Evaluation of a Vibrotactile Device For Outdoor and Public Transport Pedestrian Navigation Using Virtual Reality

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***Abstract*—It can be difficult to find your way in public transport, especially when the journey combines indoor and outdoor transportation. We designed an innovative vibrotactile device dedicated to guide a pedestrian in public transport. This multi-modal interface can be used to guide a pedestrian in unknown public transport. The device can be used by visually impaired person. The device has been tested during two main phases. The first step was to test the device using virtual reality while the second step test was to test the device in a real environment. This paper presents the first part of the evaluation of the device. We have developed a virtual reality scenario to assess the objective and subjective utility of the device. The results showed that the device could properly guide users. We also evaluated the usefulness of a warning vibration preceding a message. It was found that the vibration seems to introduce confusion to the pattern recognition by the user.**

Keywords–Vibrotactile device evaluation;multi-modal interface; tourism mobile device; public transport; virtual reality.

I. INTRODUCTION

In a large city, the range of public transport servicies is wide –buses, subways, trams, bicycles, electric cars– making the transportation network more and more complex. To address this complexity and facilitate the movement of users, information systems are available in many guises such as signs, information boards or mobile device applications. However, existing systems to assist pedestrians mostly offer visual cues, sometimes combined with sound. The need to inform the pedestrian can lead to saturation of these sensory modalities, making it difficult to grasp information during the journey. The problem is even more serious if the user is not familiar with the transport system, or if it's his first time navigating. These observations led us to consider the development of a new way to interact with the navigation aid systems. There are two objectives in this paper. The first one is to evaluate, using virtual reality, the potential interest of a preliminary alert to draw the user's attention. The second one is to evaluate a vibrating wristband to help pedestrians to navigate the city and public transport.

In Section II, we present related work on devices used to guide pedestrians using multi-modality. In Section III, we describe the device and give some details about the design of the hardware and the software. Then, in Section IV, we present the user study which was conducted using virtual reality. Finally, we present the results and discussions in Section V.

II. RELATED WORK

Pedestrian navigation aid systems mainly employ visual and auditory modality [1][2][3][4]. Indeed, cognitive resources for visual and auditory modality are already heavily used in mobile environments [5]. The solicitation of visual modalities when interacting with navigation aid systems strongly degrades the performance of pedestrian mobility [6]. In this case, the pedestrian must perform several tasks simultaneously. He must look at the screen of his mobile interface and pay attention to the environment at the same time. The auditory modality, slightly less used, is not the best communication channel in public transport. In a noisy acoustic environment saturated with visual information, the haptic modality seems to be more promising and worth exploring to provide information to travelers. The haptic perception is defined as a perceptual system composed of two subsystems: tactile –cutaneous channel– and proprioceptive –kinesthetic channel [7][8]. We believe that the use of the haptic channel is useful for navigational interfaces because it does not overlap with the main channels (auditory and visual) used during the journey. This is based on the theory of Wickens [9], which highlights the existence of different resource reservoirs, each associated with a particular processing channel. The processing channels are independent. In other words, when two different tasks are performed at the same time by different processing channels, the model predicts no performance degradation. In addition,Lee et al. [10] also shows that a vibration can automatically draw the driver's attention to information delivered by the system. Another experiment confirmed this hypothesis, indicating that a vibratory stimulation serves to focus the driver's attention on the driving situation in order to pay attention to potential risks. For example, a study was conducted consisting of sending vibration signals to the conductor's waist [11] or through the seat [12]. The haptic modality was shown relevant to pay attention to information about the environment without

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disrupting the visual and auditory channels. This validates the choice to create devices for pedestrian navigation employing the haptic modality. It is important to keep in mind that the user is continually confronted with multiple sensory stimuli. Some of them are useful while others are irrelevant. The users' perception has to filter information in order to limit the number of informations to be processed [13]. This system may be faulty when the user faces an unexpected situation. This can be caused, for example, by performing recreational activities not related to the principal activity of transport such as reading/writing an SMS. In this case, there is a shift in focus from relevant information to the secondary activity [14]. However, we know that the appearance of an event is similar to a distraction, induces an automatic attention redirection to this event. It was in 1980 that Posner [15] described this loss of concentration as "exogenous focus of attention." Haptic stimulation, used as a distraction, could therefore help to focus the user's attention back to commute.

