Navigation Systems for Motorcyclists: Exploring Wearable Tactile Feedback for Route Guidance in the Real World

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ABSTRACT
Current navigation systems for motor cyclists use visual or auditory cues for guidance. However, this poses a challenge to the motorcyclists since their visual and auditory channels are already occupied with controlling the motorbike, paying attention to other road users, and planing the next turn. In this work, we explore how tactile feedback can be used to guide motorcyclists. We present MOVING (MOtorbike VIbrational Navigation Guidance), a smart kidney belt that presents navigation cues through 12 vibration motors. In addition, we report on the design process of this wearable and on an evaluation with 16 participants in a real world riding setting. We show that MOVING outperforms off-the-shelf navigation systems in terms of turn errors and distraction.

Author Keywords
Tactile feedback; motorcycle navigation; real world evaluations.

ACM Classification Keywords
H.5.2. Information Interfaces and Presentation (e.g. HCI): User Interfaces

INTRODUCTION
Current navigation systems mainly use visual or auditory cues to present turn-by-turn instructions to users. This approach works particularly well while driving a car or walking through the city center. However, riding a motorbike is a cognitively and physically exhausting task and a particularly dangerous mode of transportation [4]. Motorbikes are not always perceived by other road users which is especially an issue at intersections. This leads to the necessity of motorcyclists being very careful and observing other road users. Focusing on a display while driving substantially increases the eyes-off-the-road time. In addition, motorcyclists particularly prefer curvy roads. Driving such roads is challenging for their driving skills and poses a high cognitive load since they have to assess the next turn and plan their optimal path. In addition, auditive feedback is challenging since the motorbike is a much less confined environment in comparison to the interior of a car. All this makes listening to the navigation system and looking at the display – thus, interacting in motion [11, 12] – dangerous for motorcyclists.

Figure 1. The MOVING system consists of a kidney belt with 12 integrated vibration motors controlled through a mobile phone application.

A solution to that is the use of navigation systems that provide tactile feedback as navigation cues. Such systems have been proposed to be included for instance in gloves [3] or vests [15]. However, the performance of these systems has mainly been evaluated in controlled lab settings or in cordoned-off areas. While these studies identified important aspects of tactile feedback for motorcyclists, the unique properties of motorbikes, such as the high amount of vibration, pose additional challenges on such systems. Thus, an evaluation in a real world environment is necessary to understand if this approach is beneficial compared to off-the-shelf navigation systems.

To evaluate the on-body placement for tactile feedback, we first report on a study measuring the vibration that is transferred from the motorbike to the motorcyclist with the goal to find the location of lowest vibration. Based on our findings, we then

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built MOVING– a tactile kidney belt that provides navigational cues through vibration motors. In a real world driving study (N=16), we evaluated this belt and compared it with an off-the-shelf navigation system. We show that MOVING outperforms the other device in terms of observed turn errors.

CONTRIBUTION

The contribution of our paper is twofold. First, we report on the design of a tactile navigation system integrated in a kidney belt – called MOVING – including a pre-study investigating the vibrations a motorcyclist perceives while driving on various roads. Second, we report on a user study comparing tactile and audio-visual feedback in a real world driving study.

RELATED WORK

Tactile feedback for navigating people has been explored in various contexts. Starting with pedestrian navigation [13], researchers created different types of tactile belts (e.g., [10, 18]). Vibration motors are placed around the torso and the motor that is actuated indicates the direction the user needs to take. Asif et al. used haptic feedback for navigation while driving a car [2]. They also used a waist belt to convey feedback similar to the previously mentioned pedestrian navigation system. By testing their system in real world traffic, they show the overall feasibility of their approach [1]. In contrast to that, van Erp and van Veen integrated vibration motors into the driver's seat [19]. Particularly in high workload conditions, they show that tactile feedback outperforms visual feedback with respect to reaction time and mental effort. Pielot et al. propose integrating tactile feedback into the handle bar of bicycles [14]. In contrast to that, Bial et al. used gloves with integrated tactile feedback [3]. In a lab study, they showed that different types of feedback can be differentiated. However, in a real world exploration with motorbikes, they found this feedback hardly differentiable. The main reason for that is the existing level of vibrations at the handlebar of motorbikes. The HaptiMoto project uses a vest with integrated vibration motors to present navigation cues to motorcyclists [15]. They integrated three vibration motors (left, center, and right) to communicate left, right, straight, and U-turn maneuvers and explored the detectability of these signals in low speed conditions (i.e., 20-25 mph). In contrast to HaptiMoto, we investigate tactile feedback in a real world scenario with various speed levels (e.g., inner city, rural roads, and motorways) and in realistic traffic environments. This forces the motorcyclists to pay attention to the environment and not only to the feedback presented to them.

