Identifying Tactors Locations on the Proximal Phalanx of the Finger for Navigation

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Abstract. Vibrotactile stimulation has been investigated to provide navigational cues through belts, vests, wrist-bands and exotic displays. A more compact solution would be the use of a ring type display. In order to test its feasibility, a user-centered experiment is conducted. The ability of participants to identify cardinal directions and inter cardinal directions by vibrotactile stimulation on the proximal phalanx is investigated. The results indicate that participants achieved 96% accuracy for cardinal directions and 69% accuracy for cardinal plus inter-cardinal directions using a static stimulation. The identification rates of dynamic stimulation are lower than that of static stimulation.

Keywords: Vibrotactile displays · Perception · Navigation · Ring device

1 Introduction

1.1 Navigation Using Tactile Stimulation

Navigation refers to the process of finding a way from one place to another. It implies asserting one's position in the environment and planning the next direction. In the following, we take an interest in the planning step only.

We usually rely on visual feedback in order to navigate but holding a map or a mobile phone while walking affect the awareness of the pedestrian [13]. Tactile has shown benefits in substituting vision since information can be conveyed to users without altering their perceptions of the surrounding environment [22]. Among tactile cues, vibrations are one of the most convenient. They can be generated using small actuators (tactors), resulting in easy-to-carry devices. Vibratory displays have shown their efficiency for in-vehicle and pedestrian navigation (e.g [3,10]), but are hardly used in everyday life.

Among existing solutions, hand-held devices have been proposed. Mobile phones that integrate one tactor are the most frequently used and handles composed of an array of tactors have also been advanced [4] but they prevent manual interactions and can induce fatigue. In a different strategy, hand-free systems have then been developed. Vibrotactile matrix have been integrated in gloves

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[21], body trunk systems (e.g [6]), anklets [2], forearm systems [16] and others. All these solutions have shown to support navigational tasks but are unlikely to be used for everyday life. Furthermore, the body trunk and the head are considered as personal areas and users acceptance can be an issue. An alternative can be found in wristbands displays. Prototypes that include one or two tactors [1,14] or watch with 6 tactors [19] have been proposed[1]. The wrist is however one of the less sensitive part of the body [23] and a more compact solution can be suggested through a ring device.

A ring display would be easy to carry, discreet and versatile since it can be adapted to any finger. The finger is a socially established part so user acceptance should not be an issue. Finally, it implies in part a tactile stimulation on the glabrous skin that is higly sensitive to vibration [18]. The solution then seems promising but the feasibility of such a device has never been investigated.

1.2 Feasibility of a Ring Device

A ring display would be made of tactors placed all around the finger and the location of the activated tactors interpreted as directional information. In order to be used for navigation, users have then to correctly localize the tactors, which is not guaranteed. The stimulation would be on the proximal phalanx of the finger and at this level the glabrous skin of the palmar surface is next to the less sensitive skin of the dorsal surface, the perception of vibrations could then be altered. The tactors would also be close from each other while localization rates are better with greater inter-disances (e.g [15,23]).

These drawbacks could be compensated by the spatial repartition of the tactors on the finger that makes information map body coordinates. A dynamic strategy could also be exploited. While a single tactor is activated during static stimulation, several ones are sequentially triggered during dynamic stimulation and recognition rates can be greatly improved using this strategy [20]. To test these hypotheses, a psycho-physical experiment is conducted. Four tactors are placed on the proximal phalanx of participants in order to map body coordinates. Their ability to identify directions using static and dynamic stimulation studied. The identification of cardinal directions is investigated (1). The identification of cardinal plus inter-cardinal directions is also examined (2).

2 Psychophysical Experiment

2.1 Set up

Four pancake tactors (*GoTronic* VM834, ∅ 8 mm, 3 V, 1200 rpm) are glued at ring level in the middle of the dorsal, volar and side surfaces of the index finger (Fig. 1 (a)). They are activated with a *Arduino Uno* card[2] controlled by a C++ program running on a Linux computer. The overall frequency is up to 3.5 kHz.

