Proceedings of EuroHaptics 2004, Munich Germany, June 5-7, 2004.

Waypoint Navigation on Land: Different Ways of Coding Distance to the Next Waypoint

Hendrik-Jan van Veen, Migh Spapé, Jan van Erp

TNO Human Factors, P.O. Box 23, 3769 ZG Soesterberg, The Netherlands
{vanveen, vanerp}@tm.tno.nl

Abstract. We investigated experimentally the feasibility of using a tactile display developed by TNO Human Factors as a wayfinding aide for soldiers in the field. Participants walked ten routes on a open field, each route consisting of six waypoints. The participants used the PeTaNa tactile wayfinding aide on all trials. PeTaNa is a wearable system that presents navigation information based on predefined routes, a GPS system, and an electronic compass. A minicomputer calculates the navigation input on the basis of heading and distance to the next waypoint. The navigation messages are presented on a tactile display consisting of eight tactors on a belt around the torso. PeTaNa proved to be a very efficient navigation tool, as after approximately 30 minutes (5 routes) all participants demonstrated very acceptable effective walking speeds (4…4.5 km/h). The differences between the coding alternatives for distance to the next waypoint were surprisingly small.

1 Introduction

We report on an experimental feasibility study on waypoint navigation on land using a tactile display developed by TNO Human Factors (TNO-HF). Tactile displays are displays for the skin, very much in the same way that visual displays are displays for the eyes. The principal advantages foreseen in using a tactile aide for wayfinding are that:

1. the individual soldier no longer needs his/her hands and eyes to use map and compass but can rely on skin stimulation for walking[1] between waypoints. This frees his/her hands and eyes for other tasks and saves time,
2. the information from the tactile aide is provided in a very direct and intuitive manner. This saves time and helps avoiding human error,
3. by making wayfinding information continuously available, the soldier is supported in maintaining situation awareness with respect to the wayfinding task at all times.

---

[1] The principles applied here do not restrict the soldier to walking. A tactile wayfinding aide could function just as well during walking as during other modes of transportation such as driving.

2. SCIENTIFIC RATIONALE

The human skin contains a variety of different sense organs that respond to thermal, mechanical, and electrical stimulation. In particular, the Pacinian Corpuscles (PC) in the skin are known to be sensitive to mechanical vibrations in a wide range around 250Hz. Upon local stimulation of the skin with such vibrations, humans are very well capable of indicating where the skin is vibrated. In 2000 we demonstrated that when different points on a circle around the torso are stimulated in this way, humans are readily prepared to indicate a direction in the outside world to which each skin stimulation corresponds [3]. We call this phenomenon the “tap-on-the-shoulder” principle: a vibro-tactile ‘tap’ on the body is intuitively associated with an external direction. Such external directions can be used to direct attention to points, directions, or events in the outer world.

In the past couple of years, researchers at TNO-HF and a small number of other laboratories around the world have applied this principle to various different situations. Applications investigated include car driving/navigation [4], orienting oneself in microgravity/space environments [8,10], controlling high speed powerboats [2], helicopter hovering [6,11], and counteracting spatial disorientation in fast jets [7]. At TNO-HF we made several different prototype tactile aides for these different applications. For waypoint navigation in two dimensions we built in 2002/2003 the PeTaNa system (Personal Tactile Navigator). This wearable system consists of a tactile display, currently a belt with eight tactors (vibro-tactile actuators) worn around the torso, plus GPS, compass and computing power.

Scientific studies about wayfinding using tactile aides on land are very scarce. Some work has been conducted in Canada (Humansystems Inc., Ontario, sponsored by DRDC) and the UK, but very little is found in the open literature (e.g., see [1,9]). Even so, the experience obtained so far in the different applications domains suggests to us that indicating the direction to the next waypoint on land using the “tap-on-the-shoulder” principle is a feasible approach. The experiment reported below, therefore, has been designed to:

- prove that waypoint navigation on land using a tactile aide is indeed feasible, and
- investigate how different ways of conveying information about the distance to the next waypoint affect wayfinding performance.

3. DESIGNING CODING ALTERNATIVES FOR DISTANCE

Besides location on the body, the main parameters of a vibro-tactile display are timing, amplitude, and frequency. Of those three, the latter two are not very well suited to code information, because the number of perceptually distinguishable levels is low (in the order of 5-7 under optimal conditions, see [5]). Therefore, as the first design step, we decided to use timing (or rhythm) as the coding parameter. The second design step is then how to translate different distances into specific rhythms. We used the following two approaches:

1. use a monotonic relation between distance and rhythm. This could be implemented in several ways, for example as a function of relative distance (e.g., the fraction of

the distance between last and next waypoint that has been completed) or as a function of absolute distance.

2. apply a three-phase model, based on the following assumptions. The first few meters after reaching a waypoint (phase 1) are important, because the user has to change direction towards the next waypoint and therefore would like to receive high-density feedback from the system. In the middle phase between two waypoints (phase 2), the user requires less feedback, and possibly merely needs a confirmation that he/she is still on track. Finally, when the user closes in on the waypoint (phase 3), again high-density information is needed. This is particularly true when the user does not approach the waypoint perfectly towards its centre.