Issues regarding the displacement in virtual worlds have been widely studied [16] and especially for large virtual environments [17][18] to avoid the cyber-sickness [19]. Slater [20] showed that the sense of immersion is impacted by the metaphor of displacement and a system allowing the user to walk under degraded conditions is better than a classical interface with buttons and joysticks. This is why we choose a particular metaphor to help the user in his displacement and given below are some details about the design of this user experience.

III. Design Details

The activities extracted from the study conducted by Brunet et al. [21] allowed us to select 8 functions to assist the user. According to this study, there are two main functions: one for guidance and one for warning the user. These two functions are represented by two different devices shown on Figure 1. Guiding is provided by D_1, a hand-held device composed of a body (in white) and a small movable part (in black). This part can be tilted in 8 directions (cardinal and diagonal). It is used to indicate the direction by putting a finger on the tilting part. For reassurance and warning functions, the second part, D_2, is worn around the wrist and is composed of 8 vibrating units. This setup allows creating specific vibration patterns for each information and alert. Changing the following settings creates different patterns of vibration:

- Vibration time
- Vibrator sequence
- Delay between each pulse

A. Wayfinding in virtual environment

The commute consists of following a path through nodes and segments. The participant must move from one node to another. This is done to simplify the interaction needed for the displacement. When he reaches a node, the movement automatically stops. Then, he can move his head to choose an orientation he wants to take. Once a direction has been selected, the participant must step forward (beyond a mark on the ground). His foot must remain in front of the mark until he reaches the next node. Between two nodes, the participant can stop moving forward by repositioning his foot behind the mark on the ground. When he decides to move again, he simply puts his foot forward and movement resumes.

The general concept of this device is based on the differences between each haptic pattern. The interaction mainly consists of seven vibrating messages delivered to the user through the bracelet. Each vibration pattern is associated with an image, which is an activity related to the user's commute (see Table I). Please find details about the signal used for each pattern in the study of Brunet et al. [22].

Figure 1. Illustration of the device. Right: Hand-held device (D_1) used to indicate the direction by tilting the small black part. Left: Worn around the wrist (D_2) composed by 8 vibrators.

TABLE I. VIBRATIONAL MESSAGES ASSOCIATED WITH THEIR IMAGES AND RELATED CONCEPTS.

Name	Sign	Concept
Knock-knock		Vehicle Alert: you need to get in/out from the vehicle.
Siren		Incident Alert: incident on your route.
Bug		Unavailability Alert: technical issue (escalator...).
Half-lap		Wrong road alert: you're going the wrong way.
Heart		Point of interest alert: you are next to one of your POI.
Waltz		Information Alert: you're next to an information center.
It's Ok		Reassurance Alert: you're on your way, no problem.

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IV. User Study

The use of Virtual Reality (VR) to realize the evaluation of our prototype will help us to shape the next user study that will take place in a real environment. VR allows us to perform device evaluation faster than in a real environment and with better control of many constraints [23]. Furthermore, VR helps us to make few design choices and minimize the cost of producing devices that would neither be used nor accepted by users [24]. In addition, VR allows the control of parameters that we could not manage in the real world such as the noise level of the environment to assess the impact of this parameter on the user's activity.

A. Hypothesis

The first hypothesis (H1) we wish to verify is that the presence of a preliminary vibrational message before the vibration itself will improve pattern detection during the commute in the virtual environment. This hypothesis is focused on D_2. It postulates that the presence of this message should reduce the number of misinterpretations. The second hypothesis (H2) consists of testing if D_1 is well designed for guiding participants. This will be confirmed by obtaining a minimum number of misorientations.

The system is designed for a wide population range so we want to verify if the devices D_1 and D_2 are easy to use for a large portion of the population. We also want to compare results among different age groups. Finally, the third hypothesis (H3) consists in verifying, by questionnaires, if the device improves the user experience. In this study, participants experience immersion in a virtual environment representing a metro station and its external surroundings. The user's dominant hand holds the device D_1. Around his dominant wrist, the user wears the device D_2 to receive vibration alerts and reassurance. The study was conducted in four steps. The first one (E1) is dedicated to learn how to employ devices D_1 and D_2. The second one (E2) is needed to learn how to move through the virtual environment with D_1 and D_2. The third (E3) is the user study itself and the fourth (E4) is assigned to filling out a questionnaire. We will describe each step in the following sections.

