“Invitation To The Voyage”: The Design of Tactile Metaphors to Fulfill Occasional Travelers’ Needs in Transportation Networks

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ABSTRACT

In spite of the availability of journey planners, too many occasional travellers are distressed when facing the complexity of public transportation networks in large cities. So are regular travellers in case of unexpected perturbations. The haptic modality offers a discrete, eyes-free and ear-free channel of communication that can provide useful information to assist users in their travel. This paper presents the metaphor-based and user-centric methodology used to develop the haptic interaction (hardware and haptic patterns). It led to the design of haptic patterns based on user requirements and tested with a custom tactile wrist bracelet. The evaluation shows that patterns were very well recognized in mobility with limited training and reached a good satisfaction level, thus validating the methodology grounded on metaphors and participatory design. Moreover, the results pointed out user differences in perceiving patterns and raised the need to tune the patterns according to the users’ choice.

KEYWORDS: Haptic interaction, user studies and evaluation, design methodology, metaphors.

INDEX TERMS: H.5.2 [Information Interfaces and Presentation]: User Interfaces—Haptic I/O, Evaluation/methodology.

1 INTRODUCTION

Public transportation networks in big cities are intrinsically complex. Occasional users face this complexity when they are about to use the network. Many services have been developed to help users overcome these difficulties. Information desks are available at the most strategic locations of the network to help occasional users. Transports agents are present to regulate the flow of passengers and to help travelers. Journey planners are accessible offline and online on smartphones for many transportation networks (e.g. see “Journey planner” in London or “Ma RATP” in Paris). These applications offer the possibility to plan journeys whilst taking into account the travel preferences of the user and considering the state of the network. They suggest itineraries given a starting point and a destination while considering users preferences.

Despite these aids, many occasional travelers hesitate or may be reluctant to use public transportation. Regular users are also confused when the network is interrupted and when they have to re-plan a new journey on the fly. Moreover, itineraries provide information about transportation means (tube lines, stops, etc.) but do not offer any user-centric information. The information remains generic (ex: “Take line 5 and change at Paddington station”) and travellers must transfer the information given by the application into their own reference frame.

To overcome these limitations, we have decided to undertake a user-centered approach to clearly define the needs of occasional and regular users with the aim of developing an “invitation to the voyage”, a user-friendly multimodal haptic application (hardware and software), designed to meet the most important needs of these travellers.

Users’ needs related to pedestrian navigation have been studied extensively but mostly for outdoor environments. Directions can be supported by visual information as in GPS applications, and presented as a succession of oriented arrows or presented verbally [5]. Some applications mostly dedicated to the visually impaired use audio interaction [12] and verbal directions have been tested successfully in the tube [20]. However as mentioned by Robinson and al. [19], many users are reluctant to use headphones for navigation purposes. Haptic interactions are also regularly proposed to support mobile navigation [11]. Haptic interaction frees the visual channel and reduces the cognitive load [8]. Haptic navigation messages are generally dynamic vibrational information indicating the direction to follow or information about distance to destination [25]. For example, Szymczak et al. [22] have developed and tested a tourist guide application on a smartphone, which vibrated when pointed in the direction of points of interest. Distance is encoded by delivering more frequent bursts when approaching the goal. We conclude that tactile navigation displays can be used in strenuous outdoor environments and can outperform visual displays under conditions of high cognitive and visual workload [7].

Nonetheless, the opportunity to use haptic interaction for location-based services supporting a journey in transportation networks has scarcely been explored [18]. In order to fill this gap, we defined a methodology based on metaphors and user requirements [13] for designing an efficient haptic interaction. These requirements were used to guide the design of the hardware and to foster the process of pattern design. We collected semantic metaphors in relation to the user’s requirements. These metaphors were then used as anchors to create tactile icons. Finally, in order to validate the methodology, the interaction was evaluated in mobility.

2 USER REQUIREMENTS ANALYSIS

The user requirements analysis consisted intwo stages. First, a focus group was organized to collect the user’s needs and their

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requirements concerning the most difficult situations they have to face when they use public transportation. Second, a more thorough analysis of the activity of a sample of travelers was conducted to analyze the tasks related to the travelling activity and also to the use of information during the journey.