SAFETY AND ETHICS

We conducted two user studies in which we asked motorcyclists to drive their motorbike in real world traffic to have a highly realistic setup. We only recruited motorcyclists with a valid license to drive a motorbike and who had at least two years of riding experience. In addition, we only scheduled rides during daytime at days without rainfall. Furthermore, participants used their own bikes so they did not need to familiarize themselves with a new motorbike. Prior to each drive, we carefully instructed the participants. We highlighted that they should ride their motorbike in a way that they follow the local traffic code and do not harm themselves or others. In addition, we performed test runs for each participant with the attached wearables so that they could get used to the form factor and feedback. These test runs were conducted on an empty parking lot without any traffic. After participants felt comfortable, we started with the actual drive. The experimenter followed the participant on his own motorcycle. We received ethical approval for our project from the local ethics board.

STUDY: INVESTIGATING ON-BODY LOCATIONS

While driving a motorbike, the vibration of the engine is almost directly transferred to the motorcyclist. Depending on the different factors such as the current driving style, the motorbike, or the motorcyclist's posture, these vibrations are perceived differently on various parts of the body. Related work indicates that other tactile stimuli might lead to a lesser chance of perceiving the navigational cue for the motorcyclist [7]. Thus, we first explored different on-body locations to understand which locations are best suited for providing tactile navigational cues. In order to do so, we built a measuring device consisting of ten accelerometers. We used this device to conduct a user study in which we measured the vibration patterns at ten parts of the motorcyclist's body.

Vibration Measurement Device

We built a vibration measurement device which uses ten MEMS-accelerometers (ADXL3452) connected to an Arduino board. Each accelerometer was integrated into a 3D-printed enclosure. We symmetrically attached the ten accelerometers at selected body parts of the motorcyclist as shown in Figure 3. We chose these locations based on related work that already explored tactile feedback for motorcyclists (e.g., [3, 10, 15]) and other aspects such as wearability [8]. For that, we attached four of the accelerometers to straps. These straps are designed to fit on the wrists and lower calves of the motorcyclist. We attached the other six accelerometers to a compression t-shirt at the waist, shoulder, and arm. In combination with the rider's biking gear and kidney belt, this helped to press all sensors against the rider's body. The sampled data is sent via Bluetooth to a mobile phone and stored in combination with a time-stamp and the current GPS location for a post-hoc analysis.

Participants and Procedure

We recruited five participants (all male) aged between 25 and 66 years ($M = 33.2$ years, $SD = 18.34$ years) through mailing lists and personal contacts for our study. All participants used their own motorcycles. The participant's motorbikes were all 4-stroke engines, with one two-cylinder, two three-cylinder, and two four-cylinder motorbikes. On average, the motorbikes had 95.6 hp ($SD = 25.3$ hp).

After participants arrived at the lab, we informed them about the purpose of the user study and handed out consent forms. Next, we equipped the participants with the measurement device (i.e., straps, t-shirt, and mobile phone). We chose a route covering various road types similar to the work of Schneegass et al. [16] to cover patterns that might be specific for certain road types. Overall, the length of the route is 35 km and takes about 40 minutes (cf., Figure 2). The experimenter accompanied (i.e., followed) each participant on his own motorcycle.

