

6th Senses for Everyone! The Value of Multimodal Feedback in Handheld Navigation Aids

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ABSTRACT

One of the bottlenecks in today's pedestrian navigation system is to communicate the navigation instructions in an efficient but non-distracting way. Previous work has suggested tactile feedback as solution, but it is not yet clear how it should be integrated into handheld navigation systems to improve efficiency and reduce distraction. In this paper we investigate augmenting and replacing a state of the art pedestrian navigation system with tactile navigation instructions. In a field study in a lively city centre 21 participants had to reach given destinations by the means of tactile, visual or multimodal navigation instructions. In the tactile and multimodal conditions, the handheld device created vibration patterns indicating the direction of the next waypoint. Like a sixth sense it constantly gave the user an idea of how the route continues. The results provide evidence that combining both modalities leads to more efficient navigation performance while using tactile feedback only reduces the user's distraction.

Categories and Subject Descriptors

H.5.2 [User Interfaces]: Haptic I/O

General Terms

Human Factors, Experimentation

Keywords

Tactile & Haptic UIs, Multi-modal interfaces, User Studies

1. INTRODUCTION

With more and more powerful handheld devices sold, location-based services and navigation systems have become common applications on our mobile phone. In particular, navigation aids, such as Google Maps, can be found on virtually any Smartphone. These aids allow us to find our way in unfamiliar environments and places we never visited before.

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Figure 1: Being distracted is a serious issue when interacting with handheld devices on the move, e.g. when employing them as navigation aids.

Typical applications locate users on a map and allow calculating route. In addition, some recent navigation systems, such as Google Maps Navigation, also provide turn-by-turn instructions by text, visual cues, or speech.

An important problem is the distraction caused by the audio-visual information presentation of such systems, as illustrated in Figure 1. According to a study by Madden and Rainie [9] one in six adults report to have physically bumped into another person because they were distracted using their phone. Ear plugs free the eyes but may lead to the "iPod Zombie Trance"¹, which refers to the loss of situational awareness from listening to audio content. According to the Sydney Morning Herald, authorities in Australia are speculating that this might be a contributing factor to the still increasing pedestrian fatalities. Safety considerations aside; looking at a display or having to listen to spoken instructions might simply be undesirable, e.g. when having a lively discussion with a companion. Therefore, interaction techniques are needed that support pedestrian navigation to not distract travellers from their primary tasks.

Recently a number of research groups have investigated different ways of enhancing Smartphone-based navigation systems with vibro-tactile feedback [8, 10, 14, 15, 21]. One emerging metaphor is the *sixth sense*, which Froehlich et al.

¹<http://www.smh.com.au/digital-life/mp3s/pedestrian-death-rise-blamed-on-ipods-20100905-14w4d.html>, Sydney Morning Herald, last visited September 21, 2011.

[3] define as "multimodal feedback to alert users of changes and opportunities in the dynamic environment." For example, Lin et al. [8] used encoded turning instructions, such as "turn right now" in vibration patterns. In our previous work [14] we proposed a *Tactile Compass* that encodes compass directions in vibration patterns. For both approaches it was shown that they can effectively guide a pedestrian to a given destination. However, it is not yet clear if and how these techniques can be used in combination with today's pedestrian navigation systems. Shall they be used to replace or complement existing visualisations? Will they be beneficial in terms of navigation performance and distraction?

To answer these questions we conducted a field study. We experimentally compared visual, tactile, and multimodal navigation instructions with a handheld pedestrian navigation system. Data from 21 participants and 63 routes were collected. The results provide evidence that the distraction could be reduced by providing tactile feedback only. The efficiency could be improved by providing multimodal feedback. These findings may help designers to tailor navigation systems and similar location-based systems towards efficiency or distraction.

2. RELATED WORK

Tscheligi and Sefelin [19] argue that considering the context of use appropriately is one of the main prerequisites for the success of pedestrian navigation systems. A well-known issue is that the interaction with the mobile device only happens in short bursts [11] and thus can be highly distracting. Thus, pedestrians might lose their situation awareness, which may be dangerous when walking through a lively, traffic-heavy area [9].