B. Tasks

Step E1 is dedicated to familiarizing the participant with devices D_1 and D_2. The user starts by learning 5 vibration patterns: The experimenter says the name of a pattern, sends it to the device (worn by the participant) and then says the name again. This procedure is repeated for each of the five different vibration patterns randomly. The procedure is repeated a second time without saying the name. We then move to the stage of verbalization by the participant itself. Each vibrational pattern is sent to the device and the participant must identify the pattern by its name. This phase is repeated as long as the participant makes errors. The participant learns how to move in the virtual environment in step E2. In this preliminary step, the device D_2 is worn by the participant for practical reasons, but is inactive. Moreover, the participant does not have access to the device D_1 during the first few minutes. The participant moves along a predetermined path (the same for all subjects) and is guided by the experimenter who tells him the directions to take. When the subject comes to a particular node (same for all participants), the experimenter allows the participant to use device D_1. At this step, the participant can move without guidance from the experimenter, but helped by D_1. During the movement, vibration patterns are sent to the participant through D_2. For each pattern, the participant must tell the experimenter the name of the pattern recognized. The experimenter valids the name of the pattern and repeats the vibration in case of error. After several nodes, the participant reaches the end of the learning path.

The next step (E3) is the user study itself. A scenario is proposed to the participant before he starts. The scenario begins on the platform. He must go downtown, to a street next to the subway entrance in order to go shopping. He must then join a friend next to a subway entrance to visit a museum. To do this, the participant and his "virtual friend" should take the metro. During the scenario, the participant is only guided by D_1 and D_2. Prior to joining his friend, the participant is asked to send an SMS to agree on the meeting place. The message to be sent is the same for all participants. The experimenter gives the participant a mobile phone at that time. While writing the SMS, D_2 vibrates. This operation is used to assess the ability of the device D_2 to be understood, even if the user is doing many different tasks at the same time –commuting, writing SMS–. During the commute to the subway, an incident on the line is announced (by D_2) and it is recommended to take another line by making a U-turn. Once back on the platform, the experiment ends. During the scenario, cultural and commercial points of interest or alerts are presented to the participant through D_2. During the experiment, the software logs steering errors. An error is recognized whenever the subject wishes to leave a node towards another node in a direction which is inconsistent with that indicated by D_1. The experimenter also records misunderstood vibration alerts.

C. Implementation

A 3D model of the metro station was implemented in Unity3D (Figure 2). The station had to be large enough so that the path can be complex so we modeled one of the largest Paris metro station. The virtual environment was rendered on a back-projected wall $(3.1m \times 1.7m)$ with monoscopic rendering. We use of ART cameras for motion tracking: both the head and the dominant foot of the user were tracked in real time thanks to passive markers. The two devices were connected to a computer using Bluetooth. Keyboard control was available for the experimenter to record errors.

V. Results and Discussions

A total of 21 subjects participated in this study. The duration of the experiment for each subject was about 1 hour. We chose to separate subjects randomly into two groups: during the experiment, the first group (G1) received a vibrational warning before the vibration itself, whereas the second group (G2) received the vibrational messages without this vibration

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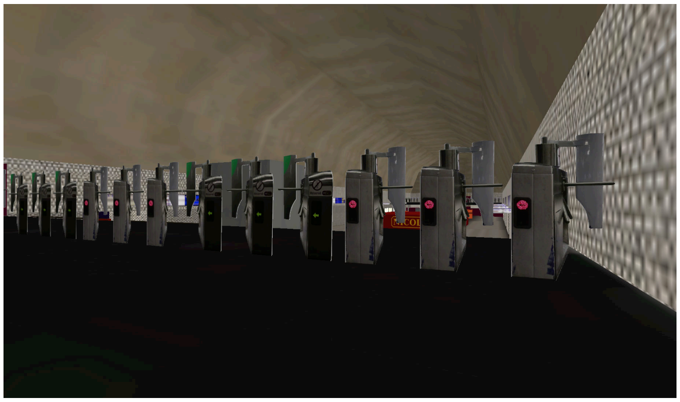
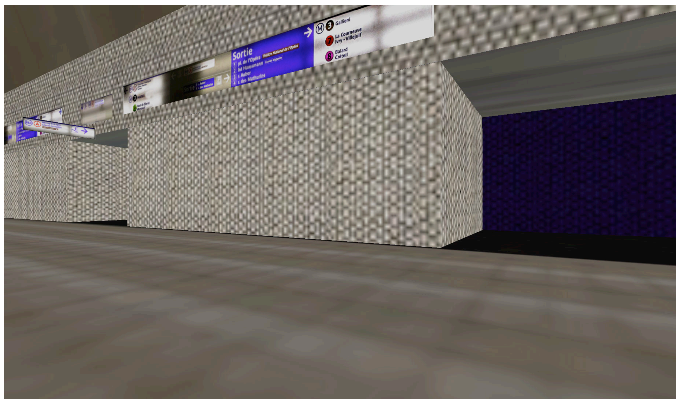


(a) A view of the metro station 3D model.



