Strike a Pose: Directional Cueing on the Wrist and the Effect of Orientation

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Abstract. Many wearable haptic devices have been developed for providing passive directional cues, in the form of belts or back displays but these systems have so far failed to make an impact in the public domain. One other potential solution is a light, discrete and aesthetically acceptable vibrotactile bracelet. However, contrary to these other systems, the wrist is subject to rotations, therefore a controversial locus for vibrotactile feedback in a navigational context. This paper presents a set of experiments aimed at both determining the basic feasibility of using this kind of bracelet and to examine to what extent the orientation of the user's wrist affects their perception of directional cues both in static and mobile conditions. It was found that changes in orientation have little negative effect overall, distraction being more of a concern.

Keywords: Vibrotactile, mobile, wearable, bracelet, haptic, wrist device.

1 Introduction

Mobile navigation has become increasingly common with the rise of GPS enabled mobile devices, which has led to the development of an abundance of pedestrian navigation applications. These applications usually deliver turn-by-turn navigational instructions via audio and visual feedback. For a mobile device user on the move, this can be a considerable distraction from the world around them. For example, visual feedback can prevent a tourist from being immersed in and discovering their new surroundings while for a pedestrian at a crossing, it can be dangerous.

Haptics offers an interesting alternative or a complementing modality [1] and using it as a means of providing eyes-free directional information is still an emerging area in terms of commercially viable applications. The transmission of tactile information has been shown to not only improve efficiency and safety but also to reduce distraction from the surrounding environment [2]. Strachan et al. [3] combined spatial audio and tactile feedback, finding that all users were able to navigate from one end of an unknown trajectory to the other using only audio and tactile feedback. Tactile feedback has also proved successful when used alone. For instance, Robinson et al. [4] developed a system aimed at supporting the discovery of geo-located information using sweeping and tilting gestures with an inertial device, with users receiving haptic

I. Oakley and S. Brewster (Eds.): HAID 2013, LNCS 7989, pp. 117–126, 2013.

feedback depending on the presence of information in the locality. They found that although the design of the interaction had some shortcomings, users were able to find targets using vibrotactile feedback alone. Pielot et al. [5] described a study with a tactile compass to convey geospatial locations with a single vibration motor and without requiring any explicit interaction. They provide direction and distance information using different patterns of vibration finding that cueing spatial locations in vibration patterns can form an effective and efficient navigation aid.

All of these systems involve a very direct pointing style of interaction with a mobile device and vibrotactile feedback delivered to the palm of the hand. This style of interaction may not be suitable in cases where a user's hands are full, whilst carrying bags or performing another task such as cycling, for example [6]; instead tactile wearable devices may be more suitable. They have often been used to provide feedback in a non-obtrusive manner and come in many flavours including gloves, shoes and belts. For example, Tsukada et al. [7] presented a tactile belt, equipped with multiple vibration motors and a GPS device, to deliver directional information around the waist. And similarly Heuten et al. [8] used a tactile belt for eyes-free navigation, finding that users were able to navigate effectively using the tactile feedback alone. Interestingly, Vélazquez et al. [9] exploited the sensitivity of the feet to convey navigational information through actuators embedded in shoes and obtained promising initial results. However, these systems have been mostly confined to the research realm; the wrist could be a solution more widely accepted as it provides a light and discrete solution, but its utility has been debated for conveying tactile feedback.

After surveying the issues surrounding the use of the wrist to provide tactile feedback and existing systems, we present a set of studies aimed first at confirming the feasibility of using the wrist as a means of providing simple tactile directional cues; and second at quantifying to what extent, if any, the change of wrist orientation hinders the ability of a wrist-mounted tactile device to aid user navigation in several realistic scenarios.

2 Wrist as a Locus

2.1 Tactile Perception and Existing Systems

Interaction involving feedback to the wrist is less common than other parts of the body and in fact there has been some debate as to its utility for receiving tactile feedback. Oakley et al. [10] described experiments examining the limitations of a vibrotactile display placed on the forearm and concluded that different arrangements of tactors can result in different levels of performance and that increasing the size of the stimulated area results in an increased perception of intensity. Their overall conclusion about the use of the forearm for tactile input is rather positive. Karuei et al. [11] explored the potential and limitations of vibrotactile displays in wearable applications, finding that wrists were one of the preferable body locations, particularly for navigation applications. Whereas Lee et al. [12] showed that the reaction time to perceive alerts on the wrist was not deteriorated by visual distraction, thus potentially making wrist-mounted tactile displays appropriate for enabling mobile multitasking.