To accommodate the pedestrian's context of use, many researchers have investigated the use of tactile information presentation. Tan and Pentland [18] proposed a 3x3 array of tactile actuators worn on the back for conveying navigation information. By e.g. having a series of pulses moving from the left to the right of the display could be used to indicate "turn right" or "right-hand side". Tactile belts are a different form of tactile displays that have proven successful to support (pedestrian) navigation. An early example by Tsukada and Yasumura [20] is the ActiveBelt, which is equipped with eight vibro-tactile actuators. It allows creating tactile stimuli around the wearer's torso to "point" into a horizontal direction. By pointing into the direction the user has to go, such tactile belts can guide pedestrians along a route. This form of waypoint navigation has found to be effective and beneficial for the user's distraction [2, 12].

Disadvantages of these early devices are that they are custom-made hardware devices, which might not always be available when the user is travelling. User might also just not want to carry such a device if navigation support is not required too often. Therefore, researchers have investigated whether navigation support can also be provided with the most ubiquitous tactile display: the vibration alarm of mobile phones. There are two predominant solutions, which Fröhlich et al [3] refer to as the *magic wand* and *sixth sense*.

The *magic wand* metaphor, as illustrated in Figure 2, follows the idea that a user points at a distant object with a handheld device to learn about its presence or access information about it. Technically this is possible as nowadays smartphones are equipped with a digital compass. Recent implementations provide feedback when the user roughly

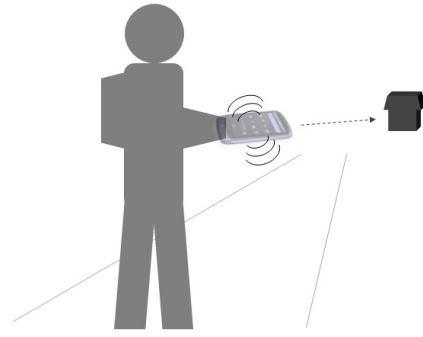


Figure 2: Magic Wand metaphor: user learns about location of an object by pointing at it with a mobile device.

points into the correct direction of a relevant geographic location, such as the travel destination [10, 15, 21]. Thus, by actively scanning the environment the user can stay aware of the general direction of her or his travel destination. It has been shown that this technique is very intuitive and allows users to effectively reach a given destination [10, 15, 21]. However, the intuitiveness is traded with the drawback that the device has to be held in the hand and actively needs to be pointed at the object, which has been found undesirable by some users [15].

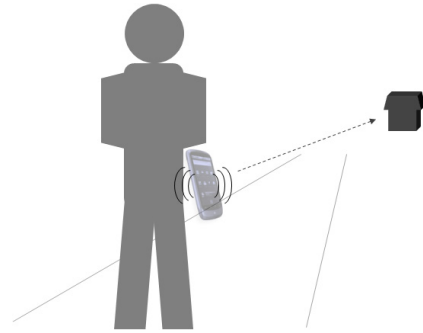


Figure 3: Sixth Sense metaphor: location of an object is encoded in e.g. vibration patterns.

The *sixth sense* metaphor, as illustrated in Figure 3, describes solutions that use multimodal feedback to alert the user about changes in the environment. This has been applied by issuing turning instructions in vibration patterns [8] as well as cueing the direction in which the user has to go in vibration patterns [14, 10]. Both approaches have proven to be effective in user studies. The advantage of the sixth sense approach versus the magic wand approach is that users are not required to do pointing gestures to acquire the presented information.

While previous work has provided evidence that tactile belts can reduce the navigator's distraction, it is not yet clear whether this benefit can also be found for these novel handheld-based interaction techniques. Also, previous work has compared tactile and visual navigation systems but did not investigate the multimodal combination of both. Thus, it is not clear what effects multimodal cueing of directions will have on the navigation performance and the user distraction, and if/how it therefore should be employed.

3. FIELD EXPERIMENT

To study these novel handheld-based interaction techniques [8, 10, 14, 15, 21] in multimodal usage we conducted a field experiment. 21 participants were asked to navigate through a crowded urban environment. In three conditions, they were equipped with either a handheld-based tactile navigation system, or a state-of-the-art pedestrian navigation system, and the combination of both. We wanted to investigate whether the handheld-based tactile feedback shows the same positive effects on the user's distraction as tactile belts do [2, 12]. Also, we wanted to investigate whether users can integrate the tactile and the visual cues in a way that is beneficial for the navigation performance.