(b) The signs are modeled in the 3D model.

Figure 2. An example of the virtual metro station.

warning. The age distribution of our population was 37.5 years on average with a median of 32.5 years. The gender distribution was balanced with 11 men and 10 women. We will discuss the results related to data acquisition in the next section and we will deal with the subjective experience in the following one.

A. *User Study Measures*

For both groups G1 and G2 (the entire population), we observed a tolerable error rate of 5.39% for D_1, while the error rate was relatively large for D_2 with 28.95%. We performed 1-way ANOVAs to detect any significant effects of the vibration alert. There was no significant influence on the user's errors on D_1 and whether or not they received the preliminary message via D_2 (F (20,1) = 0.29, p = 0.59). D_1 allowed to properly guide participants in the virtual environment, and was not affected by the different modes of D_2, which validates H2.

We found a significant influence of the preliminary message on the vibration pattern recognition (F (20,1)=3.22, p=0.09). The G1 group experienced more difficulties recognizing the vibration pattern with an error rate of 40.47% than the G2 group with an error rate of 15.39%. Many participants made a confusion between the preliminary alert and the message itself and few users tried to recognize a pattern when the preliminary alert was started and not when the message itself started. These error rates were quite large, so we have suggestions for possible improvements. We could increase the amount of time to learn how to use D_2 or simply reduce the number of messages required (5 in this study). In addition, another clue about this high error rate was the device itself. During the experiments, the vibrating motors of the prototype occasionally lost contact with the skin of the participant due to his movements.

Analysis relating to age has shown interesting results. We decided to divide our population into two groups. The separation was the average age (37.5 years old). A significant difference (F(20.1)=7.41, p=0.01) was observed for D_1 error rates. On average with D_1, participants under 37.5 years old (12 people) made 1 error, whereas participants over 37.5 years old (8 people) made 3.4 errors. The older age group experienced more difficulties in recognizing the vibrational patterns of D_2 (F (20,1)=3.35, p=0.08). Age seems to be a significant factor for the perception of the vibration of D_2.

We will now look at the particular case of the vibration recognition when the participant was asked to write an SMS during his commute. We saw a significant impact of the preliminary vibration when writing an SMS with an error rate of 18% for G2 and an error rate of 50% for G1 (F (20,1)=5.35, p=0.03). This result confirms the previous results that showed a greater error rate for G1 than for G2.

B. *Subjective user experience*

To evaluate the subjective user experience it was necessary to collect subjective data reflecting the experience felt by each participant during interaction with the prototype. The subjective aspect of the user experience takes into account the emotion felt during the session. According to the work in this field, we use some classic usability tests to evaluate the user experience starting with an evaluation of presence and immersion. All participants were asked to answer the questionnaire "presence and immersion" from [25]. Participants could give a score between 1 and 7 (the higher the better) on the control of events, system responsiveness, the naturalness of interaction, visual appearance, consistency of movement and involvement. Results are shown in Figure 3.

All responses were above average. We have not noticed any particular problems during the experiment, such as simulator sickness potentially caused by the commute except for one person prone to vertigo at the top of the virtual stairs.

We can observe a significant difference (Student's t-test) between the two groups for the first question regarding the level of control (Figure 4). We see that the older group felt less control over the system than the younger group.

C. *Overall user experience*

Mood can be experienced directly or at a reflexive level. Mood can be organized into two main dimensions: pleasant/unpleasant and calm/excitement. To extract the mood experienced, all participants were asked to fill out the Brief Mood Introspection Scale (BMIS) [26] and the SAM scale [27] at the

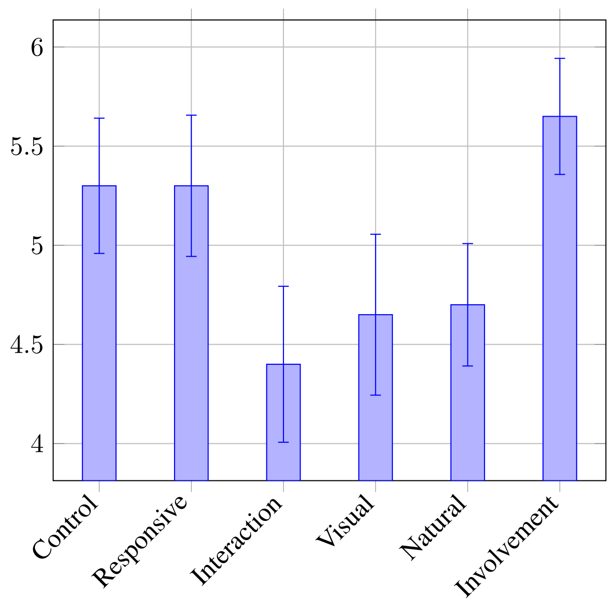


Figure 3. Response to the questionnaire on presence and immersion for the entire population.