A few wrist systems have been developed. Tsetserukou and Tachi [13] introduced BraTact, a tactile bracelet with six symmetrically arranged vibration motors, designed to alert the operator of a teleoperation system to object collisions. Schätzle et al. [14] presented VibroTac, a similar system but ergonomically improved and designed principally for forearm use. Panëels et al. [15] developed and evaluated a tactile device in the shape of a wristwatch. They found that participants encountered some difficulty discriminating directional patterns due to the small inter-distance between actuators but could effectively identify patterns based on rhythm. However, these systems were either not evaluated in a mobility context [15,14] or rely on dynamic patterns using solely rhythm and intensity [13], therefore not tackling the potential orientation issue.

2.2 The Orientation Problem

One problem with using the wrist to deliver directional instructions is that the orientation is constantly changing thus increasing the potential for confusion in the user's perception of the direction being presented. On the contrary, belt systems do not suffer from this problem since it is placed around the waist and has a consistent orientation for all users. For example with the wrist, whilst talking on the phone with the right hand, is a vibration on the right side of the wrist considered as a prompt to go right? Or is it actually to move forward? Gleeson and Provancher [16] investigated the effect of different orientations of the hand when directional shear forces are delivered to the tip of the index finger. They found that users could successfully identify directional stimuli quickly and accurately, even when the stimuli were rendered in a rotated reference frame, suggesting that the use of such stimulations on continually reorienting mobile devices is feasible. To our knowledge, the issue of wrist orientation on the perception of simple directional cues has not yet been researched.

3 Evaluation

In the context of an application designed to deliver directional cueing on the wrist, a set of studies aimed at validating the use of the wrist were conducted. First, a preliminary study tested our tactile device and the discriminability of simple cues in a static condition. The following two experiments tested the effect of changing wrist orientation on the user's perception of the directional cue in static and mobile conditions.

For all the user studies, vibrotactile cueing was provided via a band wrapped around the wrist with four actuators attached as displayed in Fig. 1. Each actuator is composed of a commercially available coin motor (Precision Microdrives 310-113), a microcontroller and a power circuit to control vibration amplitude. All the actuators are linked in series to a supervisor microcontroller which regulates the actuation level and timing; it also ensures the battery management and the Bluetooth communication with the computer. Each actuator, numbered 1 to 4, was used to provide tactile stimulation on the top, right, bottom and left of the wrist, respectively. Directional cues were presented in the form of discrete vibrations of 0.5s in length at 210Hz with an amplitude of 1.6g. They were sent to the bracelet from a tablet running Windows 7.

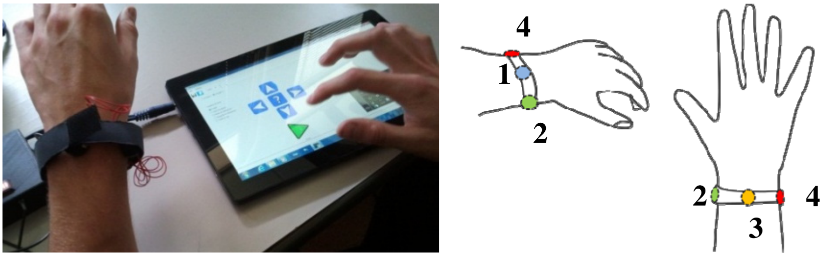

Fig. 1. Left: a user wearing the bracelet during the pilot experiment. Right: the placement and number of actuators. (1=front, 2=right, 3=back, 4=left)

3.1 Preliminary Study

To test the basic feasibility of providing directional cues with our tactile bracelet, a simple preliminary study was performed with 10 participants (8m/2f) aged between 25 and 36, all of whom were right handed and had some experience with tactile devices. The bracelet was mounted on the non-dominant wrist, to leave the dominant hand free for tapping answers on the tablet, as illustrated in Fig. 1.

Participants were first given a brief period of training with the interface, with a number of example vibrations. They subsequently felt 40 random vibrations they had to identify, i.e. 10 vibrations for each actuator corresponding to one of the directions, see Fig. 1. All participants were asked to wear headphones in order to block the sound of the vibrations and any potential effect this audio feedback may have otherwise had.

The recognition rates were 93% for the top actuator and 95% for the others: participant recognition of the four locations was excellent in these controlled conditions. This confirms that this bracelet can be used in fixed orientations to stimulate the wrist in an informative way.