3.1 Evaluation Environment

The study was conducted in the summer of 2010. It took place in the pedestrian zone of *Oldenburg, Germany*, a European city with about 150,000 inhabitants. The winding layout of the streets makes it difficult to stay oriented, even for locals. During shopping hours the city centre becomes very crowded, so a lot of attention is required to evade other people and obstacles. We defined two training routes and three evaluation routes (see Fig. 4). Each route covered about 450 meters. All routes started and ended in calm, less frequented areas and led through the central, most crowded area.

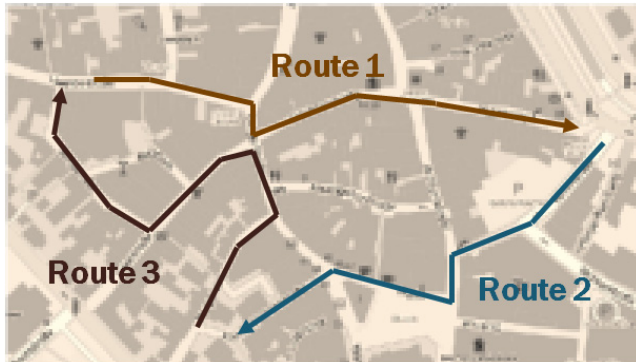


Figure 4: The three evaluation routes covering the city centre of *Oldenburg, Germany* (the two test routes are not shown). Map by OpenStreetMap.org

3.2 Visual Navigation System

As baseline for the experiment we used a self-built navigation system similar to Google Maps. We did our own implementation to provide OpenStreetMap data which - unlike Google Maps - has all pedestrian paths available. Otherwise, the application provides all the relevant functionality available in Google Maps: the user's position and orientation is indicated by an icon drawn onto the map. The map can be set to automatically rotate and align itself with the environment, so the "up" direction on the screen corresponds to the device's orientation. The route is highlighted on the map. Additionally an arrow icon in the bottom left corner of the screen visually indicates into which direction to go. In pilot studies we learned that many users feel embarrassed and distracted by speech output, especially in lively areas. Therefore, only visual feedback was provided.

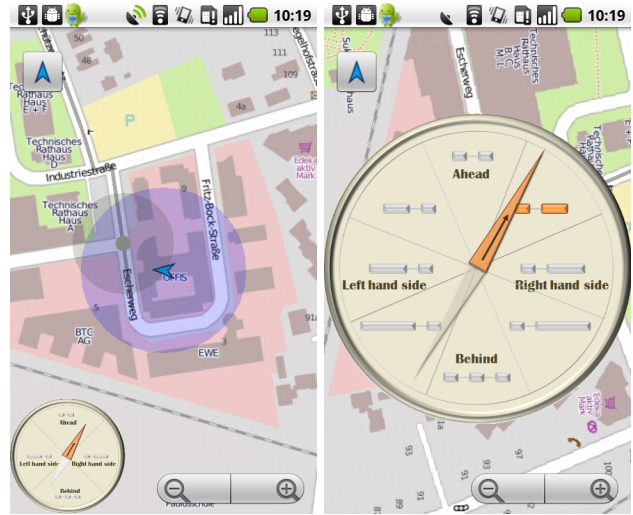


Figure 5: Screenshot of the visual navigation system used in the study. The user location and the route are shown on a map. The icon in the lower left provides a visual cue where to go. It also visualises the vibration patterns associated with each direction (see grey bars in enlarged version).

3.3 Tactile Navigation System

For the tactile navigation system we combined previously proposed instances of the magic wand and the sixth sense metaphor.

As instance of the magic wand metaphor we used the pointing design proposed by [15, 21, 10], which allows the user to scan for a geographical entity by pointing gestures. When the device e.g. points at the next waypoint, this waypoint is considered being "ahead".

As instance of the sixth sense metaphor we used the Tactile Compass proposed in [14], which provides directional information in vibration patterns. When the user e.g. walks towards the next waypoint, two short pulses indicates "ahead" (see Fig. 5 for all eight vibration patterns). The Tactile Compass has found to be an effective navigation aid [10, 14] without requiring any active gestures, which may be tiresome during extended usage [15].