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[1] The latter is not specifically dedicated to navigation but it is a potential application.

[2] https://store.arduino.cc/arduino-uno-rev3.

Signals sent to tactors are 300 ms pulse at 3 V. The resulting vibration is about 200 Hz in the range of optimal sensitivity of Pacinian corpuscles (200 Hz ↔ 250 Hz) [11]. The tactors are fixed on the non-dominant hand of the participants, leaving the other hand free to provide feedback via a computer located on a table in front of them. The hand with tactors is placed palm down and the index finger raised using foam in order to prevent tactors/table and tactors/skin contact. The complete set up is shown in Fig. 1 (b).

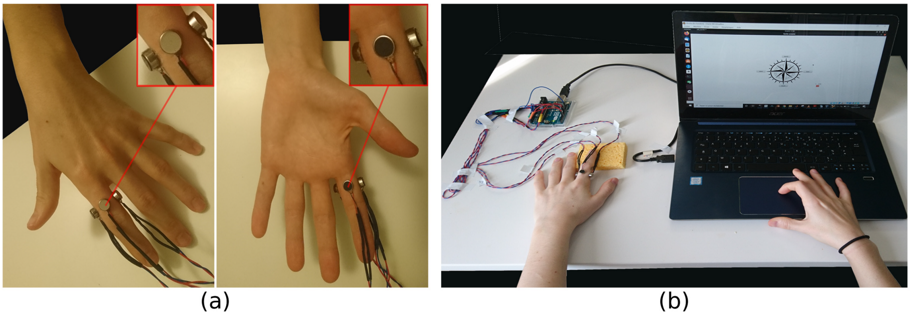

Fig. 1. (a) Pictures and close ups of tactors fixed on the proximal phalanx of the index finger. (b) Picture of the complete set up (tactors and computer) with a particpant.

2.2 Method

A compass and buttons corresponding to directions are displayed on the computer. Vibro-tactile stimulations are transmitted to the participants who have to identify the encoded directions, using a touch-pad to make responses.

During a session, the order of the stimulations is randomly predefined so it is the same between participants. Stimuli are tested in a row and no breaks are allowed. Once a participant gives an answer, no feedback is provided and the next stimulus appears after 3 s. Pink noise is played to them through headphones and they are not blindfolded but are asked to focus on the computer screen.

2.3 Participants

Eight participants (2 males), ages 27 to 43 (mean age 31 years ± 5.8), volunteer. They are selected because they do not report any visual impairment or physical issues. Seven of them are right-handed according to Coren's handedness test [5].

3 Identifications of Cardinal and Inter-cardinal Directions

3.1 Static and Dynamic Stimulations of Cardinal Directions

The ability of the participants to identify cardinal directions is examined. In a first session, static stimulation is tested. The tactors and the compass keep the same orientation (Fig. 2 (a)). The activation of the tactor on the dorsal surface of the finger corresponds to a North command, the tactor on the volar surface describes the South, a tactor on the side encodes the East and so on (Fig. 2 (b)).

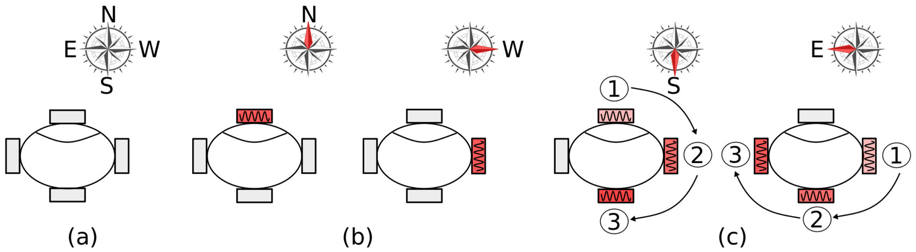

Fig. 2. (a) Relative directions between the index finger from face and the compass. Static (b) and dynamic (c) stimulation of cardinal directions. Sinusoids represent activated tactors and red color apparent locations of vibrations. Numbers and shades of red indicate a sequence of activation. (Color figure online)

In another session, dynamic stimulation is investigated. The tactors and the compass remains in the same positions, however three tactors are activated sequentially. For instance, the North is encoded by the activation of the tactor on the volar surface, the side and finally on the dorsal surface. The same scheme, always clockwise is chosen for the other directions (Fig. 2 (b)).