3.2 Change in Orientation in Static Condition

This experiment was designed to test the effect of changing wrist orientation/user pose on the user’s perception of the directional cue. The four poses, as illustrated in Fig. 2, were chosen to mimic typical mobile situations: hands in the pockets (Pose 1), talking on the phone (Pose 2), looking at the phone (Pose 3) and holding a bag (Pose 4). As in the first experiment the bracelet was strapped to the participant’s non-dominant wrist. The participants were asked to hold the phone in the non-dominant hand for poses 2 and 3, justified by the fact that people regularly switch hands to write notes while using the phone, for example.

9 new male participants, aged between 22 and 45 were recruited. They received the same patterns as in the preliminary study and were asked to identify them, except that this time they would also assume the poses described above. They were introduced briefly to the vibrations and trained with the poses. They were divided in two groups: group 1 (4 participants) was asked the part of the wrist that the vibration was on, while group 2 (5 participants) was asked the direction that they felt the vibration was indicating to them, i.e. their perceived direction. Mappings of actuator to pointing direction for each pose were selected and used as a baseline from which to compare the participant performance.

Fig. 2. From left to right: The default 'rest' position, the 'hands in pockets' pose, the 'talking on phone' pose, the 'looking at phone' pose and the 'holding bag' pose

Both groups were prompted to change pose between each trial rather than perform a batch of trials with one pose. This was both to stop the user adjusting to a particular pose and to more accurately mimic the instantaneous response of a user to a directional cue, as is more likely to happen in a real life situation.

Results. Group 1, who were asked simply to locate the source of the vibration on their wrist, took less time in general than group 2, who were asked to indicate their perceived direction (see Fig. 3). This is particularly pronounced for pose 1 (hands in pockets) and much less pronounced for pose 4 (holding bag). This is likely due to the fact that for pose 1 the wrist is slightly rotated in the pocket and so the direction was not clearly defined in the participant's mind. For pose 4, holding the bag naturally aligned the actuators to the directional axis making the participant's decision easier.

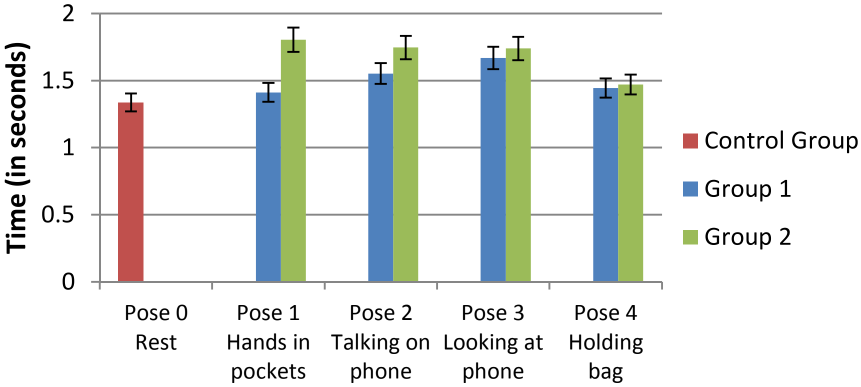

Fig. 3. The average time for the preliminary study (control group), group 1 (asked to locate the actuator position on the wrist) and group 2 (asked to indicate the perceived direction)

Fig. 4 shows the average user performance for both groups. The accuracy of the answers from group 2 was calculated from the estimated baseline (e.g. for talking on phone, a left vibration indicated front). The scores for the participants in group 1 were very similar to the "static" control group and were much more accurate than group 2. This difference is again particularly pronounced for pose 1 (hands in pockets) where the directional mapping was not clear to the participant and much less pronounced for pose 4 (holding bag) where the alignment of the wrist was well defined.

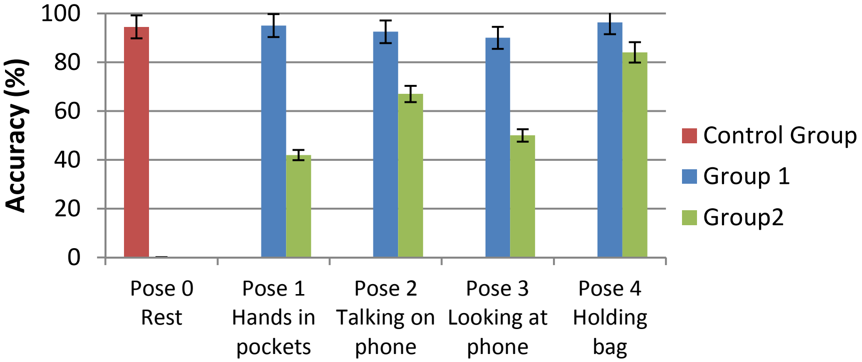

Fig. 4. The average accuracy of answers for the preliminary study (control group) and the two groups (group 1 - cues, group 2 - direction compared to the baseline) for the experiment

