. Interact.* 6, MHCI, Article 197 (sep 2022), 24 pages. https://doi.org/10.1145/3546732

[15] Joe Marshall, Alexandru Dancu, and Florian "Floyd" Mueller. 2016. Interaction in Motion: Designing Truly Mobile Interaction. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems* (Brisbane, QLD, Australia) *(DIS '16)*. Association for Computing Machinery, New York, NY, USA, 215–228. https://doi.org/10.1145/2901790.2901844

[16] Andrii Matviienko, Swamy Ananthanarayan, Shadan Sadeghian Borojeni, Yannick Feld, Wilko Heuten, and Susanne Boll. 2018. Augmenting Bicycles and Helmets with Multimodal Warnings for Children. In *Proceedings of the 20th International Conference on Human-Computer Interaction with Mobile Devices and Services* (Barcelona, Spain) *(MobileHCI '18)*. Association for Computing Machinery, New York, NY, USA, Article 15, 13 pages. https://doi.org/10.1145/3229434.3229479

[17] Andrii Matviienko, Swamy Ananthanarayan, Stephen Brewster, Wilko Heuten, and Susanne Boll. 2019. Comparing Unimodal Lane Keeping Cues for Child Cyclists. In *Proceedings of the 18th International Conference on Mobile and Ubiquitous Multimedia* (Pisa, Italy) *(MUM '19)*. Association for Computing Machinery, New York, NY, USA, Article 14, 11 pages. https://doi.org/10.1145/3365610.3365632

[18] Andrii Matviienko, Swamy Ananthanarayan, Abdallah El Ali, Wilko Heuten, and Susanne Boll. 2019. NaviBike: Comparing Unimodal Navigation Cues for Child Cyclists. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3290605.3300850

[19] Andrii Matviienko, Swamy Ananthanarayan, Raphael Kappes, Wilko Heuten, and Susanne Boll. 2020. Reminding Child Cyclists about Safety Gestures. In *Proceedings of the 9TH ACM International Symposium on Pervasive Displays* (Manchester, United Kingdom) *(PerDis '20)*. Association for Computing Machinery, New York, NY, USA, 1–7. https://doi.org/10.1145/3393712.3394120

[20] Andrii Matviienko, Hajris Hoxha, and Max Mühlhäuser. 2023. What does it mean to cycle in Virtual Reality? Exploring Cycling Fidelity and Control of VR Bicycle Simulators. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA. https://doi.org/10.1145/3544548.3581050

[21] Andrii Matviienko, Damir Mehmedovic, Florian Müller, and Max Mühlhäuser. 2022. "Baby, You Can Ride My Bike": Exploring Maneuver Indications of Self-Driving Bicycles Using a Tandem Simulator. *Proc. ACM Hum.-Comput. Interact.* 6, MHCI, Article 188 (sep 2022), 21 pages. https://doi.org/10.1145/3546723

[22] Andrii Matviienko, Florian Müller, Dominik Schön, Paul Seesemann, Sebastian Günther, and Max Mühlhäuser. 2022. BikeAR: Understanding Cyclists' Crossing Decision-Making at Uncontrolled Intersections Using Augmented Reality. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 366, 15 pages. https://doi.org/10.1145/3491102.3517560

[23] Andrii Matviienko, Florian Müller, Marcel Zickler, Lisa Alina Gasche, Julia Abels, Till Steinert, and Max Mühlhäuser. 2022. Reducing Virtual Reality Sickness for Cyclists in VR Bicycle Simulators. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 187, 14 pages. https://doi.org/10.1145/3491102.3501959

[24] Justin Mittelstaedt, Jan Wacker, and Dirk Stelling. 2018. Effects of display type and motion control on cybersickness in a virtual bike simulator. *Displays* 51 (2018), 43–50. https://doi.org/10.1016/j.displa.2018.01.002

[25] Sara Nygårdhs, Christer Ahlström, Jonas Ihlström, and Katja Kircher. 2018. Bicyclists' adaptation strategies when interacting with text messages in urban environments. 20, 3 (2018), 377–388. https://doi.org/10.1007/s10111-018-0478-y