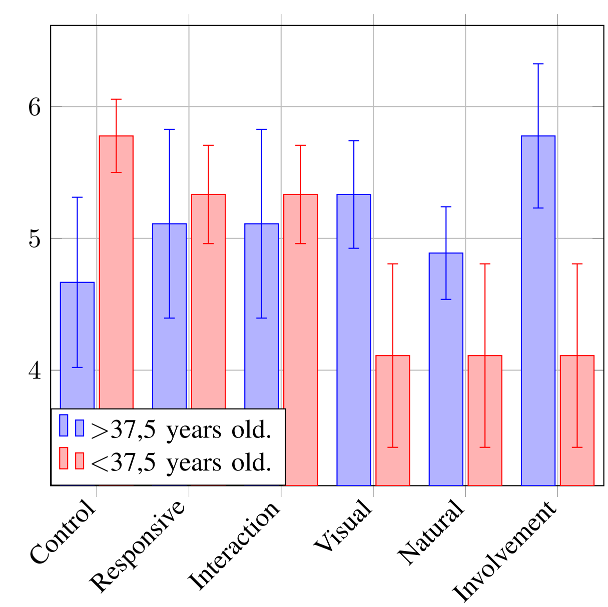


Figure 4. The answer averages to the question of presence and immersion for both age groups.

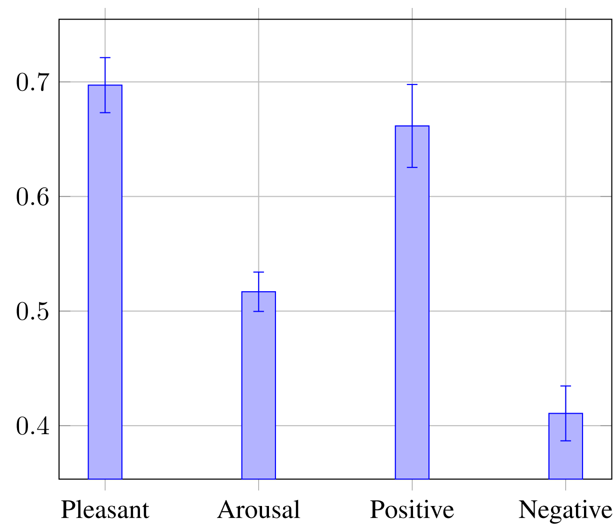


Figure 5. The BMIS mood scale in average for the entire population.

end of the user study. The well-known BMIS scale consists of 16 adjectives. Two adjectives are selected for each of the eight emotional states. The adjectives are: Lively, drowsy, happy, grouchy, sad, peppy, tired, nervous, caring, calm, content, loving, gloomy, fed up, jittery and active. Participants had indicate how well each adjective describe their mood by choosing among the different sentences:

- definitely do not feel;
- do not feel;
- slightly feel;
- definitely feel.

The BMIS questionnaire allowed us to assess the emotion felt during the interaction. Positive mood was observed for all participants with a pleasant and positive experience with a lower level of excitement for negative sentiment (Figure 5). Figure 6 shows the result averages of the BMIS questionnaire for both age group.

Emotions can be described in terms of three independent dimensions: pleasure/displeasure, degree of arousal, domination/submission (PAD model) [28]. These three elements are independent and may occur without impacting each other. The SAM questionnaire [27] is an instrument to measure emotional states based on pictures to achieve a self-evaluation of an object or event based on the three main emotional dimensions. SAM provides a list of pictures for each dimension of the PAD model associated to a scale from 1 to 9. It has the advantage of being filled out very quickly, hence there are no mistranslation issues and both children and adults can fill it out. The SAM scale allows us to extract a general emotional state of the participants. Figure 7 shows the score averages for all the participants. It can be seen that participants had fun during the experiment. Younger participants felt more pleasure than the older group, and they also felt a stronger sense of dominance compared to the older participants (Figure 8). The feeling of excitement is relatively low for both groups, which confirms