All the participants performed both sessions using a counterbalanced design in order to control potential effects of the order. During each session, each cardinal direction is tested 30 times for a total of 120 trials.

3.2 Static and Dynamic Stimulations with Inter-cardinal Directions

The ability of participants to identify inter-cardinal directions is investigated.

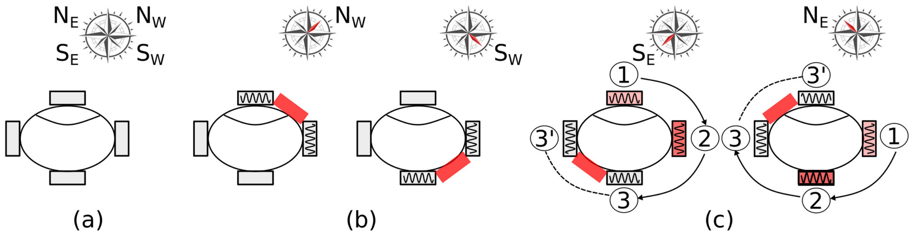

Fig. 3. Stimulations of inter-cardinal directions. See the caption of Fig. 2 for details.

While the tactors are only located at cardinal locations, inter-cardinal directions are simulated by activating two tactors simultaneously. The vibrations should be perceived in the middle [12]. Static and dynamic stimulations of inter cardinal directions using such dual tactors activations are explained in Fig. 3.

All participants tested static and dynamic stimulation. A counterbalanced design is again employed. During each session, each stimulation is tested 30 times for a total of 240 trials. This part of the experiment is conducted after the sessions testing only cardinal directions.

3.3 Identification Rates

Participant answers are entered into a response matrix so that correct responses are analysed. The percentages of correct identifications by participants and over participants are shown in Fig. 4.

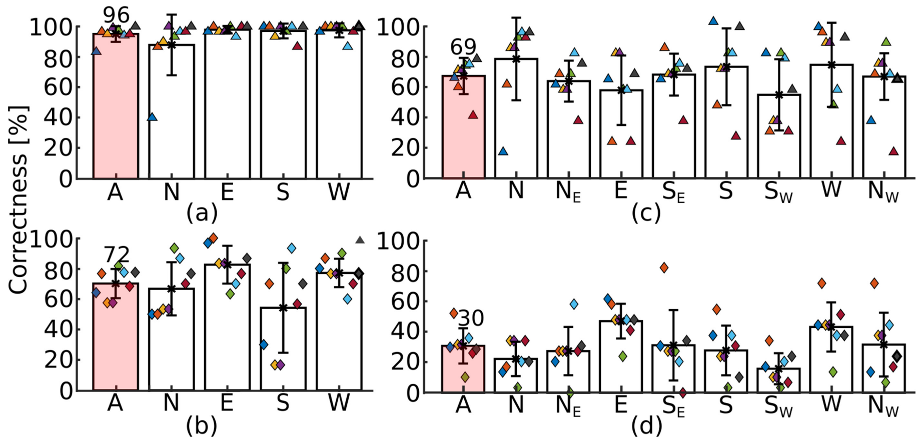

Fig. 4. Correct identifications of cardinal directions during static (a) and dynamic (b) stimumaltions, and of cardinal/inter-cardinal directions during static (c) and dynamic (d) ones. Individual results are exhibited by markers using one color by participant. Bars and errorbars represent the means and standard deviations over participants. "A" stands for All directions, "N" for North, "S_E" for South-East and so on. (Color figure online)

