The Influence of Vibration on Performance of Navigation Tasks

Ming-hui Sun[3], Wen-zhao Gu[1,2](✉), Ming Ding[5], and Xiao-ying Sun[4]

[1] National Space Science Center,
Chinese Academy of Sciences, Beijing 100190, China
guwz2014@163.com
[2] University of Chinese Academy of Sciences, Beijing 100190, China
[3] College of Computer Science and Technology,
Jilin University, Changchun 130022, China
[4] College of Communication Engineering,
Jilin University, Changchun 130022, China
[5] Nara Institute of Science and Technology, Ikoma, Japan

Abstract. In this paper, we explore the efficiency of vibration feedback techniques in pedestrian navigation systems. For vibration feedback technology, many researchers have provided a variety of different modes of vibration, such as vibration belt, vibrating bracelet and vibration shoes. And there are some researchers to discuss the perception of the human body parts, which part is more suitable for vibration feedback. However, there are still some discussion points that are not taken into account, for example, the identification rate of vibration feedback mode in the processes of walking or running. In order to find the answer, we rebuild the vibration feedback mode to have a new experimental evaluation of the identification rate of these vibration modes. We noticed that when using a hand-held vibration feedback device, it can reduce the visual and auditory feedback. On the other hand, because of the rapid development of the current society, the environment is different in different position, so, when getting the maximum recognition rate of vibration pattern, we can't use this vibration navigation replace the existing navigation completely. However, it is a good choice that the kind of high-efficiency vibration feedback navigation system is used as an auxiliary system of the existing navigation.

Keywords: Tactile feedback · Mobile device · Multiple vibration motors

1 Introduction

It is a huge challenge for us to find an appropriate travel path that we want in a strange environment. It usually takes navigation instruments to learn the surrounding environment is what kind of, destination in which and the space position relationship with

---

Supported by the National Youth Natural Science Foundation of China (No. 61300145), the Postdoctoral Science Foundation of China (2014M561294), the Science and Technology Development Program funded projects of Jilin Province (20150520065JH) and National Key Research and Development Program of China (No. 2016YFB1001300).

G. Sun and S. Liu (Eds.): ADHIP 2017, LNICST 219, pp. 307–318, 2018.
https://doi.org/10.1007/978-3-319-73317-3_36

the surrounding buildings. In order to become familiar with the unfamiliar environment, many people sometimes need to adapt to the current unfamiliar environment. But when there is no navigation equipment, it is difficult for us to find the path that we want. This makes the application of navigation system become widespread. However, most of current navigation systems use visual feedback or audible feedback manner to pass the navigation information, and the use and application of the scene is relatively single, only the driving trip. It's difficult to apply to the scene, such as walking, which greatly limits the navigation system more widely used.

Tactile vibration has been used another way to provide haptic feedback on touch screen equipment [1–5], when users touch the target on the screen (buttons, drop-down menus, etc.), the device's vibration motor will produce vibration. This way can help users determine whether they touch the target object. Thus, the expression of vibration technology information is an effective mode of human-computer interaction and information delivery methods [6], and as an important delivery channel of information, to make up for the shortcomings and deficiencies in specific conditions (When in a noisy environment and other public places, the navigation voice of navigation system and other surrounding sounds mixed together, making it difficult for the user to identify, which will make voice broadcast efficacy may be greatly reduced or even useless; if the navigation instruments are used in walking, it's not easy to long time staring at the screen to observe the navigation path, which will display the navigation function is not the ultimate role to play; if the headphones are used that based on the voice prompt, which will hinder the whistle sound like vehicle and other sound effects with great navigation). A recent report [11] shows that in smart phone users under the age of 30, 62% of the people encountered serious car accident case since playing with mobile phones not to look at the road, and 43% of people have been aware of this potential threat. It is necessary for us to focus on the road conditions when the vehicle is long. In this case, the use of visual and auditory navigation system has been greatly restricted. And an auxiliary navigation system can be of great help, such as driving travel tasks [12–14] or pedestrian navigation [14–16]. Vibration feedback technology is a good choice for the auxiliary navigation system. The vibration feedback technology can not only help people with normal vision, but also have great help to people who have a disability. This technology can also be used in many ways, such as driving travel and walking, and has broad application prospect.