Technically the tactile information presentation techniques are applied as waypoint navigation techniques [2, 12]. Therefore, routes are divided into sets of waypoints. The system constantly conveys the direction of the waypoint that has to be reached next. Once this waypoint has been reached the system switches to the subsequent waypoint. The user is thus dragged along the route until reaching the destination. In our particular implementation we also allowed the user to skip waypoints when e.g. going cross country, finding a shortcut, or simply taking a wrong turn.

The success of waypoint navigation also depends on how close the user needs to get to a waypoint until the system switches to the subsequent waypoint. Switching too late causes the user to reach the decision point without knowing where to go. Switching to the next waypoint too early can result into direction information that may be hard to interpret, since e.g. the system points at a building. In a series of pilot studies we optimised the switching time to provide the

new directional information in the most suitable moment. One of the tweaks we used was to switch to the next waypoint earlier, the faster the user walked and the less accurate the GPS signal was.

3.4 Participants

21 participants (10 female, 11 male) took part in the study. Their age ranged from 18 to 41 with an average of 26.6 years (SD 6.68). Prior to the study we assessed the participants' familiarity with (pedestrian) navigation systems and their sense of direction. The sense of direction was assessed by the Santa Barbara Sense of Direction Scale (SBSOD) [5]. In a possible range from 1 (low) to 100 (high) the participants scored 54.72 (SD 15.37) in average. The participants judged their familiarity to be average with car navigation systems (3.05, SD 1.02 / 1=low - 5=high) and below average with pedestrian navigation systems (1.95, SD 1.16 / 1=low - 5=high). Although no personally identifiable information was collected all participants signed an informed consent. All participants received a gift to compensate their participation in the study.

3.5 Design

The navigation system configuration served as independent variable with three levels: *visual*, *tactile*, and *combined*. In the *visual* condition the participants only used the visual feedback of the navigation system. In the *tactile* condition the screen was blinded so only the tactile feedback could be used. In the *combined* condition, both, the tactile feedback and the visual feedback were available.

The experiment followed a within-subjects design, so every participant contributed to all three conditions. The order was counter-balanced to cancel out sequence effects. The following dependent measures were taken to assess the navigation performance, the cognitive workload, and the level of distraction:

Navigation Performance.

Inspired by previous field studies (e.g. [7, 16, 12]) navigation performance was measured in terms of completion time, number of navigation errors, number of orientation phases, and number of orientation losses. *Completion time* was defined as the time the participants travelled from start to end of each route. A *navigation error* was counted when a pedestrian took a wrong turn and entered the wrong street for more than 5 meters. *Disorientation events* were defined as situations where the participants stopped for more than 10 seconds or stopped and expressed their disorientation verbally. An *orientation phase* was counted when the participant stopped shortly (less than 10 s) to re-orient themselves.

Cognitive & Mental Workload.

The cognitive workload was measured by subjective and objective measures. As subjective measures we issued the widely accepted Nasa TLX [4] questionnaire. As objective workload measure we monitored the participants' walking speed, as Brewster et al. [1] suggested that people walk slower when the cognitive workload increases while interacting with a handheld device. The walking speed was extracted from the GPS signal.

Distraction.

The distraction was quantified by measuring how much participants interacted with the mobile device and how well they could pay attention to the environment. To assess how

well the participants paid attention to the environment we asked the participants to count the number of cafes, hair dressers, and pharmacies and name the sum of all of these shops at the end of the route. Since the experimenters were aware of all of these shops they could calculate the ratio of how many shops have been detected. Interacting with the device was divided into two groups: looking at the map and using the pointing gestures. The participants were considered *looking at the map* when the device was held in an angle that allowed that participant to look at the display. The participant was considered *pointing* when the device was held nearly parallel to the ground. Since in the *combined* condition the user could also be looking at the map when pointing and vice versa, such situations were contributing to both dependent measures at the same time. How the device was held was logged automatically by the device, so these measures could be taken without having to use a video camera.

3.6 Procedure

Informed consents, demographic questionnaires, and additional information were sent out to the potential participants prior to the study. Only those participants who signed the consent forms were invited to the study.

Training sessions allowed the participants to get used to the navigation system. A dedicated application was developed to train the tactile feedback. It allowed the participants to explore and learn the different patterns. To complete the learning phase, 16 random patterns had to be recognized. Response time and recognition errors were logged for later analysis.