2.1 Focus Group

Ten users (6f/4m) of the local transportation network in Paris (RATP) and with varied expertise levels concerning their knowledge of the network and related tools (e.g. smartphones or other aids) participated in the focus group. The aim was to collect information about the difficulties encountered while traveling. The focus group was based on a travel scenario that included several phases of a journey: access to the transportation means (bus, tramway or tube), the journey in itself and interchanges (e.g. tube to tube or tube to bus). The major difficulty reported by the participants stems from facing traffic perturbations (e.g. incident, accident, public works), requiring them to re-plan their itinerary on the fly. This difficulty is exacerbated by a lack of personalized information regarding the itinerary to follow in these unexpected situations. The participants expressed the need to be informed in a way that would allow them to anticipate actions, such as when to get on and off the transportation vehicle. Users also commented on the importance of the hedonist aspect of the travel (being informed of a cultural event or place near to where the user is) even if they were regular users.

2.2 Task Analysis

22 participants (11f/ 11m) were recruited with different levels of expertise with the local transportation network (novices and experts). Each participant performed the same travel scenario, exhibiting the main difficulty identified with the focus group, i.e. a journey disrupted by the closure of the means of transportation they had to take. Therefore, each participant had to re-plan his/her itinerary on the fly to successfully reach the given destination. The travelling task was followed by an auto-confrontation interview, relying on the video recording of the journey, where participants explained the cognitive activities involved in the task and for managing the information. The resulting task analysis highlighted the main functionalities needed to assist in the travel, namely: “guiding to”, “alerting”, “providing detailed information” and “reassuring the user” (see Table 1).

Main Functions	Messages delivered by the device
Guidance	Guide to the right direction
Time management	1. Alert of the imminent arrival of the vehicle for entering it or getting off
Information integration	2. Network incident / accident (with the level of severity) 3. Alert of the unavailability of one or more network component(s) from his/her route (elevator or escalator shutdown)
Confirmation / Verification	4. Alert that s/he is on the wrong way. 5. Reassure the user that s/he is still on the right way.
Related activities	6. Alert of a nearby point of interest according to their preferences 7. Alert of a cultural or leisure-related information relative to his/her location

Table 1. Main functionalities of the application that emerged from the needs analysis (focus group and task analysis)

3 DESIGN OF HAPTIC INTERACTION

Given the benefits of the haptic modality in delivering cues [21] [15], vibrotactile was chosen for providing guidance, alert and reassurance messages. In the navigation context, tactile feedback has already proved its utility for providing directional cues [11]. Considering the locus of the interaction, our choice was set on the wrist as it is socially more acceptable than a belt. This choice was also supported by Cholewiak and Collins [6], who indicated that the wrist and the elbow presented the highest tactile acuity on the arm. Our study focused on alert and reassurance messages, as previous work already tackled guidance messages [1], [25].

The information conveyed by haptic patterns can be encoded along different attributes. Brown et al. [2] demonstrated that rhythm, roughness and tempo can be used as design attributes. Quian [17] indicates that the duration of the patterns can also be taken into account. In these studies the haptic patterns, also called Tactons or haptic icons [24], are perceptually discriminable patterns but they are abstract entities without any clear relationship to the message they are supposed to convey. A learning step is required before using the patterns and only a limited set of about 7 items is used in the applications.

With the aim of enhancing stimulus response association [23], we suggest that using a design methodology of haptic interaction based on metaphors may be a way to tighten the relation between a haptic pattern and its meaning. Our hypothesis is that metaphoric patterns, even with a large set, will lead to very few errors with a limited training.

3.1 Metaphor-Based Design Methodology

Designing haptic patterns based on the metaphors associated with the functions of the application (see Table 1) may overcome the limitations inherent to the use of abstract patterns by reducing learning and memory load. Metaphors are analogies that can be used to illustrate unfamiliar entities [16]. They are often suggested for the design of haptic patterns. The main criticism [3] is that metaphor-based tactons can lead to unstructured signals without any clear salience. However, metaphor-inspired designs resulted in interesting developments like the Comtouch based on the handshake metaphor [4]. Piateski and Jones [14] proposed tactile displays for use in a navigation task. Directional information in haptics derived directly from their visual counterpart (Left/Right; Up/Down), with equivalent moving patterns. Warning and stop messages were transposed to haptics on the basis of intuitive haptic patterns proposed by the authors and closely related to the message they had to convey. As indicated by [16], the success of the metaphor-based design depends on the choice of the metaphors. For the application they developed, the authors themselves carried out this choice.