We found a navigation path by a hand-held device to pass navigation path information to their user. We adopt this kind of form mainly because of the current mobile device and the widespread existence in our daily life, and that can make this kind of technology have great adaptability. Our navigation system includes two types of feedback - speech (semantic) feedback and vibration feedback - to provide between two exact location and path information.

The main contribution of this project is to design and implement a vibration navigation system, which provides navigation path information to users by vibration feedback in many different situations. Our navigation system is composed of a mobile device with a touch screen and a hardware device that generates vibration feedback. The vibration part of the hardware device is placed on the top of the diamond with 4 vibration motors (Fig. 1). When the user takes the device, it can generate different vibration modes according to the different positions of the palm and fingers.

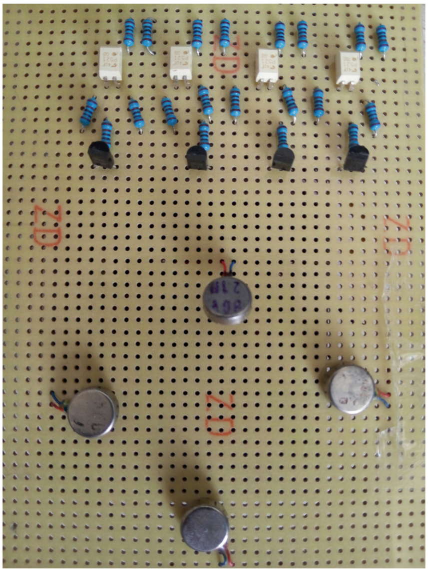

Fig. 1. The hardware parts of vibration navigation system and the location of the four vibration motor

In this paper, we first discuss the research on the information related to the mobile touch screen device and the vibration feedback technology. Secondly, we will describe our prototype system and various vibration modes in this project. Thirdly, we will describe an experiment to detect whether a user can accurately distinguish between different vibration modes, and traveling at different speeds, the system interacts with the user's productivity. Finally, we summarize the whole thesis and plan for the future work.

2 Related Work

Vibration feedback technology has been used as an important interface for the user to interact with the touch screen device and it has been familiar with the majority of users [1, 3, 5]. In this section, we will review the previous vibration tactile feedback technology on mobile devices, and focus on the wealth of information that is intended to convey, rather than a simple vibration. Why do we need vibration feedback? The simple reason is that the feedback is more intuitive, and in many cases, we do not need to look at the screen, we know our own operation effect.

2.1 Vibration Feedback Technology on Mobile Devices

Today, the touch screen has been widely used in a variety of mobile devices, such as smart phones, tablet PCs and music players. Most of these devices provide users with vibration feedback through the vibration motor embedded. Fukumoto and Sugimura may be the first researchers that the vibrators are embedded in the Active Click system [1] for the user to know the details of their touch event on a touch screen. In the Active Click system, it can be used for user to know that they touch a project on the display, and the way of vibration feedback can help to complete a variety of tasks, such as information input [3] and list item selection [2].

For one vibration motor, it can provide a variety of different vibration modes by changing the frequency and intensity of the vibration. Poupyrev et al. Research shows that different vibration modes can convey different information, and the method of vibration feedback can be used to improve the speed of selection in the linear list with the increase of 1/5. And the combination of multiple vibration motor can generate more vibration mode, which can be transmitted to the user more information. On the other hand, the mobile device can be attached to the vibration motor, which can be used to provide vibration feedback to the user, rather than the vibration motor embedded in their own. Brown et al. had placed the multiple vibration motor attached on the participants' arm to obtain the vibration feedback to transmit the calendar information [7].