To test the effect of distance coding on waypoint navigation we implemented five different coding alternatives in the PeTaNa navigation device according to the approaches above. In summary: in the present experiment direction information was always coded with the location on the torso (each of the eight tactors covering a 45° sector in the horizontal plane), and distance information was always coded with the temporal rhythm of the vibration.

4. METHOD

4.1 Participants

Twelve participants were tested: 6 females and 6 males, ranging in age between 18 and 24. All were in good condition. They were paid for their participation, and had signed the informed-consent agreement after extensive written and verbal instructions of the methods used in the experiment.

4.2 Apparatus

The main components of PeTaNa (minicomputer, compass, and batteries) were housed in an aluminium box with a GPS receiver on top of it to minimise electromagnetic interference. The box itself was placed inside a stable survival-backpack worn on the back, resulting in a self-contained wearable system. Information about current position and compass angle were sampled by the 486 computer at a rate of 1 Hz. Based on the location of the next waypoint, the computer calculated the desired heading and activated the vibro-tactile actuator closest to the relative direction (i.e., with respect to the current heading of the observer) of that next waypoint. The computer in the box connected to a belt with eight vibro-tactile actuators. These tactors were placed at adjustable distances on an elastic strip. The location of the elements was adjusted so that the elements were pointing in 45 degree angles, independent of the size and form of the wearer’s torso. The 1.5 by 2 cm tactors were custom built by TNO-HF and were based on pager motors such as those used in mobile phones. The tactors vibrated with 160Hz and were turned on for one second at a time. The pause between subsequent one second pulses depended on the distance to the next waypoint and the experimental condition, see next section. Reaching a waypoint (i.e., being within 15 m) was communicated to the user by making all eight tactors vibrate together for one second. On reaching the final destination (the final waypoint on a route), all eight elements vibrated once every two seconds, until the device was rebooted or a new waypoint was selected

4.3 Design

We used a within-subjects approach with ten different routes and five different conditions, and created random sequences of the conditions to balance any condition-learning effect. Thus, each participant walked the ten predefined routes in the same sequence, while combinations of routes and conditions differed between participants. The same sequence of conditions was used within each participant for the first five (training-routes) and the last five (testing-routes) routes. All routes were between 360 and 390 meters in length, and all used the same two locations as first two waypoints. Each route consisted of 6 waypoints located on an open field of grass of about 110 x 90 meters, surrounded by bushes. Apart from the first (start walking) and the second (start measuring) waypoint, all waypoints were placed on different locations for different routes. A total of five conditions was used:

1. Three-phase model in absolute mode. Phase 1: first 15m, pause 2s; Phase 3: last 20m, pause 1s; Phase 2: pause 6s.
2. Three-phase model in relative mode. Phase 1: first 10%, pause 2s; Phase 3: last 10%; pause 1s; Phase 2: pause 6s.
3. Monotonic model in absolute mode. The pause was 1/10th of the number of meters left to the next waypoint (i.e., every second of pause signalled 10 m of distance). However, in the first 15 m of a leg (the path from previous to next waypoint), a signal was given every 2s, otherwise the pause would have been too long to pick up the new heading. Formally this could be considered a two-phase model.
4. Monotonic model in relative mode. The pause started at 10s and was reduced with 1s for every 10% closer to the waypoint.
5. Control condition. Pause duration was fixed at 2s.

4.4 Procedure

After reading the written instructions, participant and experimenter walked to an open field of grass. During this walk and during training, participants were told which condition was oncoming and what they could expect (e.g., ‘the vibration-rate will increase as you come nearer to your target waypoint’). Subjects were instructed to finish the experiment as fast as possible, while maintaining a normal walking speed. During the training, the experimenter was allowed to correct unwanted behaviour such as walking in the bushes. The five training routes took on average around 30 minutes in total, while the five testing routes lasted approximately 25 minutes together.

5. RESULTS

All participants were able to complete all routes without problems. Based on the data logged by PeTaNa, we calculated the effective walking speed as the leg distance (distance along a straight line between two waypoints) divided by the walking time. To our surprise, there were no significant differences between the five distance coding conditions on the effective walking speed. One of the major reasons for this might be insufficient training. The within-subjects design resulted in a change of distance coding after each route. Combined with a single route during the training, this makes it more or less first shot performance and too little training to really learn the meaning of a specific coding. Closer inspection of the data revealed that the two monotonic models were better at short distances (< 85 m) than the two three-phase models (see Fig. 1). An important observation is that the control condition was walked faster than all other conditions, independent of distance.