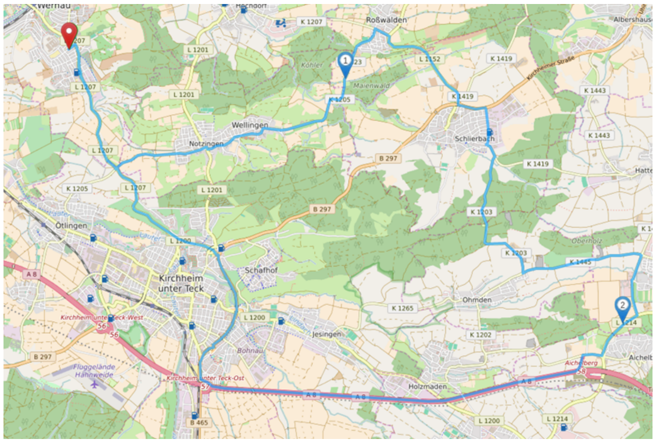

Figure 2. Selected route used for the study to investigate appropriate on-body locations for tactile feedback. (Map © OpenStreetMap contributors – tiles CC-BY-SA, https://www.openstreetmap.org/copyright)

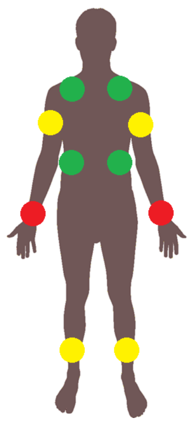

Figure 3. Tested on-body locations used to investigate appropriate on-body locations for tactile feedback (i.e., locations with only little ride-based vibrations). The colors indicate the suitability of each location: Ride-based vibration is lowest at the hips, followed by shoulders, calf, arm, and wrist.

Results

We calculated the jerk (i.e., the derivative of the acceleration) of all three axes combined as a measure of the strength of the vibration [9]. The higher the jerk, the more vibration is perceived by the user at a specific body location. Figure 3 depicts the average jerk for each body location. The results show that the waist is the location with least vibration ($M = 1.86\,\mathrm{m/s^3}$), followed by the shoulders ($M = 1.92\,\mathrm{m/s^3}$). The highest jerk was measured at the calf ($M = 2.84\,\mathrm{m/s^3}$), arm ($M = 3.50\,\mathrm{m/s^3}$), and wrist ($M = 4.81\,\mathrm{m/s^3}$). Thus, smart watches do not seem to be suitable devices for providing feedback while riding a motorcycle. The type of road also influences the results: Roads with particularly bad pavement generated more vibration. This was the case for the freeway and a back road, both roads that are in need of renovation.

PROTOTYPE: MOVING – A TACTILE KIDNEY BELT

Based on our findings from the study to investigate on-body locations, we developed MOVING (MOtorbike VIbrational Navigation Guidance) a smart kidney belt capable of providing tactile navigation cues through vibration motors. The system consists of a kidney belt with 12 integrated vibration motors (cf., Figure 1). The vibration motors are connected to an Arduino Nano. We use the Android based motorbike navigation App *Kurviger Pro*[1] that sends Android system Intents[2] for each navigation cue. The MOVING application listens to these intents and forwards them via Bluetooth to the Arduino board that generates vibrations accordingly.

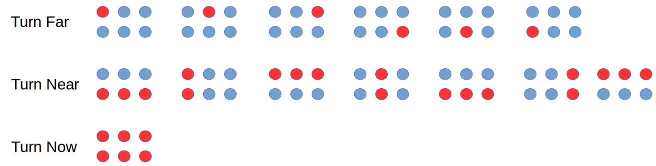

Figure 4. The vibration motor activation order of MOVING. A red dot shows an enabled vibration motor and a blue dot shows an idle vibration motor.

Vibration Motor Placement

As described in the previous section, we conducted a study to investigate the optimal on-body location with least vibrations for placing the vibration motors. The results show that shoulders and waist are the areas with least vibration. Since we opted for a tight fit of the vibration motors, we chose the waist and, thus, used a kidney belt to integrate the system. We explored various layout pattern for the vibration motors throughout the development process of MOVING. Related work either used a single vibration motor per side [15] or a set of vibration motors distributed around the body [10]. In a first version, we used an array of 2 by 1 vibration motors on both sides. Compared to related work [15], this approach provides a higher intensity. Since we wanted to provide different feedback pattern, we integrated an array of 2 by 3 vibration motors on both sides. Thus, we could communicate information not only by changing the intensity but also by enabling subsets of these vibration motors. These feedback patterns can be designed in a way that they are easier to perceive compared to changes in the intensity [2].