These initial results show that while users have little trouble locating the source of a vibration on their wrist in both static and changing poses (with scores very similar in these two conditions), some confusion is experienced when the user needs to associate the vibration to a perceived direction. Overall, these results tend to indicate that the extra cognitive work involved in associating a perceived direction does have an effect on performance. We hypothesize that locating vibrations in a frame of reference relative to the user's wrist (physical location on their own body) rather than relative to the world (location in space) is less cognitively demanding and less subject to ambiguity.

The findings of this study lean towards the absence of degradation of cue perception with wrist orientation changes. To further demonstrate this result, an evaluation in more realistic mobile settings was conducted next.

3.3 Mobility Study

To pursue the investigation of the influence of wrist orientation in the delivery of directional cues, the same study was performed while walking. 13 participants (5f/8m) aged between 24 and 56 were recruited to take part; most had some experience with tactile devices. Three of them were left-handed.

Each participant was given an introduction to the bracelet and the corresponding directions indicated by the four actuators. The users were required to wear the bracelet on their dominant wrist and walk along a set trajectory outdoors accompanied by an experimental coordinator. During the walk each user received vibrational cues on their wrist, after each of which they were required to orally indicate the direction to the coordinator or if they simply did not know, while continuing to walk. As the user did not need to answer directly on the tablet, they were permitted to wear the bracelet on the dominant wrist as would be the case in a real setting. The walk was divided into five phases. The first phase involved walking with a natural style, with the bracelet by the side. The second and third involved both carrying and dragging a suitcase, the fourth involved holding a phone at the ear and the fifth involved writing a text message (SMS). All were performed with the bracelet wearing arm and all while receiving the vibrotactile cues. The last condition was added in order to compare the effects of simple orientation changes to an orientation change with additional distractor tasks. The two distractor tasks involved writing the numbers 1 to 10 in letters and the second involved writing the name of five colleagues on the participants' own phone. 20 vibrations were sent per phase (5*20=100 stimuli). At the end, the participants were asked to fill a questionnaire.

Results. Fig. 5, showing the users' correct responses, indicates a reasonably good performance overall (poses 93.3%, SMS 79.6%). The normality of the distribution was tested using the Kolmogorov-Smirnov test which showed that for three of the positions (normal walking, holding suitcase and pulling suitcase) there is a significant deviation from normality, therefore violating the assumption of parametric data. As a consequence, the non-parametric Friedman test was used to compare the different conditions. The accuracy scores did significantly differ for the five conditions: $\chi^2(4) = 22.33$ $p<.05$. Given the small score difference between the four positional conditions, we suspected the significant difference was due to the distractor condition. Therefore the Friedman test was run again on the first four positional conditions and showed no significant difference between them $\chi^2(3) = 7.564$, $p>.05$. Subsequent post hoc Wilcoxon tests were conducted comparing the SMS condition with the other four. The two-tailed significance for all four comparisons is < 0.0125 (using the Bonferroni correction) meaning the SMS condition significantly differs from all of the poses.

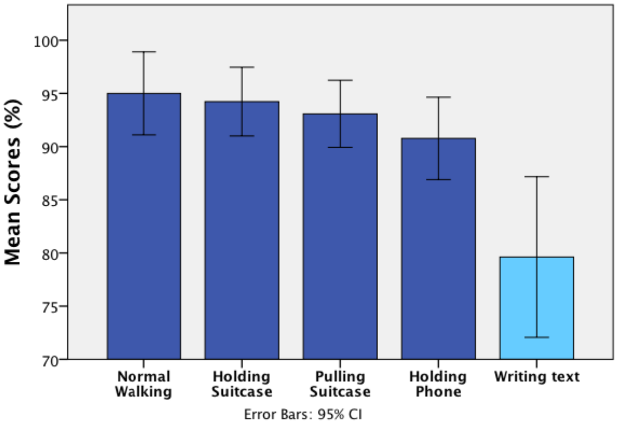

Fig. 5. User performance for each position

The overall performance is very similar in both static and mobile conditions: group 1 of the static study reached an overall performance of 93.4%, while it reached 93.3% in the mobile study with the distractor condition excluded.