These projects described have shown that different vibration modes can transmit the different task information to the user. These different vibration modes can be generated by controlling the number of vibration motor, vibration frequency and vibration intensity. The multiple vibration motors placed in the body of the participants will have a greater use of space. However, the placement of multiple vibration motors is also a significant problem. Sahami et al. placed six vibration motors on both sides of the smart phone (three per side) in order to test the accuracy of distinguishing the different vibration mode [8]. In their experiments, the results show that the accuracy of the 8 different vibration modes can be reached by the 70–80%, but they are difficult to distinguish the position of vibration source at each time when a vibration motor is generated, and at that time, the accuracy of the average can only reach 36%.

2.2 Existing Navigation System

Today, navigation system has been widely applied to people daily life. When driving, there will be a vehicle-mounted navigation to guide for us, and when walking, navigation equipment on the mobile device will become essential. These two kinds of common navigation instruments have become an indispensable product of our daily travel, and both of them are used visual feedback and auditory feedback to remind the travel path. Auditory feedback is that the navigation instrument transmit the path information to the user through the voice broadcast function; visual feedback is that a navigation instrument displays the path information on the screen for the users to see and obtain navigation path information. However, both of them have some disadvantages. For example, on the visual feedback, users can't be a long time staring at the screen to observe a navigation path information, the screen can not work for a long time and power supply system will also be a problem difficult to solve; on the other hand, on the auditory feedback, if the user's environment is too noisy, voice broadcast will greatly reduce the efficiency, even be in failure, and if the headphones are used, the sound of great navigation like vehicles whistle sound will be limited, which makes the traveling at a greater risk of environment. Meier et al., who have studied the human sensory perception which part is more suitable for vibration, placed vibration feedback system on the top of the shoes [17] and made a confirmed study, but the study is lack of the research of travel speed.

The application situation of navigation system described above is relatively simple, such as car navigation systems generally only apply to the process of driving velocity or position of great rapid changed, navigation instrument on the mobile device can only have a greater effect on the lower speed of movement. Therefore, the use of them has been limited. However, tactile vibration feedback can play a role in a noisy environment or a variety of moving speed. In a noisy environment, the auditory feedback is limited, but the vibration feedback can be used to provide the travel path information which can not be disturbed by surrounding noise; when in different speeds, the vibration feedback is used to provide travel path information, which can not be limited by the speed of travel, such as driving and walking can use the same navigation instrument. As a consequence, the vibration feedback can play a role in many different situations.

3 System

The vibration navigation system is a kind of navigation system which is designed to be able to be used in different situations and to use the vibration feedback to remind the navigation path information. The difference between the vibration navigation system and the existing navigation system is that it increases the vibration feedback, and uses the voice broadcast and vibration feedback to transmit the path information. In next section, we will describe the hardware part of the vibration feedback and voice broadcast, and the different vibration modes.

4 Hardware

Figure 2 shows the hardware part of our vibration navigation system. Similar with SemFeel [9], we welded a circuit board, the circuit board contains four vibration motors, respectively, in accordance with the upper and lower left and right four directions. The distance between two vibration motors is greater than 1 cm, because there is a study shows that when the distance of two vibration source is not more than 1 cm, if the vibration source is generated, it will be difficult to distinguish which vibration source is [10]. The circuit board is connected with a single chip microcomputer and a Bluetooth module. The single chip microcomputer is used to control the vibration of the motor, the Bluetooth module is used to receive the navigation path information, and the circuit board is connected with a battery box for power supply.

Voice broadcast uses iFLYTEK speech technology broadcasting technology to broadcast. In mobile devices, the path information is transmitted to the iFLYTEK speech technology broadcast module. When obtained the path information, it uses the speech broadcast technology to broadcast to complete auditory feedback function.