Feedback Pattern

Since we include six vibration motors at each side we are able to design different patterns. We integrate three different turn pattern in order to communicate three different distances (cf., Figure 4). As related work suggest, we strive to vary the rhythm and intensity to create differentiable patterns [2]. For turns which are *far* away, we use a pattern that triggers single vibration motors one after another in a circular manner (cf., Figure 4 – top). Each vibration impulse lasts 500 ms with breaks of 75 ms in between. The pattern is repeated two times. When the user approaches the turn, the *near* pattern starts, which uses two to three motors at a time as shown in Figure 4 – middle. Here, each vibration impulse lasts 300 ms with breaks of 75 ms in between. Again, this pattern is repeated two times. If the user reaches the turn, one vibration impulse for all six vibration motors on the corresponding side is triggered (cf.,

[1] https://play.google.com/store/apps/details?id=gr.talent.kurviger.pro

[2] i.e., broadcast messages that describe the operations to be performed

Figure 4 – bottom). This impulse lasts for 1700 ms in total. While the far pattern creates a circular motion, the near pattern creates a vertical motion and feels like a turn indicator. The now pattern has no motion at all. Thus, every pattern uses a different orientation of motion, different rhythm, different intensity, and different duration.

Additionally, we provide a pattern to notify the user about *roundabouts* and which exit to take. Roundabout instructions do not need a distance encoding since the user drives towards the roundabout and only needs to know which exit to take. In this case, MOVING vibrates on both sides with all motors with pulses of 500 ms duration and breaks of 500 ms in between. The number of pulses is equal to the exit to take. For example, two pulses mean that the rider has to take the second exit. This pattern is presented at three distances as well, similar to the turn patterns.

Feedback Timing on the Road

As described before, we use three classes of turn instructions: On the road, the *far* signal is presented between 750 m and 1,500 m before a turn. Next, the *near* signal is issued about 250 m before the intersection. Around 70 m before the intersection, the *turn now* signal is presented. Theses classes are adopted from the classification of level crossings by Fukuda et al. [6]. We worked closely with the vendor of the navigation software to ensure that the instruction notifications are consistently presented for every turn.

REAL WORLD DRIVING STUDY

We conducted a real world driving study in which we compared MOVING to an off-the-shelf (visual) navigation system.

Design

The study took place on real roads around Stuttgart (see Figure 5) during regular traffic to provide a highly realistic setting for the evaluation. We particularly focus on the number of navigation errors the motorcyclists make as our main measure to decide whether tactile or visual navigation instructions are less error-prone. We used a within-subjects design, with the navigation cue (tactile and visual) being the independent variable. The participants followed two equivalent routes, one for each condition. The conditions were counterbalanced for the routes among all participants while the order of the routes was the same for all participants.

Participants

We recruited 16 participants (14 male, 2 female) aged between 18 and 66 years ($M = 34.5$ years, $SD = 15.4$ years). All of them had at least two years of driving experience (maximum: 37 years, $M = 11.9$ years, $SD = 11.7$ years) and ride their motorcycles between 1,000 km and 15,000 km per year ($M = 5,968$ km, $SD = 3,626$ km). Ten of the participants use navigation systems while riding their motorbike: eight of them used visual-only systems, while the other two relied on systems that provide only auditory instructions. The participants used their own motorbikes. Each participant received a compensation of 15 €.