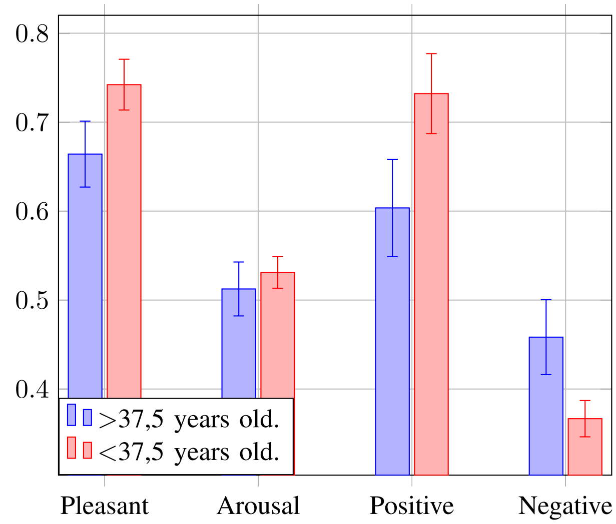


Figure 6. The score averages of the BMIS questionnaire for each group.

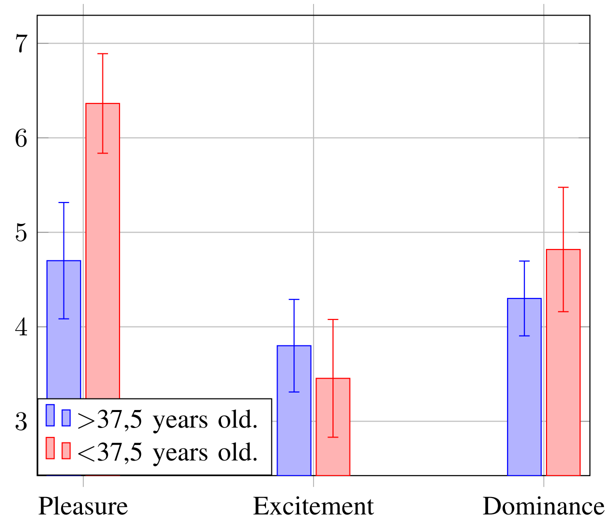


Figure 8. The score averages of the SAM scale for each age group.

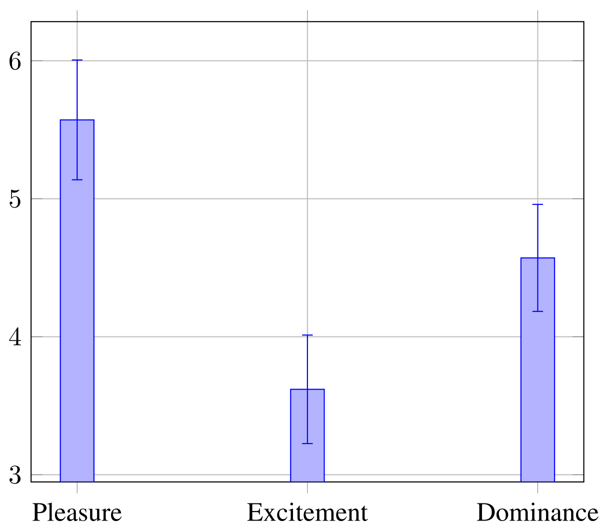


Figure 7. The SAM scale score averages for the entire population.

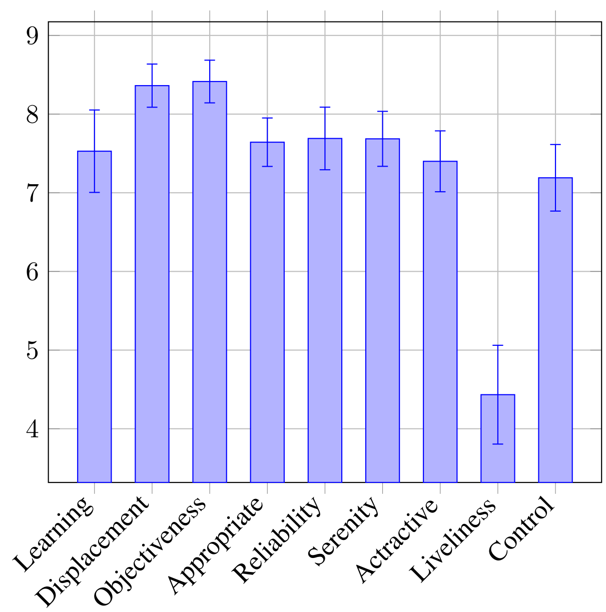


Figure 9. The score averages for all the participants regarding their feelings about interaction with D_1.

that the participants were relaxed during interactions with the device.