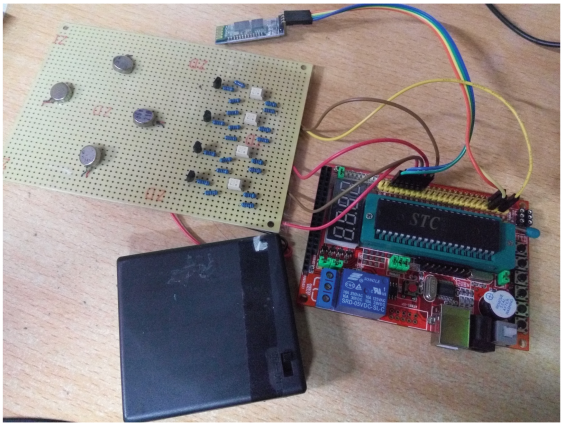

Fig. 2. Hardware

5 Interactive

Our vibration navigation system includes software and hardware. The software part is installed on the mobile device, and the starting point and the destination of the navigation path are finished by the software part. After the input is completed, the path planning is performed to obtain the navigation path information which is passed to the hardware to generate vibrations via Bluetooth technology; In the hardware part, the navigation path information is obtained from the software by using the Bluetooth technology, and the information is processed to control the multiple vibration motors to generate different vibration feedback.

When the vibration mode is generated in the hardware device, the different vibration modes can be generated according to the number of vibrator, the order of vibration and frequency and intensity. In our equipment, we use the number of vibration motor and the order of vibration to generate different vibration modes, not to consider the vibration frequency and intensity of these two factors. In the vibration of each vibration motor, we set the vibration time of 500 ms, 1000 ms and 1500 ms, because a longer time of vibration may be not practical.

6 Vibration Feedback Mode

Figure 3 shows that we designed 11 kinds of vibration modes. These vibration modes are divided into four categories: single motor vibrations (left, right), two motor vibrations (upper-right, upper-left, right-upper, left-upper, down-upper), three motor vibrations (right-upper-left, down-upper-left, down-upper-right), four motor vibrations (left-down-right-upper). The 11 kinds of different vibration modes represent different turning when driving or walking. In the following experiments, each vibration motor is only set one kind of vibration intensity in our equipment, because we mainly want to observe the accuracy rate of different vibration modes in various situations, and the recognition degree of vibration feedback mode in many situations.

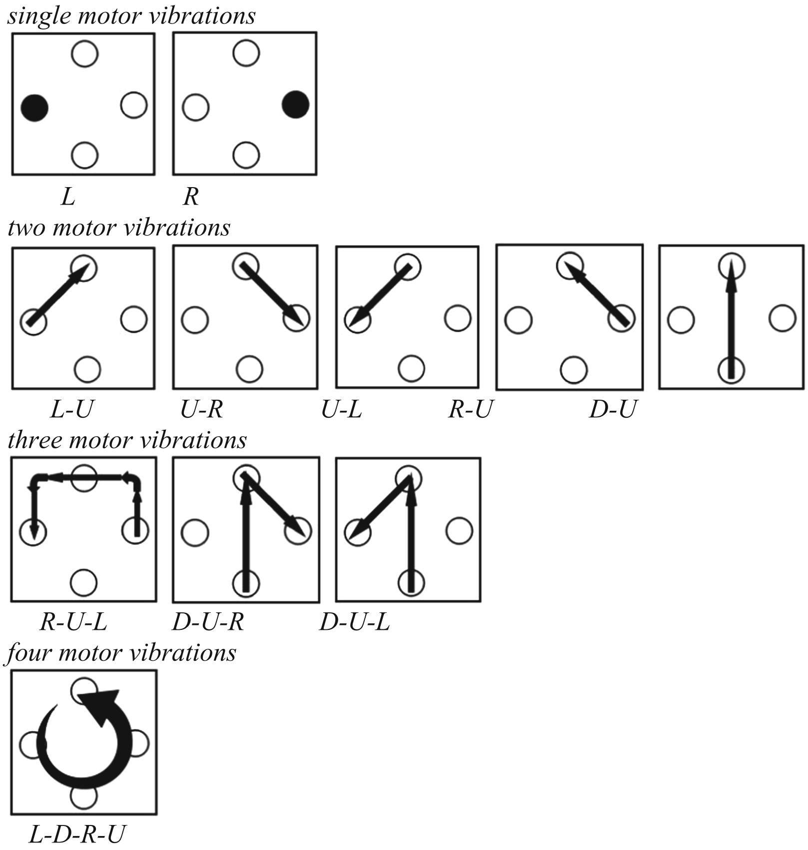

Fig. 3. The eleven kinds of vibration modes (U represents upper, L represents left, R represents right, D represents down)