Afterwards the participants could train the use of the application on two test routes. The first route was done with visual and tactile feedback, the second with tactile feedback only. During both routes we trained the participants to use the pointing gesture or to look at the device' screen only when needed and otherwise keep the device in a position where the arm was relaxed.

When the actual evaluation started we explained the participants that they had to count cafes, hair dressers, and pharmacies they pass by on their route. The navigation time started to be recorded when the route was selected on the mobile device. The experimenter followed the participant in some distance and took notes about navigation errors, orientation losses, and orientation phases. The experimenter also watched out for the number of shops to be counted when participants left the correct route due to a navigation error. When arriving at the last waypoint of the route the completion time was automatically taken. The participants filled out the Nasa TLX for the past condition and then switched to the next condition.

After having completed all three routes we conducted an open post-hoc interview with the participants. The goal was to learn about any of the participants' impressions and suggestions. Our strategy was to not ask any question unless the interview went stuck but encourage the participants to express their thoughts freely. The whole procedure took about 90 minutes for each participant.

4. RESULTS

All participants succeeded to reach the destination in all three conditions. In the following we present the quantitative and qualitative findings.

4.1 Quantitative Results

This section presents the quantitative results of the dependent variables. The diagrams show mean value and standard deviation per condition. Statistical significance was analyzed using ANOVA and Tukey post-hoc tests.

Navigation Performance.

Figure 6 shows the results related to the navigation performance. No significant effects could be found on the *completion time* ($F(2) = 2.93, p = .06$) and the number of *orientation losses* ($F(2) = 0.47, p = .63$). There was a significant effect on the number of *navigation errors* ($F(2) = 3.65, p < .05$). In the *combined* condition participants took less wrong turns than in the *visual* or the *tactile* condition (both $p < .05$). Further, there was a significant effect on the number of *orientation phases* ($F(2) = 4.93, p < .01$). In the *tactile* condition the participants made more short stops than in the *visual* condition ($p < .01$). In summary, participants stopped more often to reorient when using the tactile feedback only. The multimodal combination of visual and tactile led to less navigation errors.

We also found several noteworthy correlations: participants with better knowledge about the city had a higher walking speed in the *visual* condition ($r = .47$). More previous experience with navigation systems lead to lower completion times ($r = -.37$) and fewer orientation phases ($r = -.47$) in the *tactile* condition. In the *visual* condition participants with more previous experience looked at the device less often ($r = -.34$). Participants who completed the training faster performed better in terms of completion time ($r = .44, .53, .67$), navigation errors ($r = .55, .69, .42$), disorientation events ($r = .50, .60, .11$), and orientation phases ($r = .46, .50, .59$) (for conditions visual, tactile, combined).

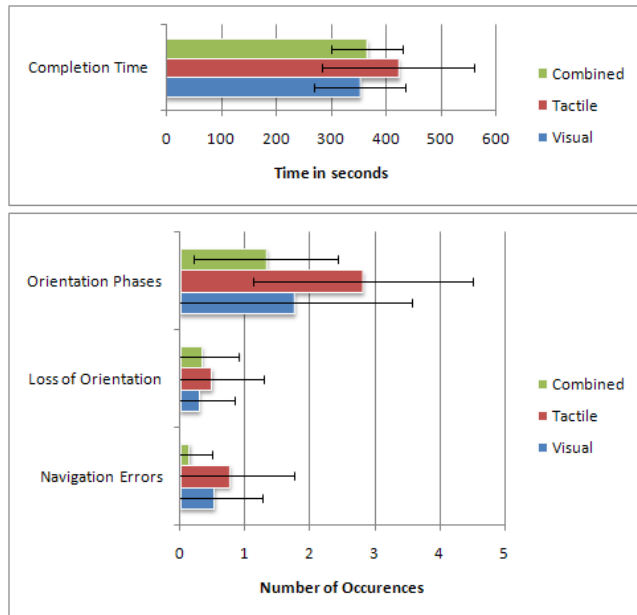


Figure 6: Navigation performance measures.

Cognitive Workload.