Participants are able to identify cardinal directions alone with great accuracy during static stimulation. The percentage of identification is closed to the perfect score with 96% (std = 5.1%) of correctness. However, the score drops by 24% reaching 72% during dynamic stimulation and a higher variability is exposed (std = 5.1%). To test whether the difference between static and dynamic simulations is significant, a non-parametric paired Wilcoxon signed-rank test (percentages don't follow a normal distribution) is used. The mean percentages correct over all directions are compared. The null hypothesis states that there is no difference between static and dynamic stimulations is rejected (p = 0.008). The alternative hypothesis then supports that the type of stimulations has an effect on correct identifications.

Other results are related to the tests of cardinal directions plus inter-cardinal ones. In static stimulation, the global identification is uncertain with an overall score of 69% and variability ($std = 11.5\%$). Inter-cardinal directions are not well recognized. In the dynamic case, the identification rate is even lower with only 30% ($std = 11.2\%$) of correct identifications. The statistical analysis is performed on these data and the null hypothesis is rejected ($\mathrm{p} = 0.012$), again supporting that the type of stimulations has an effect on correct identifications.

4 Discussions

4.1 Cardinal Identifications

Following the results of the experiment, the feasibility of a ring finger display for navigation is discussed. Cardinal directions can be transmitted efficiently using a static stimulation as shown by identification rates closed to the perfect score. A ring display could then be employed to navigate in cities that apply the Hippodamian model (or grid plan) and the tactile feedback will not need to be supplied by vision. Identification rates can reach perfect score during more casual simulations as it is the case during everyday navigation or by using a repeated command strategy.

The feasibility of the system should however be examined during a navigation task since conditions are likely to differ. For instance, results have been obtained while the hand orientation remains constant. According to past studies, wrist motions have a little negative effect on direction identification [17] and while they affect a little bit the detection, factors such as intensity can be adjusted to compensate [9]. Mobility should then not be an issue. However as phalanxes have a higher mobility than the wrist, this point should be further explored.

4.2 Inter-cardinal Identifications

The use of a ring display in places that do not apply Hippodamian model is however challenging since the transmissions of inter-cardinals directions are approximate. Identification rates of cardinals directions are even lower when inter-cardinal are displayed than when they are not. Participants have then difficulty to differentiate the activation of one and two tactors. Additional tactors placed at inter-cardinal locations instead of dual tactors activation should lead to the same results, or even wors. The higher the number of tactors, the harder the identification [8], especially since they will no longer be on noticeable loci.

The use of a dynamic pattern does not help. Results for dynamic simulations are associated with poorer identification rates than static simulations in both part of the experiment. The simultaneous activation of three tactors was confusing for participants and this issue may results from the short inter-distance between tactors or a wrong choice of pattern. This pattern was chosen as a compromise between long motion and limited activation of tactors. Based on the results, different patterns should be explored. In the same way different type of dynamic stimulation have been tested on other body parts (e.g the back [7]), the same should be done on the phalanx.

An alternative solution could be to exploit temporal pattern. The identifications of cardinal directions only during static stimulation are accurate and correspond to discrete feedback. Cardinal directions displayed with short breaks could then encode inter-cardinal directions. North-East would correspond to the activation of the North, a few milliseconds break, then the activation of the East only. This solution could also answer the variability issue. Indeed dynamic patterns and direct presentations of inter-cardinal directions both increase between-subject variability. This issue can be raised because of different phalanx dimensions or type of skin that may have a detrimental effect on vibrations propagation. The static stimulation however minimizes the issue.

5 Conclusions and Perspectives

The feasibility of a ring vibro-tactile display for navigation have been investigated in a user-centered experiment. Participants were able to identify accurately cardinal directions transmitted by static stimulation of four tactors at ring level. The transmission of inter-cardinal directions was more challenging and a dynamic stimulation was not beneficial. A research will work towards the test of patterns that could be recognized accurately as inter-cardinal directions.

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