[26] Martin Pielot, Benjamin Poppinga, Wilko Heuten, and Susanne Boll. 2012. Tacticycle: Supporting Exploratory Bicycle Trips. In *Proceedings of the 14th International Conference on Human-Computer Interaction with Mobile Devices and Services* (San Francisco, California, USA) *(MobileHCI '12)*. Association for Computing Machinery, New York, NY, USA, 369–378. https://doi.org/10.1145/2371574.2371631

[27] Sasank Reddy, Katie Shilton, Gleb Denisov, Christian Cenizal, Deborah Estrin, and Mani Srivastava. 2010. Biketastic: Sensing and Mapping for Better Biking. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Atlanta, Georgia, USA) *(CHI '10)*. Association for Computing Machinery, New York, NY, USA, 1817–1820. https://doi.org/10.1145/1753326.1753598

[28] Duncan Rowland, Martin Flintham, Leif Oppermann, Joe Marshall, Alan Chamberlain, Boriana Koleva, Steve Benford, and Citlali Perez. 2009. Ubikequitous Computing: Designing Interactive Experiences for Cyclists. In *Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services* (Bonn, Germany) *(MobileHCI '09)*. Association for Computing Machinery, New York, NY, USA, Article 21, 11 pages. https://doi.org/10.1145/1613858.1613886

[29] Gian-Luca Savino, Jessé Moraes Braga, and Johannes Schöning. 2021. VeloCity: Using Voice Assistants for Cyclists to Provide Traffic Reports. In *Proceedings of the 29th ACM International Conference on Multimedia* (Virtual Event, China) *(MM '21)*. Association for Computing Machinery, New York, NY, USA, 3482–3491. https://doi.org/10.1145/3474085.3475509

[30] Patrick A. Singleton. 2019. Walking (and cycling) to well-being: Modal and other determinants of subjective well-being during the commute. *Travel Behaviour and Society* 16 (2019), 249–261. https://doi.org/10.1016/j.tbs.2018.02.005

[31] Gábor Sörös, Florian Daiber, and Tomer Weller. 2013. Cyclo: A Personal Bike Coach through the Glass. In *SIGGRAPH Asia 2013 Symposium on Mobile Graphics and Interactive Applications* (Hong Kong, Hong Kong) *(SA '13)*. Association for Computing Machinery, New York, NY, USA, Article 99, 4 pages. https://doi.org/10.1145/2543651.2543660

[32] Haska Steltenpohl and Anders Bouwer. 2013. Vibrobelt: Tactile Navigation Support for Cyclists. In *Proceedings of the 2013 International Conference on Intelligent User Interfaces* (Santa Monica, California, USA) *(IUI '13)*. Association for Computing Machinery, New York, NY, USA, 417–426. https://doi.org/10.1145/2449396.2449450

[33] Velko Vechev, Alexandru Dancu, Simon T. Perrault, Quentin Roy, Morten Fjeld, and Shengdong Zhao. 2018. Movespace: On-Body Athletic Interaction for Running and Cycling. In *Proceedings of the 2018 International Conference on Advanced Visual Interfaces* (Castiglione della Pescaia, Grosseto, Italy) *(AVI '18)*. Association for Computing Machinery, New York, NY, USA, Article 28, 9 pages. https://doi.org/10.1145/3206505.3206527

[34] Wouter Walmink, Danielle Wilde, and Florian 'Floyd' Mueller. 2014. Displaying Heart Rate Data on a Bicycle Helmet to Support Social Exertion Experiences. In *Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction* (Munich, Germany) *(TEI '14)*. Association for Computing Machinery, New York, NY, USA, 97–104. https://doi.org/10.1145/2540930.2540970

[35] Philipp Wintersberger, Andrii Matviienko, Andreas Schweidler, and Florian Michahelles. 2022. Development and Evaluation of a Motion-based VR Bicycle Simulator *(MobileHCI '22)*. Association for Computing Machinery, New York, NY, USA. https://doi.org/10.1145/3546745

[36] Paweł W. Woźniak, Lex Dekker, Francisco Kiss, Ella Velner, Andrea Kuijt, and Stella F. Donker. 2020. Brotate and Tribike: Designing Smartphone Control for Cycling. In *22nd International Conference on Human-Computer Interaction with Mobile Devices and Services* (Oldenburg, Germany) *(MobileHCI '20)*. Association for Computing Machinery, New York, NY, USA, Article 23, 12 pages. https://doi.org/10.1145/3379503.3405660