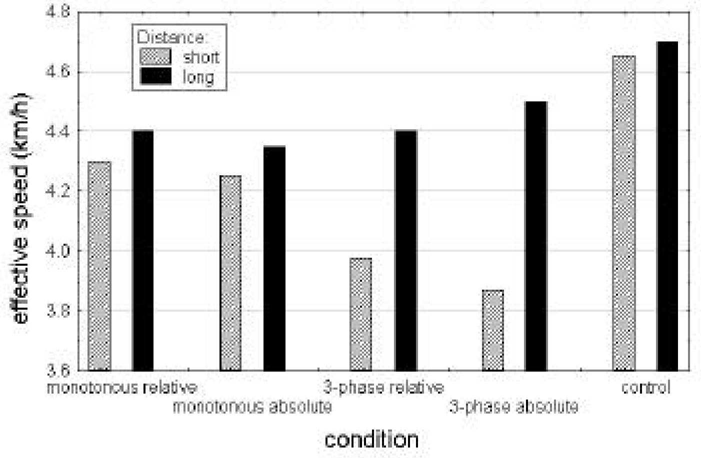

Fig. 1. Effective walking speed as a function of condition and distance to the next waypoint. Higher numbers indicate faster speeds and therefore better performance

6. CONCLUSIONS

PeTaNa proved to be a very efficient navigation tool, as after approximately 30 minutes (5 routes) participants demonstrated very acceptable effective walking speeds (4…4.5 km/h) which are somewhat below normal walking speeds (please note that effective walking speeds do not compensate for ‘zigzagging’, meaning that a detour reduces the effective walking speed). So, PeTaNa offers a remarkably intuitive system that is quickly learned to a very efficient extent.

In general, the differences between the coding alternatives were small, but navigating was slightly more efficient in the condition in which participants received feedback unrelated to distance-to-next-waypoint (the control condition). We suspect this may be due to the fact that whenever someone is walking the wrong way, he or she primarily needs to have information on how to correct his or her behaviour. While in the distance-related feedback conditions participants had to wait for 5-8 seconds at this point of ‘directional uncertainty’, latency in the constant feedback condition was relatively short: always 2 seconds. This theory may or may not be proven justified after future research on PeTaNa, but partly based on participants’ verbal reports we would strongly advice to keep the frequency of feedback always at or above a minimum of 1 vibration every four seconds.

REFERENCES

1. Bosman, S., Groenendaal, B., Findlater, J.W., Visser, T., Graaf, M. de & Markopoulos, P. (2003). GentleGuide: An exploration of haptic output for indoors pedestrian guidance. In: *Proceedings of the Mobile HCI*, 8-10-2003, Udine, Italy (in press).
2. Dobbins, T. & Samway, S. (2002). The use of tactile navigation cues in high-speed craft operations. *Proceedings of the RINA conference on high speed craft: technology and operation.* Pp. 13-20. London: The Royal Institution of Naval Architects.
3. Erp, J.B.F. van (2000). *Direction estimation with vibro-tactile stimuli presented to the torso: a search for the tactile ego-centre* (Report TM-00-B012). Soesterberg, The Netherlands: TNO Human Factors.
4. Erp, J.B.F. van & Veen, H.A.H.C. van (2001). Vibro-Tactile information presentation in Automobiles. In: Berber, C., Faint, M., Wall, S. & Wing, A.M. (Eds*.). Proceedings Eurohaptics 2001*. Pp. 99-104. Birmingham, UK: Univeristy of Birmingham.
5. Erp, J.B.F. van (2002). Guidelines for the use of vibro-tactile displays in human computer interaction. In: *Proceedings Eurohaptics 2002*. Ed. By S.A. Wall (et al.). Edinburgh 2002. P 18-22.
6. Erp, J.B.F. van, Veltman, J.A., Veen, H.A.H.C. van & Oving, A.B. (2003). Tactile torso display as countermeasure to reduce night vison goggles induced drift. In*: NATO RTO HFM panel symposium on “Spatial disorientation in military vehicles: causes, consequences and cures”*, La Coruna, Spain, 15-19 April 2002. RTO-MP-086. P 49.1-49.8
7. Erp, J.B.F. van, Bos, J.E., Groen, E.L. & Veen, H.A.H.C. van (2003). *Een tactiel vest als instrument om spatiële desoriëntatie tegen te gaan* (Report TM-03-A017). Soesterberg, The Netherlands: TNO Human Factors.
8. Erp, J.B.F. van & Veen, H.A.H.C. van (2003). A multi-purpose tactile vest for astronauts in the Internation Space Station. *Proceedings of Eurohaptics 2003*, Dublin, Ireland.
9. Ertan, S., Lee, C., Willets, A., Tan, H. & Pentland, A. (1998). A wearable haptic navigation guidance system. In: *Digest of the Second International Symposium on Wearable Computers*, 164-165.
10. Rochlis, J.L. & Newman, D.J. (2000). A tactile display for Internatinal Space Station (ISS) extravehicular activity (EVA). *Aviation, Space, and Environmental Medicine, 71 (6),* 571-578.
11. Rupert, A.H. (2000). Tactile situation awareness system: proprioception protheses for sensory deficiencies. *Aviation, Space, and Environmental Medicine, 71,* A92-A99.