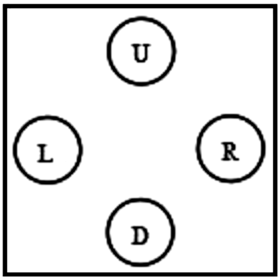

Fig. 4. Vibration direction (U represents upper, L represents left, R represents right, D represents down)

7 Experiment: Recognition Rate of Vibration Direction Under Different Moving Speed

Participants
Twelve people (six male and six female, aged 18 to 40) were recruited for this experiment. One male and one female used the left hand to carry out the experiment, others used the right hand of the experiment, and all of them often used the smart phones and other mobile devices with the vibration function. All the participants were compensated for their time and effort with 20 yuan.

Apparatus
In this experiment, we used the vibration direction shown in Fig. 4. We installed the software on the Android smart phone, and the software part was written in Java language, running on the Android platform. The hardware part written in C language ran on the C51 microcontroller. The software and hardware parts were connected by the Bluetooth.

Variables
In this experiment, the independent variable included four vibration positions (upper, left, right and down) and three kinds of movement (motionless, walking and running). According to the study, the average walking speed was 1.25 m/s, we set the average value for our experiments in the speed of walking [18]. The speed of running would be changed according to different people and different external factors. We had done a preliminary experiment before the experiment for the running speed. We made the average value of 4.5 m/s as the speed of our running. In this experiment, we measured the perception rate of vibration direction. In this experiment, the vibration direction and velocity were the main variables of our study. Each participant needed to take part in:

$$4(\text{directions}) * 3(\text{movements}) * 3(\text{repetitions}) = 36 \text{ trials in total.}$$

Procedure
Before the start of the experiment, we explained the purpose of the experiment and the experimental process to the participants. After the end of the explanation, the participants started to be familiar with the equipment and vibration modes. Each experiment equipment vibrated at least three times, and the interval time was 5 s. After three vibration was completed, the participants rated the ease of perception of the vibration on a 7-point Likert scale [19] (the 1 represents the most difficult to perceive the vibration mode, and the 7 is the easiest to perceive the vibration mode) to record every time the degree of perception. Meanwhile, the participants made an oral evaluation of the vibration mode, and the experiment organizers took notes.

In this experiment, the vibration direction was random. Each direction of the experiment was in the three movements of motionless, walking and running. When walking and running, we all used the same walking machine.

After the end of all the trials, each of the participants would have to fill in a questionnaire (see Fig. 5). In the questionnaire, the participants were asked about the interval of vibration time, the vibration mode, the system's evaluation and

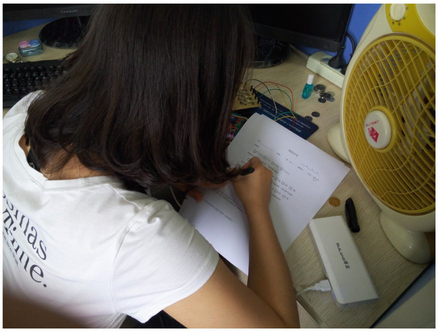

Fig. 5. Questionnaire survey

improvement suggestions and other issues. When the experiment was over, the participants were asked if there is a suggestion or question to the system. It took around one hour for each participant to finish the experiment.