Our hypothesis is that a design methodology based on metaphors that are derived directly from the users’ expressed needs can lead to original, user-friendly and yet effective haptic interaction to convey alert and reassurance messages. Whereas using directly the messages of the application as an inspiration source could constrain creativity as they are principally focused on alerts.

We propose a methodology in three stages. The first step aimed to collect and select intuitive metaphors associated with the different types of messages delivered by the device. In a second step, another group of participants used the semantic metaphors as anchors for the design of associated haptic patterns. Finally, haptic patterns were tested in mobility.

3.2 Metaphors Collection and Selection

25 participants (9f/16m) took part in the metaphor collection experiment. The average age was 30.75 years [23-60 years]. 17 participants were familiar with haptic interfaces. The participants were first introduced with the terminology of the term “metaphor” and were trained to associate quickly a verbal metaphor to messages presented verbally by the experimenter (e.g. for the message “I feel good” they could propose the following metaphors: “a bubble bath” or “the sound of a wave on the beach”). They were then presented with the 7 messages the device should convey (see Table 1) within a given context. For example, in the case of the message “alert of the eminent arrival of the tube”, the following context was delivered to the participant: “you are on the tube platform; you are waiting and reading a journal. The device indicates the imminent arrival of your tube. Which objects/melodies/noise/etc. would you associate to this message?”. The participant was asked to verbalize the metaphors that she/he spontaneously associated to the given message. The experiment lasted about 20 minutes per participant. The seven messages were given in random order. Amongst the 64 collected metaphors, 8.1% (5 metaphors) were common to 10 participants or more, 17.2 % (11 metaphors) were common to 5 participants or more and 34.4 % (22 metaphors) were expressed by more than one person. Only one person suggested the remaining ones. The following stage consisted in the selection of the more intuitive metaphors by a broader range of participants to reduce the amount of elicited metaphors.

The selection of the metaphors was performed with 104 participants (48f/56m), with an average age of 31.6 years [15-88 years]. Participants had various backgrounds (e.g. engineering, medicine, art, ergonomics and computer sciences). In order to ensure easy and wide participation, an online survey was made available. For each message, participants were asked to select one or two of the most intuitive metaphors in the list. For each message, the metaphors with a score greater than or equal to 10% (more than or equal to 10 participants) were selected for the following step in the methodology. This selection resulted in a set of 38 metaphors.

Each message was associated with 5 or 6 possible metaphors. For example, the metaphors proposed for Message 1, which meant to alert the user of an imminent arrival of the vehicle (or imminent arrival at destination), were: Bell, Knock-Knock, Heho, Alarm Clock and Gong. The complete list of metaphors is presented in Table 2.

	Semantic Metaphors
Message 1- Vehicle arrival	Bell, Knock-Knock, Heho, Alarm clock, Gong
Message 2- Network accident	Siren, Barrier, Fasten seat belt sign, Rock to bypass, Windows waiting loop, buzzer
Message 3- Component unavailability	Warning, Stairs, Exclamation mark, Wheels becoming square, Bug noise
Message 4- Wrong way	Turn around, “No” nodding, Msn wizz, Blocking wall, Compass, Fairy
Message 5- Right way	Radar, Flickering light bulb, Nice music, Heart, Big arrow, Little bell
Message 6- Point of interest	Light bulb on, Open a book/guide, Camera flash, Classical music, Question mark
Message 7- Cultural information	Loading bar, Purring cat, Sliding sensation, Dancing man, Soft music

Table 2. Metaphor selected for the 7 messages of the application

3.3 Pattern Design

Once selected, the metaphors were used as anchors for the design of haptic patterns for each of the alert and reassuring messages.