The confusion matrices in Fig. 6 show that there is little confusion between patterns (<= 10%) with most recognition rates above 84%. The most common confusions for the positional conditions (≥4.6%) are between top and left for normal walking, pulling the suitcase and answering the phone, bottom and right for normal walking and answering the phone (and right/bottom), and left and bottom for answering the phone. These confusions could be due to the spatial distribution with the right/left actuators being close to the top/bottom actuators and covering less skin. Apart from the left/bottom confusion when holding the phone, none of these conditions seem to be due to the orientation issue (in the phone condition, the "left" actuator is orientated downwards). For the distractor condition (SMS), there was a lot more confusion. Top was largely confused with left (=20%), right with top (>9%), bottom with right and left (>6%). Amongst these, only the last one could be due to an orientation issue but the confusion rate is very low. It is likely then that the distraction of the SMS task played a significant role.

The questionnaire included questions about the difficulty of the main task, the localization of vibrations and their association with particular directions. Participants were asked to rate these on a scale of 1 to 6, the latter being the most difficult. Results, with averages between 2 and 3, indicated that in general participants had no problem recognising where the vibrations originated from and associating each of them with a corresponding direction (average score of 2 out of 6). The two conditions considered the most difficult were writing the SMS, due to the concentration required, and pulling the suitcase as the vibrations from the suitcase rolling interfered with the perception of the vibrations from the device. Nearly all (N=12/13) the participants replied positively to whether they thought these kind of cues would enable them to navigate more easily. They reported on the advantages of not looking at the screen constantly and focusing on potential surroundings or dangers. Nearly all (N=12/13) participants suggested the provision of repetition, either on demand or as part of the pattern design. Many (N=9/13) suggested the introduction of a signal announcing the pattern to grab the user's attention before any kind of recognition is required, in particular when the user is distracted. Finally, many (N=8/13) participants thought that the patterns could be better designed for discrimination, for instance a more complex combination of tactile parameters could be used (amplitude, location, rhythm).

These qualitative findings support the quantitative results in the sense that the orientation alone does not seem to pose a problem for the recognition of direction, and provide some leads for improvement of the feedback design.

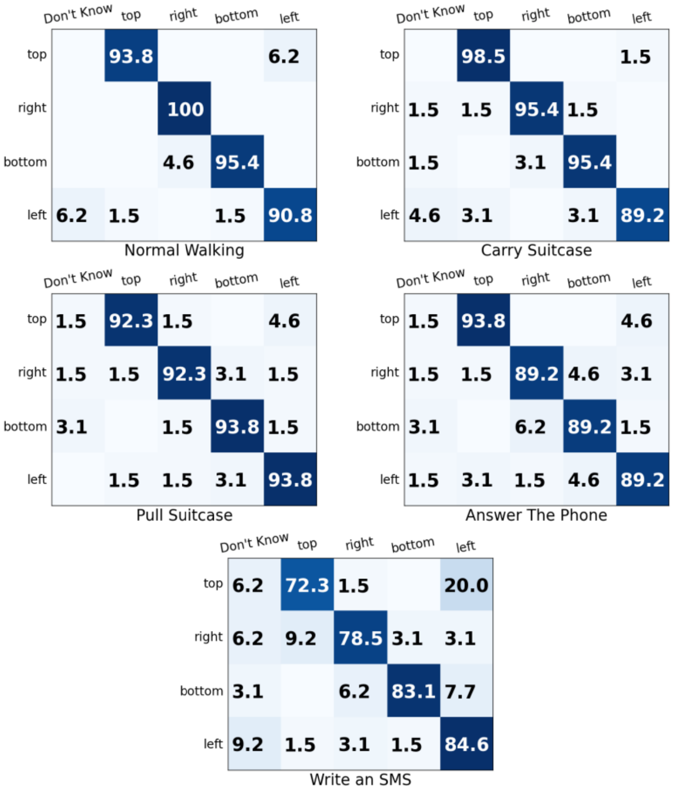

Fig. 6. Confusion Matrices for the 5 poses described. User responses are from left to right

4 Conclusion

We have investigated the feasibility of using a vibrotactile bracelet to convey simple directional cues. In particular, we have conducted a set of studies examining the potential issue of orientation change both in static and mobile conditions. The results show that the orientation of the user's wrist does not have a strong effect on the presentation of tactile directional cues. There was however, a clear effect of distraction as discussed in [10]. In future studies, more emphasis will be placed on the role of distraction in a real navigation scenario as it is likely to be an important factor in such tasks. Overall, we can conclude after this experimental validation, combined with positive feedback from our participants, that the wrist is an excellent candidate for the provision of passive vibrotactile feedback.

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