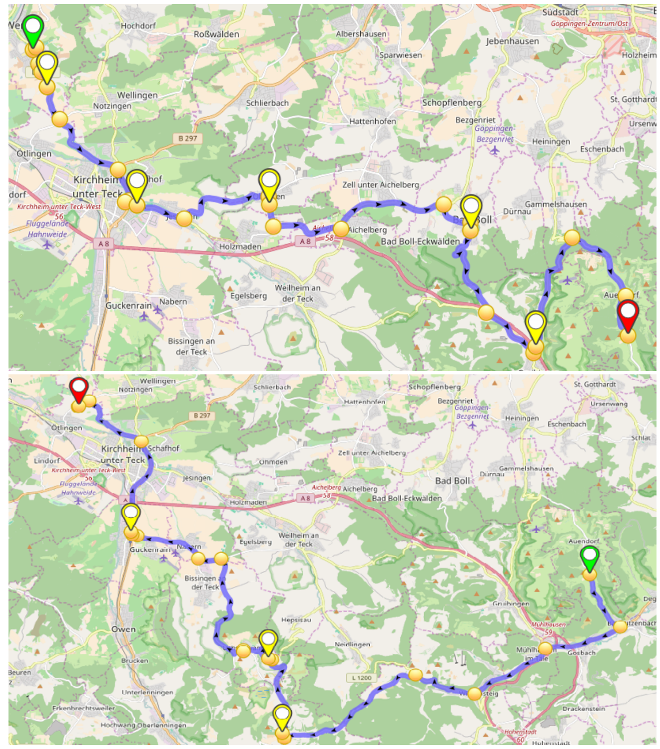

Figure 5. The two routes used for the evaluation of our prototype. Each participant drove both routes with a counterbalanced order of navigation cues. The green markers indicate the start, the red markers the finish. The yellow dots indicate the most important waypoints where navigation cues were provided. (Map © OpenStreetMap contributors – tiles CC-BY-SA, https://www.openstreetmap.org/copyright)

Routes

To evaluate both feedback methods, participants were asked to ride along two routes, one for each condition (see Figure 5). To ensure that participants were not able to predict the next turn, we did not chose the same streets in both routes. The second route starts were the first one ends, and its finish is somewhat near the starting point. Nevertheless, both routes have similar characteristics. The altitude variation is the same and the number and type of left and right turns are fairly similar. Although an exact equality between routes was impossible to ensure, we are confident that the two selected routes are similar enough, and that the counterbalancing of the conditions compensates any possible effect due to the difference between both routes. Thus, half of the participants used tactile cues on the first and visual cues on the second route and the other half used visual cues on the first and tactile cues on the second route. The ride time for each of the two routes was about 38-40 minutes.

Procedure and Apparatus

We instructed the participants to follow the traffic rules and signs on the road at all times, always overruling any indication provided by the navigation systems in case of conflicts. The participants were strongly advised to stop at a safe parking space whenever they felt unwell or uncertain (e.g., about a navigation cue), without risking a penalty from our side.

We mounted a smartphone on the participant's motorbike to display the navigation system (i.e., running the Kurviger Pro on this phone), as well as to host the MOVING's application. We also mounted a GoPro camera to record the events along the participant's ride.

The navigation system was a regular motorbike navigation software that is commonly used by motorcyclists. This system was used in both conditions. In the *visual* condition, the drivers were allowed to look at the visual output of the App. In the *tactile* condition, the screen was covered to prevent glances onto the map. However, the App was still used to provide the (originally visual) navigation cues that were then converted to vibration cues by the MOVING system. Since MOVING monitors the Android application Intents provided by the navigation App and uses this as a basis for the vibration cues, we ensured that instructions were given at the same location for both conditions. While using MOVING in the tactile condition, we covered the phone display to ensure that the vibrations are the only navigational feedback the participants perceived. We used the timing of the navigation cues as described in the prototype section.

After obtaining the participant's informed consent, the experiment started by introducing the first type of navigation cue; visual or tactile, depending on the particular condition for each participant. The participant was then asked to try out the system as long as necessary to feel comfortable using it. Once the participant fully understood how the navigation system works and how the navigation cues look like, we asked them to ride a short test route. This area was specifically cordoned off and isolated from general transit to ensure safe conditions when getting accustomed to the system. Once the participants expressed full confidence on their use of the corresponding navigation tool, they started with the first route. The experimenter followed the participant on his own motorbike, in case the participant needed any assistance. Whenever the participants made a turning error, the experimenter signaled them to turn around at a safe location and get back to the correct route.

The first route ended at a parking lot that allowed to switch the systems. At this point, we introduced the other navigation system for the second condition. Again, we instructed participants to test the navigation method until fully understand its functioning, and try it on the parking lot as long as desired, until feeling fully confident about its use. When the participants finished the tryout, they followed the second route, which led to the parking place where the experiment finishes. Also on this route, the participants were followed by the experimenter, in case any need of assistance or route correction was required.