8 Experiment Results

When the speed is less than or equal to 5 km/h, it is in a state of walking, and when the speed is greater than 5 km/h, it is running. After measuring, when the vibration time was 500 ms and the participants were able to feel the vibration, the maximum speed could reach 10.5 km/h. At that time, we had felt weak. On the other hand, when the vibration time was 1500 ms and the participants were able to feel the vibration, the maximum speed could reach 11.2 km/h. At that time, we also had felt weak. In summary, when the traveling speed is less than 10 km/h, the accuracy of vibration perception of the four directions could reach more than 90%. When the traveling speed between the 10 km/h–11 km/h, according to the vibration of long sequence from short to long, the accuracy of vibration perception would gradually reduce. When the speed was greater than 11 km/h, the three vibration time of the current equipment were close to the failure. However, if the vibration time were increased, it will still play a role in vibration perception.

9 Experiment Discussion

The experimental data and conclusions are basically satisfied with the original idea. In this experiment, the accuracy of vibration perception can reach more than 90%, and the error of the vibration perception is caused by the following several points:

(1) Vibrator is stuck to the circuit board, so all the vibration equipment are in vibration. Thus, it is difficult to perceive the vibrator vibration correctly.
(2) In the actual walking process, when the walking speed is faster, but the vibration intensity is weak, the vibration perception is not very obvious.

(3) When the vibration time is too short, vibration perception is not obvious and not easy to distinguish the vibration direction.
(4) The actual initiation voltage of each vibrator is different, when using the same power to supply, the vibration strength is not consistent.

We only need to miniaturize the device and change the vibration time to enhance the user's vibration perception. In addition, we need to further explore the recognition rate of our vibration mode at different speeds of walking process, in order to study the speed of travel and the recognition accuracy of different vibration mode in the case of perceived range.

10 Conclusion and Future Work

Vibration feedback effectively increases the application range of the navigation system, especially when the user can not directly view the touch screen. In this paper, we restore the hand-held vibration feedback device which connect with a plurality of vibrators embedded to explore the recognition rate of vibration feedback modes under different moving speed. Our two experiments showed that the accuracy of the user's identification of the vibration direction can reach about 90% when the travel speed is less than or equal to 10 km/h. For the 11 vibration modes, the accuracy of identification is not high and only about 70%, but the idea or direction is correct, it just need to improve the experimental equipment and experimental steps to improve the identification accuracy of the vibration mode.

We believe that we can accomplish the goal of assisting the existing navigation technology or navigation equipment by improving the identification accuracy of vibration mode, and can provide users with more convenience. The experimental results of this paper show that the design of vibration mode in vibration navigation technology needs to be further improved in order to improve the recognition accuracy of vibration mode. Because the vibration mode is higher, the vibration feedback technology can be better to assist users in navigation. In addition, this navigation can be carried out in a variety of situations to navigate, without considering the changes in the environment (within the carrying capacity of the device). This system can make people's sense focus on a single task, as far as possible to avoid the emergence of a variety of tasks in the same sense. We believe that this vibration navigation system will be used as an auxiliary system for existing navigation system to give many travelers bring great convenience.

In the future work, we will gradually improve the vibration navigation system (for example, to modify the design of vibration mode), in order to improve the recognition accuracy of vibration mode. And we will consider the energy supply of the vibration system, so that it can work for a long time. Meanwhile, we will also apply the vibration feedback mode to more fields, giving more physical meaning to the vibration feedback mode, so that it can be applied in other fields, such as the rapid selection of the touch screen.

Acknowledgement. We would like to thank the School of Computer Science and Technology, Jilin University, for providing us with experimental field and equipment. And we also want to thank the National Youth Natural Science Foundation of China (No. 61300145), the Postdoctoral Science Foundation of China (2014M561294) and the Science and Technology Development Program funded projects of Jilin Province (20150520065JH) to provide funding. This study has been partially supported by National Key Research and Development Program of China (No. 2016YFB1001300).