3.3.1 Equipment

A custom prototype vibrotactile bracelet was used for designing and testing haptic patterns. Vibrotactile stimulation was provided through eight independent actuators mounted on a velcro band wrapped around the wrist (see Figure 1). Each actuator was composed of a commercially available coin motor (Precision Microdrives 310-113), a microcontroller and a power circuit to control the amplitude of the vibration. Each motor can provide a vibration up to 1.4g using 0.2W in a frequency range of 140 to 240Hz. The actuators were linked in series to a supervisor microcontroller that synchronizes the actuation level, the spatial distribution and the timing of the tactile stimuli. The supervisor is also responsible for the battery management and the Bluetooth communication with the computer. Specific software running on Windows 7 was developed for the design, testing and recording of tactile patterns onto the supervisor’s memory as well as for sending commands via Bluetooth to the tactile bracelet.

Figure 1. Custom-made vibrotactile wrist bracelet

3.3.2 Pattern Design Session

The metaphors were presented in the form of 7 PowerPoint slides corresponding to the 7 messages (see Figure 2).

Alarm clock Knock-Knock Siren

Figure 2. Examples of images used for the design stage

25 new participants (12f/13m) were recruited for the design experiment with a mean age of 34.7 years [22-88 years]. Among them, 13 participants were familiar with haptic interfaces. All metaphors for each message were on the slide and the participant had to choose one of them, thus resulting in 7 patterns per participant. The participants were not aware of the corresponding messages used to elicit the metaphors. A pattern was designed with a custom-made interface used to define the actuator(s) (1 to 8), their amplitude (1 to 7) and the duration of each frame (10 frames in total and each frame can last from 0 to 1.6 sec). We collected a total of 175 tactile patterns. All the participants spontaneously indicated that it was easy and enjoyable to design patterns.

3.3.3 Pattern Categorization

Given the high number of patterns collected in the design study, the next step consisted in the characterization of the salient parameters of each haptic pattern and the selection of the most representative pattern for each message. Four juries (3 experts in haptics and one novice) were recruited. They elaborated their own categories to group patterns by their perceptually dominant parameters.

The resulting classification taking into account categories common to at least two juries, highlighted two types of parameters: the structural parameters, defining the pattern's identity, and the tuning parameters, enabling the global modulation of the pattern. Three main structural parameters were identified and could also be combined. The juries agreed on the following definitions:

- *Rhythm variation*: includes patterns with complex melodies, or presenting one to three repetition(s) of the same vibration.
- *Amplitude variation* within the pattern: is defined either by an increasing or/and decreasing amplitude or by an oscillating amplitude.
- *Localization variation*: groups patterns presenting circular, half circular and back and forth movements around the wrist and other more complex variations.

The tuning parameters include: the number of repetition of the pattern, the tempo (speed of the overall pattern) and the level of overall amplitude.

3.3.4 Patterns Selection and Final Design

This categorization was validated in the following step and further used to select the most representative haptic metaphors for each of the 7 messages. 21 participants were asked to classify the 175 patterns in the categories defined in section 3.3.3 and an additional "Unclassifiable" category. Each category was first described to the participants. Then, they used a custom developed classification interface where patterns were represented by numbered buttons that could be pressed to play the corresponding pattern and drag'n'dropped into the category boxes. By removing the patterns that were unclassified by the majority of participants (70%), the 38 initial metaphors used (see section 3.2) were effectively reduced to 21 distinct metaphors.

At the end of the classification, the frequency of the association between the haptic patterns and the categories were averaged for each semantic metaphor (as several patterns were designed for each metaphor). This enabled to characterize the salient parameters for each metaphor (see section 3.3). 21 patterns were redesigned for each metaphor (see Figure 3) by solely keeping the most dominant parameters to simplify the perception of the pattern. After the selection of patterns and their redesign, 4 patterns were associated to Message 1 (m.1), 2 to Message 2 (m.2) and 3 for each of the other five messages. They are associated as follows to the messages (Table 1):

- **Message 1** (arrival of the vehicle): is represented by the gong, heho, knock-knock and alarm metaphors. The pattern gong is designed with localization variation whereas the three others with rhythm variation (vibration repeated n times).
- **Message 2** (an incident): is represented by buzz (simple rhythm variation as one medium-long vibration) and siren (dominated by an amplitude variation).
- **Message 3** (unavailability of network component(s)): includes the wheel becoming square (localisation variation), bug (simple rhythm variation with a long vibration) and warning (short vibration repeated n times).
- **Message 4** ("wrong way"): is represented by fairy, turn around (both with localisation variation) and "No" nodding (short vibration repeated 2 times).
- **Message 5** (reassurance): is associated to nice music, heart rate (complex rhythm variation) and radar (location variation).
- **Message 6** (a point of interest): is represented by flash (rhythm variation with one short vibration), symphony of Beethoven and valse (with complex rhythm variations).
- **Message 7** (cultural information): is represented by sliding sensation (location variation), "We will rock you" (complex rhythm variation) and purring (amplitude variation).