Figure 7 shows the results related to the cognitive workload. There was a significant effect on the participants' walking speed ($F(2) = 5.01, p < .01$). Participants walked faster

in the *visual* condition than in the *tactile* condition ($p < .01$) or in the *combined* condition ($p < .05$). Thus, the objective cognitive workload was higher when the tactile feedback was present. However, the subjective judgement of the cognitive workload via the NasaTLX showed no significant differences between the conditions ($F(2) = 1.04, p = .36$).

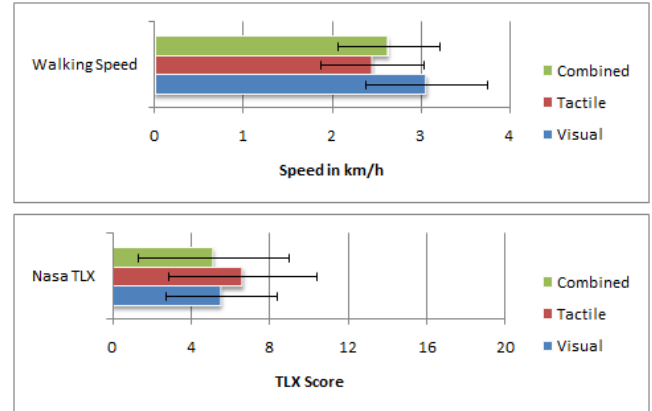


Figure 7: Cognitive workload measures.

Distraction.

Figure 8 shows the results related to the distraction. There was no significant effect on the number of shops found ($F(2) = .94, p < .40$). But, there was a significant effect on the amount of interaction ($F(2) = 3.41, p < .05$). The interaction was significantly lower in the *tactile* and in the *combined* condition than in the *visual* condition (both $p < .05$). Considering only the time spent *looking at the map* in the conditions where the map was available, the participants in the *visual* condition looked significantly less often at the map compared to the *combined* condition ($p < .05$). In the two conditions where the tactile feedback was present, the participants used the pointing gesture significantly less often in the *combined* condition than in the *tactile* condition ($p < .01$). In summary, the visual feedback reduced the amount of pointing interaction and the tactile feedback had a positive effect on the amount of distractive interaction.

4.2 Comments and Observations

In the beginning of the experiment, many participants were questioning whether the tactile feedback only was sufficiently easy to use. During the study, however, none of the participants failed interpreting the tactile cues. One participant nicely summarized this by stating: *when reading the information sheets I never thought these vibration patterns would work. But in retrospect, it was much more intuitive than I expected.*

4.2.1 Navigation Strategies

Visual Condition.

In the *visual* condition the predominant strategy was "read 'n' run": the participants studied the map, memorized the upcoming route segment, and then passed the memorized part as quickly as possible without looking at the map. Participants using this strategy were walking faster than in any other situations we observed. Since the study took place in summer, sunlight reflections were one of the major issues in

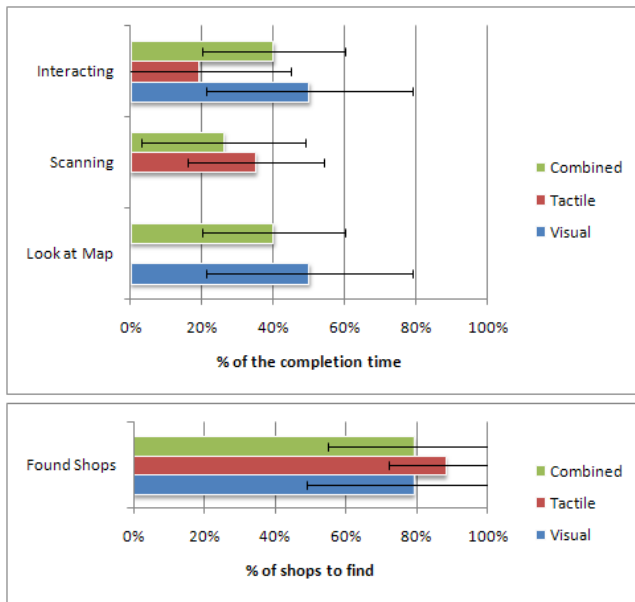


Figure 8: Distraction-related measures.

reading the map. Three participants reported to have major trouble with reading the display (see Fig. 9).



Figure 9: Participant struggling to read the display due to sunlight reflections (left). Participant scanning for the next waypoint (right).

Tactile Condition.