After the participants performed the second ride, we conducted a semi-structured interview to also gather qualitative feedback on both types of navigation cues and on the amount of distraction caused by each interaction method.

Results

Overall, the participants made eleven turn mistakes using the off-the-shelf visual navigation system ($M = 0.69$, $SD = 1.08$) and one turn mistake using MOVING ($M = 0.06$, $SD = 0.25$). Since a Shapiro-Wilk test revealed non-normal distribution, we conducted a Wilcoxon-Pratt Signed-Rank test. The tests show that participants made statistically significant less turn errors using MOVING ($Z = 2.23$, $p = .01$). We do not see any specific patterns when and where navigation errors happened during both routes.

During the interview, 14 of the 16 participants stated to prefer MOVING. As main reasons, the participants mentioned a reduced level of distraction and as a consequence an improved capabilty to concentrate on the driving task and the road. Additionally, the participants liked that they did not have to take the eyes off the street. This was also identified as one major reason for missing a turn, namely when the drivers concentrated on the driving task, which made them forget to look at the navigation screen. Some participants stated that this happens frequently when using their own (visual) navigation devices as well.

As reasons for using visual off-the-shell navigation systems, the participants stated to have a better feeling of the distance until the next turn and being able to see the course of the next curve. When asked about the different vibration patterns, 15 of the 16 participants stated that it was easy to differentiate them from each other while riding the motorbike. All participants agreed that the visual system is more distracting compared to the vibration system and that they would use MOVING regularly.

When asked about auditive instructions, the participants which had used audio navigation on the motorcycle before indicated that the auditive modality is less preferred since they felt these audio instructions to be distracting and rather uncomfortable.

DISCUSSION

The experiment revealed that tactile navigation on a motorcycle is possible in real-world situations. Our results show that participants made fewer errors when using tactile navigation instructions compared to visual instructions. This is contrary to other experiments where tacile navigation was used in urban environments for bicycle navigation [17] as well as for pedestrian navigation [13]. However, we need to keep in mind that the navigation context of riding a motorcyle as we did in our experiment is clearly different with regard to turn complexity and ambiguity and frequency of turns.

Within the interviews, participants stated that both approaches yield their own advantages and disadvantages. The main advantage of a visual navigation system is that it provides a good overview of the upcoming turn maneuver but might be hard to perceive or even dangerous to use. Combining both approaches might yield the best results by having the visual cues as an additional modality to complement the tactile feedback. The participants also mentioned that the auditive channel is less preferred and considered to distract the driver and to be rather uncomfortable.

Limitations

Since we conducted the study in the wild, we were not able to create two fully identical routes. We chose the routes so that both include the same road types and took about equally long (40 minutes each). However, they still differ slightly from each other. We also did not cover all potential types of intersections that exist. Nevertheless, we are confident that we picked a representative route with road types commonly used by motorcyclists. Additionally, we compared our approach only to visual feedback. While visual feedback is the dominant feedback modality for navigation systems, other feedback modalities are also common in current systems (e.g., auditory feedback). The exclusion of auditive feedback was not only based on rider's preferences but also based on prior work which showed that auditive feedback and warnings for motorcycles might be less suited since they are obtrusive and can easily become annoying [5]. Given (also from personal observations and discussions with riders throughout the study) that auditive instructions are rarely used, we wanted to evaluate realistic situations, and, thus, focused on visual feedback in our experiment. We plan to compare the tactile feedback used in MOVING with other (multimodal) feedback modalities in the future.

CONCLUSION

In this work, we report on the design and evaluation of a tactile navigation kidney belt for motorcyclists called MOVING. We explored the systemic motorcycle vibrations on different parts of the body to infer an optimal on-body location for the placements of the vibration motors. The MOVING system consists of 12 vibration motors integrated into a kidney belt in order to provide tactile navigation cues to the rider. In a real world evaluation, we explored how such a system performs compared to an off-the-shelf (visual) navigation system. Compared to other evaluations of wearable systems, we performed this evaluation in a real world environment providing a realistic setting. We showed that in this setting tactile cues outperform visual ones. In particular, motorcyclists using MOVING made less turn errors and perceive the system as less distracting compared to an off-the-shelf navigation system.

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