We can note that the patterns corresponding to the same message do not necessarily belong to the same category of parameters, thus some confusion could be possible between patterns from different messages. Moreover, as patterns were designed while being static, it was important as a last step to evaluate the performance of each of these patterns in mobility.

4 VALIDATION OF THE HAPTIC PATTERNS IN MOBILITY

4.1 Experiment

The objective of this step was to evaluate whether the patterns designed using our methodology were perceived and distinguished whilst participants were mobile.

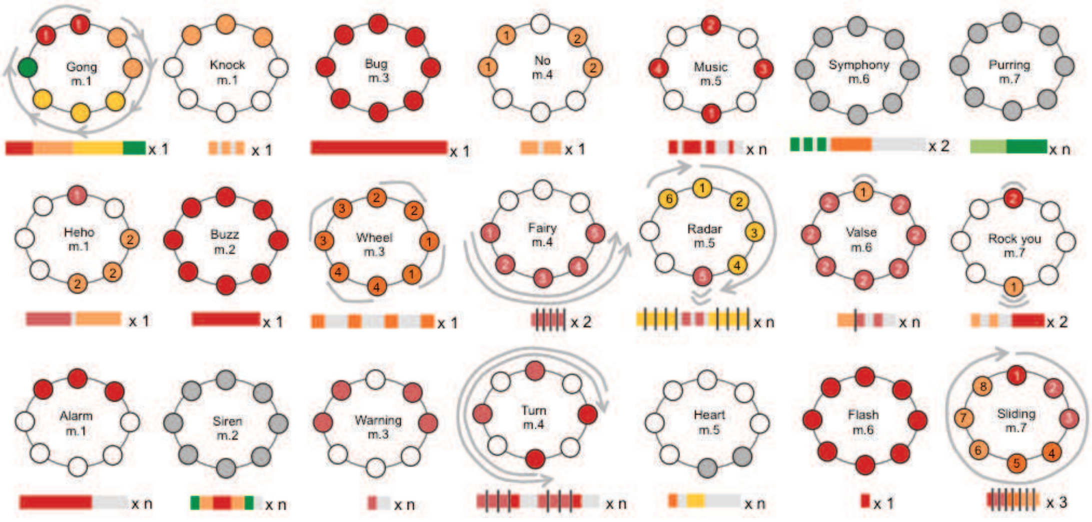


Figure 3. Pattern design for each metaphor and each messages (indicated at the center of the bracelet). The colors represent the level of amplitude: light green for 1, dark green for 2, and then a color gradient from yellow to red for levels 3 to 7. The numbers and arrows indicate the order of vibration. The bar below each pattern holds the information about duration (length of the bar), repetitions (x number), pauses between vibration (light grey) and changes between actuators but at the same amplitude (dark vertical bar).

24 participants (8f/16h) took part in the mobility study. The average age was 31.6 years [22-62 years]. They wore the vibrating bracelet on their non-dominant wrist (see Figure 1).