As suggested, the participants used the pointing gestures only when there was a specific need for more accurate information, such as when the GPS signal strength declined or when the participants wanted to reorient themselves at a crossing. Usually the participants pointed the device forward into their walking direction. They tried to learn the direction of the next waypoint from the pattern rather than actively pointing the device in different directions to find the "ahead" pattern by pointing into different direction. Thus, the pointing interaction studied in [10, 15, 21] has rarely been observed. Although there was no technical need, there was a tendency that the participants stopped when doing pointing gestures.

In the post-hoc interview many participants stated that they found the tactile feedback surprisingly more easy to be used than they had expected. The lack of an overview was named five times as notable drawback. Four participants stated that they were missing the map to understand how the route proceeded beyond the next waypoint. However, regarding the *tactile* condition six participants expressed that they were not missing the map at all.

Combined Condition.

The combination of tactile and visual feedback was named most often as the preferred condition. The participants enjoyed to have the map to get an overview and at the same time receive constant confirmation by the tactile cues. Many participants focused on one source of information primarily and used the other as support. Eight participants reported to have relied on the map and used the tactile feedback to be reminded of an upcoming turn. Seven participants reported to have primarily used the tactile feedback and used the map only when being uncertain. Unlike the *visual* condition, the "read 'n' run" strategy was hardly observed in this condition.

4.2.2 Cognitive Workload and Distraction

Many participants stated that they were constantly monitoring the tactile feedback. Three participants explicitly mentioned that processing the constant feedback was mentally demanding. On the other hand, four participants appreciated the continuous feedback. They felt that people having bad sense of direction would greatly benefit from the constant confirmation.

With respect to the distraction, participants appreciated that the tactile feedback made it unnecessary to look at a display. Nine participants positively mentioned the private and eyes-free usage, in particular when the display is hard to read due to sunlight reflections.

4.2.3 Tactile Compass Design

In order to identify areas of improvement we also collected feedback on the design of the tactile feedback. In the dedicated training session the participants recognized 78.19% (SD 14.61) of the presented patterns correctly. Roughly 80% of the errors was a confusion of neighbouring directions, e.g. left was chosen instead of left-behind. In the post-hoc interviews we identified two reoccurring issues:

The first issue was the number of directions to present. Our design cued eight directions in vibration patterns. However, seven participants stated that they mentally ignored the intermediate directions and therefore navigated by ahead, behind, left-hand side and right-hand side only. Additionally, five participants reported to have difficulties to discriminate the *ahead* and the two adjacent directions (ahead/right - ahead/left). Three participants explicitly suggested reducing the number of directions to four.

The second issue was the constant presence of the tactile feedback. It was explicitly appreciated by four participants who felt to have a bad sense of direction. However, the bigger share of the participants pointed out that their attention was drawn too much by the constantly repeated vibration patterns. Some said that they could not stop listening for changes in the vibration signals. During the study we observed many cases, where the participants appeared to concentrate a lot on the tactile patterns (see e.g. Fig. 9). Suggestions for improvement were to play the tactile pat-

terms only on the user's request or only in situations where it is necessary, e.g. when approaching a turn or when leaving the route.

5. DISCUSSION

All participants were able to reach the given destinations with the visual, the tactile, and the multimodal, combined feedback. The multimodal feedback improved the navigation performance by reducing the number of navigation errors. The tactile feedback only led to less distractive interaction with the handheld device. The presence of the tactile feedback in the *tactile* and the *combined* condition led to slower walking speeds, which we believe may be a sign for an increased cognitive workload.

Navigation Performance.

The results support previous work showing that cueing directions is possible with a single actuator [10, 12, 15, 21] and can form effective navigation aids. Although no statistically significant differences could be observed, there was a tendency towards a decreased navigation performance in the *tactile* condition. We did not find this surprising given the fact that most participants had previous experience with visual navigation systems while the tactile system was completely new to them. The time needed to get to the destination increased by 15% for the *tactile* condition, which may still be acceptable if reducing distraction is preferred over efficiency. Although we included two training routes, the question remains whether the performance would converge over time as the user gains more experience in using the tactile compass.