We will now discuss the user experience for both devices D_1 and D_2 separately. Using a Likert scale, we will be able to evaluate the usability of each device.

D. User experience with D_1

Concerning D_1, it can be noted that the score is never below 7 out of 10 except for the liveliness (Figure 9). The subjects perceived a slow interaction with D_1.

Table II summarizes the responses to open-ended questions about D_1. Four participants thought that D_1 was simple and an intuitive guide during the commute and five participants felt that the system properly indicated the direction. However, five respondents indicated that they preferred to find their way using a map or a GPS-based application.

E. User experience with D_2

Use of D_2 is overall lower than the score of D_1 as shown by Figure 10 especially for the training phase. Subjects were able to adapt to the device and seemed not to have trouble memorizing the patterns. Table III summarizes the responses to open-ended questions about D_2. Three participants thought that device D_2 provided good vibration recognition and two

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TABLE II. SUMMARY OF COMMENTS REGARDING THE USE OF D_1.

Positive points - D_1	Number of people
Simple and intuitive guide	4
Properly indicates the direction	5
Usefulness in open space without signs	2
Useful if I'm in a hurry	1
Useful for a blind or visually impaired person	4
No opinion	5
Negative points - D_1	**Number of people**
It would be easier if the button were still ahead when we have to go forward	1
Cumbersome	3
I prefer to find my way using a map/GPS	5
Lack of independence	1
Smartphone is sufficient	1
Using signs is easier	1
Requires concentration	2
Lack of autonomy	1
Lack of direction update	3
No opinion	5

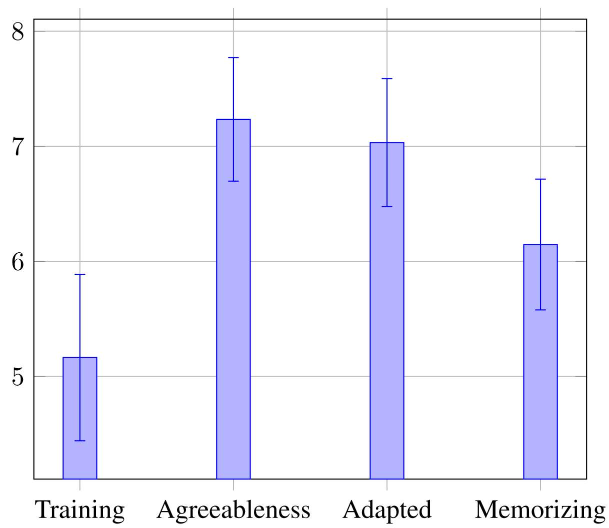

Figure 10. The score in average for all the participants regarding their feelings about the interaction with D_2.

participants have highlighted the fun aspect of D_2. However, six participants have noted difficulties to distinguish patterns (lack of discrimination) and five participants have found important memorization effort.

F. Impact of the alert

Based on answers to the question (does the jingle allow to anticipate the identification of the vibration?), participants said yes up to 6.9/10. Depending on the different conditions during the commute (walking, walking and writing an SMS, walking in a noisy environment), some participants seemed to be distracted by the SMS (Figure 11) and indicated that they had experienced difficulties related to the recognition of vibration. This is confirmed by the observed error rate of 50% for the pattern recognition.

TABLE III. SUMMARY OF COMMENTS REGARDING THE USE OF D_2.

Positive points - D_2	G1 (10)	G2 (10)	Number (20)
Good vibration recognition	2	1	3
Provides vital information	1		1
Not encumbered hands	1		1
Fun aspect	1	1	2
Discrete interaction	1	1	2
No opinion	12		12
Negative points - D_2	**G1 (10)**	**G2 (10)**	**Number (20)**
Cognitive load	3	3	6
Lack of discrimination	2	4	6
Smartphone is sufficient	1		1
Prefer to use eyes and ears	1		1
Memorization effort	1	4	5
Lack of control	1		1
Vibrations disturbance		2	2
No opinion	3	2	5