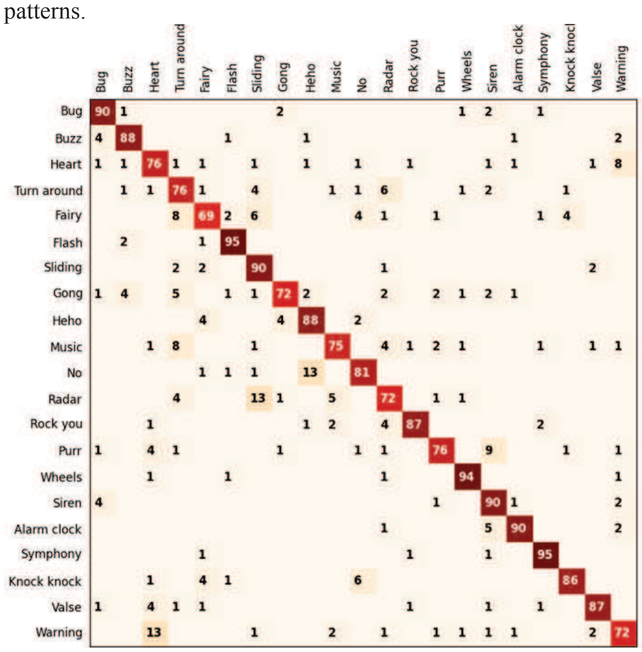
Participants had five minutes to familiarize with the 21 metaphors/patterns. By clicking on the metaphors' icons, displayed on a tablet PC, the participant generated the associated pattern. The participants were then asked to rate their satisfaction about haptic pattern on a 10-point Likert scale (a high score indicating a very positive rating). This "satisfaction" rating was presented as a global score that evaluated both how well the metaphor and the pattern matched and the subjective recognition performance. After this introduction, the 21 patterns were generated randomly and participants were asked to find the associated metaphor whilst being stationary and later while walking. Feedback was provided to the participants about the accuracy of their answer. Throughout the experiment (training and test), a sheet presenting the different metaphors (visual icons and name as we can see in Figure 2) was provided to the participants to reduce the memory load.

In the recognition test when mobile, the 21 haptic metaphors were presented to the participants three times each in random order. The participants indicated verbally which metaphor was presented and the experimenter recorded their answers on the interface. At the end of the test, participants had to rate again each pattern with the Likert scale.

4.2 Results

4.2.1 Identification Rates

The results from the mobility study were compiled into a confusion matrix (see Figure 4), displaying the identification rate for each metaphor as well as the confusion rates with other patterns.



	Bug	Buzz	Heart	Turn around	Fairy	Flash	Sliding	Gong	Heho	Music	No	Radar	Rock you	Purr	Wheels	Siren	Alarm clock	Symphony	Knock knocl	Valse	Warning
Bug	90	1						2							1	2		1			
Buzz	4	88				1			1								1				2
Heart	1	1	76	1	1		1		1		1		1			1	1			1	8
Turn around		1	1	76	1		4			1	1	6			1	2			1		
Fairy				8	69	2	6				4	1		1				1	4		
Flash		2			1	95															
Sliding				2	2		90					1								2	
Gong	1	4		5		1	1	72	2			2		2	1	2	1				
Heho					4			4	88		2										
Music			1	8			1			75		4	1	2	1			1		1	1
No					1	1	1		13		81										
Radar				4			13	1		5		72		1	1						
Rock you			1						1	2		4	87					2			
Purr	1		4	1				1			1	1		76		9			1		1
Wheels			1			1						1			94						1
Siren	4													1		90	1				2
Alarm clock												1				5	90				2
Symphony					1								1			1		95			
Knock knock			1		4	1					6								86		
Valse	1		4	1	1								1			1		1		87	
Warning			13				1			2		1		1	1	1	1			2	72

Figure 4. Identification results from the mobility study

All patterns were very well identified. The mean recognition rate was 83.3%. Over 63 presentations (3x 21 patterns) patterns were recognized 52 times. 13 patterns have recognition rates over 80%, 7 between 70 and 80%, and one with a rate of 69%. This shows that overall patterns were well perceived in mobility but some are better recognized in mobility than others.

The highest confusion rate reaches 13%. This was observed for only three pairs of patterns: 'Heart' and 'Warning', which have a similar rhythm variation; 'Radar' and 'Sliding', both having a circular movement; and 'Heho' and 'No', which were both patterns with two vibrations in time with a single repetition (see Figure 3).

4.2.2 Qualitative Results

In addition to the identification rates, the participants' satisfaction about each pattern was also rated before and after the mobility test. The patterns reached a good satisfaction level (Mean=7.34, SD=1.9) in static condition (see Figure 5), which did not drop in mobility (Mean=7.21, SD=2.01).

However, the standard deviation and overall the large span of responses highlighted the considerable difference in satisfaction for each pattern amongst participants (see Figure 5). This result is probably due in part to differences in sensitivity to vibrations, and to personal acceptance of the metaphors.