The combination of both modalities, in contrast, could improve the navigation performance in terms of navigation errors. Similar findings have been made with body centric cues provided by tactile waist belts. In two studies [17, 13] it was shown that cueing the location of the destination can improve the navigation performance. However, there are two notable advancements: (1) the work presented here is based on abstract patterns and pointing gestures, not body centric cues. The latter are presumably easier to interpret. (2) in the reported studies the tactile displays were used in combination with maps. Here we provided turn-by-turn instructions, which are presumably more powerful. Thus, we could show that navigation performance can still be increased, even if the tactile cues are less intuitive and the visual cues are more intuitive.

Cognitive Workload.

The results indicate that the tactile feedback induced cognitive workload. The walking speed was significantly higher in the *visual* condition which according to Brewster et al. [1] is a sign of less cognitive workload. Many participants who reported that they have been constantly feeling for vibration patterns confirmed this. Notably, this happened in the *tactile* and in the *combined* condition, although in the *combined* condition the participants could have used the system as in the *visual* condition by just ignoring the tactile feedback.

We are surprised that we did not observe an equivalent of the cocktail party effect, where people selectively listen to a single speaker while ignoring all other conversations and background noise. Our results indicate that even in the *combined* condition, where interpreting the tactile patterns was not necessary at all, the participants tried to interpret them. One explanation might be found in the work by Ho et al.

[6] who found that the sense of touch can be used to attract and direct the human's attention. The tactile cues could have attracted the users' attention even in situations where it was unnecessary. Future design iterations could address this issue by simplifying the tactile icons further (e.g. by reducing the number of directions) and providing information only when necessary. On the good side, these findings indicate that tactile cues are well perceived on the move and do not suffer from external interferences. So, tactile cues would be particularly effective in drawing the user's attention if required.

Distraction.

The tactile feedback had a positive effect on the distraction. Complementing the visual system with tactile feedback helped reducing the time spent interacting with the device significantly. Compared to the *visual* condition the participants looked less often at the map. Compared to the *tactile* condition the participants used the pointing gesture less often. Taking the overall time spent scanning & looking on the map into account, the participants were interacting most when having visual feedback only. These findings show that the reduction of the user's distraction shown for tactile belts [2, 13, 12] also applies to the sixth sense and the magic wand metaphors for handheld devices.

However, although the participants found most shops in the *tactile* condition, no significant effect was found on the detection rate. This can be explained by the fact that the detection rates were generally high (between 77 % and 88 %). We therefore cannot confirm the findings by Elliott et al. [2] where soldiers could spot most "targets" with a tactile navigation system. However, Elliott et al. compared their tactile navigation system with a head-mounted display and an alphanumeric handheld GPS coordinate representation. Both baseline systems presumably require more effort to interpret the navigation information compared to the navigation system used in our study. Thus, the findings by Elliott et al. might be confirmed when the tactile feedback is employed with improvements with respect to the cognitive workload and more training.

Limitations of the study.

Some participants were not completely unfamiliar with the city centre. This could account for the "read'n'run" strategy we observed in the *visual* condition and thus have favoured the conditions with the visual feedback. In completely unfamiliar environments the tactile feedback might therefore have performed better in comparison. In particular, this shows that maps are distracting even though users already have some understanding of their content. In terms of ecological validity we do not see the results threatened, as it is not uncommon to use navigation systems in somewhat familiar environments.

6. CONCLUSIONS

The main contribution of this paper is the first field study reporting from an experimental investigation of visual, tactile, and multimodal (visual *and* tactile) feedback for providing turning instructions in a pedestrian navigation system on handheld devices. The study provides evidence that the tactile feedback reduces the user's distraction while the multimodal feedback improves the navigation performance. Further, it suggests taking into account to reduce the amount

of tactile feedback to not increase the cognitive load unnecessarily.

These findings will allow tailoring navigation systems towards the context of use, i.e. whether navigation performance or reduced distraction is required. The findings may also be applied to applications beyond navigation systems, as cueing directional information is a core feature of many location-based services. The results suggest that providing tactile feedback will improve the user's situation awareness and therefore be beneficial for the safety of use.

Future works needs to address the challenge of reducing the cognitive workload. Solutions we proposed, such as reducing the complexity of the directional information and reducing the amount of feedback should be subject of further studies. Further, all studies on tactile feedback in navigation systems studied time-limited usage only. Longitudinal studies are in order to investigate how tactile feedback performs, once the participants get acquainted to it.

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