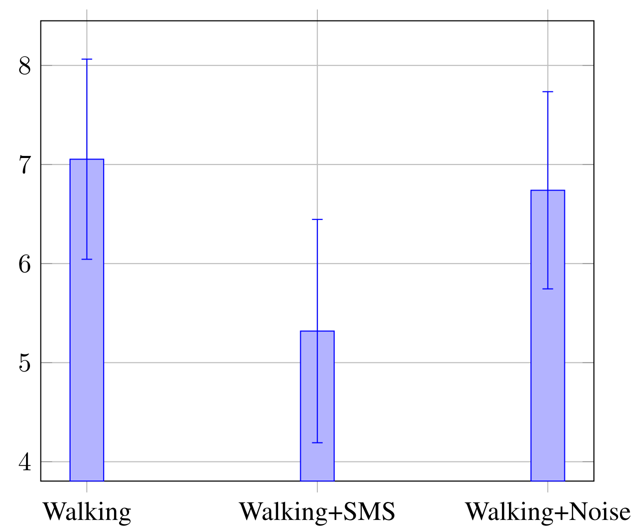

Figure 11. Feeling for G1 on the impact of the preliminary alert during different commuting conditions.

We can note that the alert seems not to be useful while writing a text message for G1, the group which received the alert (Figure 11). This has been confirmed by observations with a significant recognition error rate during this phase (more than 60%). We can observe (Figure 12) that the alert was well received for the younger group during all three phases (walking, walking + SMS, walking + noise) unlike the other group where the alert was rather negative while writing an SMS. Table IV summarizes the responses to open-ended questions about the alert. Five participants thought that the alert helped them to listen to the message but two participants said that the presence of the alert was annoying and caused

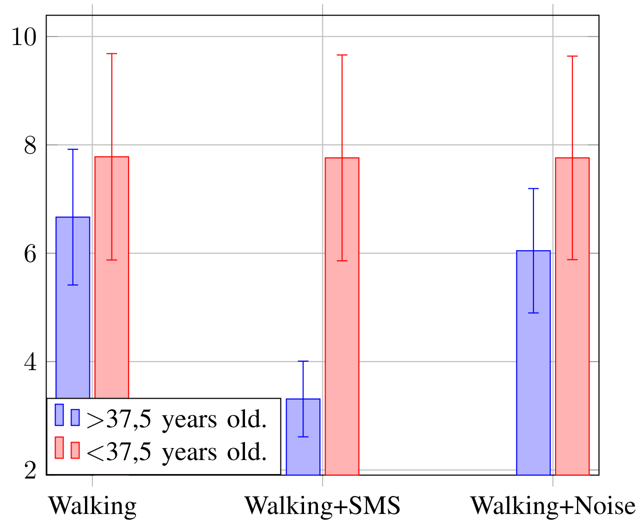

Figure 12. Feeling averages for each age group regarding the vibration pattern recognition.

confusion with the message itself.

TABLE IV. SUMMARY OF COMMENTS FORM PARTICIPANTS IN GROUP G1 REGARDING THE ALERT.

Positive points - Alert	**G1 (10)**
Helps prepare to "listening" the message - promotes wakefulness - caution - concentration	5
No opinion	4
Negative points - Alert	**G1 (10)**
Not essential	2
Presence of alert is annoying and causes confusion with the message itself	2
No opinion	3

VI. LIMITATIONS AND FUTURE WORK

As we said earlier, the used device was a prototype and still has many possibilities of evolution. Indeed, the bracelet could rarely not have been in perfect contact with the skin of the user, which could have lead to a loss of information.

Following this study using virtual reality, we conducted a study in a real environment. We designed the test protocol for the real environment following the results of the study presented here, and we have, for example, specifically emphasized the appearance of the jingle. Results of the study conducted in real environment will be presented in another paper.

Today, we plan to target a population with visual impairments to confirm the interest of this device for this population.

VII. CONCLUSION

This paper focused on the evaluation of a vibrotactile device for outdoor and public transport pedestrian navigation using virtual reality. A user case was implemented in which a pedestrian had to commute in a large virtual metro station. In this study, we evaluated each of the four proposed hypotheses. We note that our first hypothesis is not validated because the preliminary alert seems to bring confusion to pattern recognition with lower performance for participants compared with those who did not receive the preliminary message. This result, however, can be addressed due to the fact that the device used is only a prototype. The second hypothesis was to assess the guide performance of the device and the data shows that the system is useful to guide users through the station. We noticed a significant difference concerning the age of users. People in the younger age group generally report that it is easier for them to recognize a vibration. Finally, the analysis of questionnaires allows us to conclude that the user experience is quite positive. However, it is difficult to decouple the impact of the experience in the virtual environment with the use of the device itself, which is why we will conduct another user study in the real environment of the metro station modeled in this paper.

VIII. ACKNOWLEDGMENTS

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