References

1. Fukumoto, M., Sugimura, T.: Active click: tactile feedback for touch panels. In: CHI Extended Abstracts, pp. 121–122. ACM (2001)
2. Hall, M., Hoggan, E., Brewster, S.: T-Bars: towards tactile user interfaces for mobile touchscreens. In: Proceedings of MobileHCI, pp. 411–414 (2008)
3. Hoggan, E., Brewster, S.A., Johnston, J.: Investigating the effectiveness of tactile feedback for mobile touchscreens. In: Proceeding of CHI, pp. 1573–1582. ACM (2008)
4. Hoggan, E., Anwar, S., Brewster, S.A.: Mobile multi-actuator tactile displays. In: Oakley, I., Brewster, S. (eds.) HAID 2007. LNCS, vol. 4813, pp. 22–33. Springer, Heidelberg (2007). https://doi.org/10.1007/978-3-540-76702-2_4
5. Poupyrev, I., Maruyama, S., Rekimoto, J.: Ambient touch: designing tactile interfaces for handheld devices. In: Proceedings of UIST, pp. 51–60. ACM (2002)
6. Wang, G.: Route guidance for blind based on haptic technology and their spatial congnition. Xinjiang University (2013)
7. Brown, L.M., Brewster, S.A., Purchase, H.C.: Multidimensional tactons for non-visual information presentation in mobile devices. In: Proceedings of MobileHCI, pp. 231–238. ACM (2006)
8. Rantala, J., Raisamo, R., Lylykangas, J., Surakka, V., Raisamo, J., Salminen, K., Pakkanen, T., Hippula, A.: Methods for presenting braille characters on a mobile device with a touchscreen and tactile feedback. IEEE Trans. Haptics **2**(1), 28–39 (2009)
9. Yatani, K., Truong, K.N.: SemFeel: a user interface with semantic tactile feedback for mobile touch-screen devices. In: UIST 2009, pp. 111–120. ACM (2009)
10. Palmer, C.I., Gardner, E.P.: Simulation of motion of the skin IV responses of pacinian corpuscle afferents innervating the primate hand to stripe patterns on the optacon. J. Neurophysiol. **64**(1), 236–247 (1990)
11. EARSandEYES: Handy im Straßenverkehr: Jüngere unterschätzen das Risiko. Ears and Eyes Creating new Grounds (2014). http://www.earsandeyes.com/en/presse/handy-imstrassenverkehr/?pdf=1
12. Labiale, G.: In-car road information: comparisons of auditory and visual presentations. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting, vol. 34, no. 9, pp. 623–627. SAGE Publications (1990)
13. Liu, Y.C.: Comparative study of the effects of auditory, visual and multimodality displays on drivers' performance in advanced traveller information systems. Ergonomics **44**(4), 425–442 (2001)
14. Zeichner, N., Perry, P., Sita, M., Barbera, L., Nering, T.: Exploring HowMobile Technologies Impact Pedestrian Safety. NYC Media Lab Research Brief (2014)
15. Pielot, M., Boll, S.: *Tactile Wayfinder*: comparison of tactile waypoint navigation with commercial pedestrian navigation systems. In: Floréen, P., Krüger, A., Spasojevic, M. (eds.) Pervasive 2010. LNCS, vol. 6030, pp. 76–93. Springer, Heidelberg (2010). https://doi.org/10.1007/978-3-642-12654-3_5

16. Rümelin, S., Rukzio, E., Hardy, R.: NaviRadar: a novel tactile information display for pedestrian navigation. In: Proceedings of the 24th Annual ACM Symposium on User Interface Software and Technology, pp. 293–302. ACM (2011)
17. Meier, A., Matthies, D.J.C., Urban, B., Wettach, R.: Exploring Vibrotactile Feedback on the Body and Foot for the Purpose of Pedestrian Navigation. ACM (2015)
18. Knoblauch, R.L., Pietrucha, M.T., Nitzburg, M.: Field studies of pedestrian walking speed and start-up time. Transp. Res. Rec.: J. Transp. Res. Board **1538**(1), 27–38 (1996)
19. Dawes, J.: Do data characteristics change according to the number of scale points used? An experiment using 5 point, 7 point and 10 point scales. Int. J. Market Res. **50**(1), 61–77 (2008)