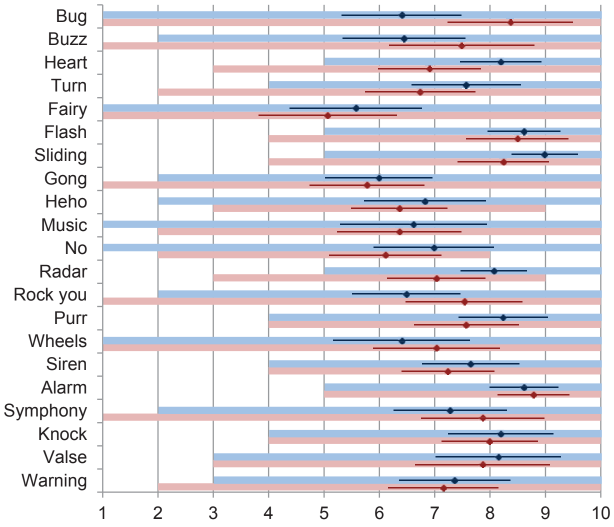


Figure 5. Mean Likert scale rating for each pattern (1 indicates a low and 10 a high rating) and standard variations. The span of response is presented in static (blue bar) and in mobility (red bar).

5 DISCUSSION

This paper presented the methodology aimed to create haptic patterns for an application dedicated to meet occasional travelers' needs in large transportation networks. The analysis of their needs indicated that guidance is an important functionality of the application, but other functionalities such as for example, reassurance about the correct route and alerts about malfunctions on their line, are also required. Therefore, we collected and selected metaphors related to the users' needs. They were then used as anchors for the design of the haptic interaction.

The resulting final set of haptic patterns was subsequently evaluated in a mobility study to validate their design and discrimination. The results of this study indicate that with very short learning, participants demonstrate a very good recognition rate (83%). This result is coherent with Chan et al. [3] indicating that after a very short learning phase 95% accuracy was obtained with 7 icons having a tight relationship with their meanings. Jones and al. [9] also indicated that a mean identification score of 96% was obtained with 15 haptic signals mimicking gestures and provided by a tactile display mounted on the back. However our study used a larger number of items (21 items). This result could suggest that designing haptic patterns having a tight relation to their meanings has a direct impact on the amount of haptic patterns that can be used in an application and may overcome the magic number 7 [8].

The haptic metaphors designed for the application relied on three main parameters: rhythm, the modulation of amplitude and the change in the location of the vibration around the wrist. These parameters are coherent with the literature [2], but also show some discrepancies due to the rich design space offered by the bracelet compared to embedded actuators on a cell phone. Subjective evaluations indicated large discrepancies in patterns ratings amongst participants, which underline the diversity of preferences amongst users. One solution is to provide the user with an interface dedicated to tune the haptic pattern to his preferences. Our study showed that the variation in tempo, the number of repetitions of the same pattern and the overall amplitude of the pattern can be used for this adjustment. The other possibility is to let the user choose their preferred pattern within a limited and constrained design space to avoid the possible confusion between slightly different patterns. For example if the end-user selects the "Heart" pattern for the "reassurance" message, the application will have to suppress the "Warning" pattern to the list of the possible patterns for message 3.

6 CONCLUSION

This paper presented a user-centered methodology that faced the challenge to design an attractive consumer application. Our study supports the need for a shift in the design methodology towards an ergonomic approach taking into account the specific users' needs for specific tasks.

The results of the evaluations indicate that attractive yet effective haptic patterns with limited learning can be designed using a metaphor-based methodology. Participatory design also proved its efficiency in creating original patterns. End users can be very creative in designing original patterns and enrich the production of pattern. Their production, however, must be supervised by specialists in haptic interaction or by design standards to ensure discrimination of the messages and perceived quality. Participatory design is an alternative to using solely engineering design. We still need to demonstrate that participatory design leads to more constructive design, which is one perspective of our work. This will be achieved by comparing our methodology to existing methods involving solely the engineers.

A large-scale evaluation is planned in the short term future to further validate the resulting set of patterns in their context of use. The evaluation will be conducted with a representative sample of occasional travelers as well as with regular travelers during an unplanned journey. The analysis will cover performance data, acceptance data and a large part of the study will cover behavioral data related to the way haptic interaction is actually discovered and used when on the move.

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