Haptic Patterns and Older Adults: to Repeat or not to Repeat?*

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Abstract— **Haptic technologies can open up new avenues for assisting older people in their daily activities, in particular in navigation and orientation tasks. A number of haptic wearables have already proven their usefulness for younger individuals. However, older adults' specific needs for a haptic navigation aid have seldom been investigated. The same is valid for the design of haptic patterns that would be both acceptable and efficient for the elderly. This paper is a contribution in this direction. It is focused on the design of a set of haptic patterns for and by the elderly. It presents the user evaluation that was conducted to assess the recognition rate of these patterns during a navigation task in an urban environment. Fourteen elderly participants took part in the study. The results showed that repetitions of a sequence within a pattern were not crucial for their discrimination and recall. On the contrary, they can cause memorization difficulties and confusion. We discuss these results and propose a number of recommendations for the design of haptic patterns adapted to the older adults' needs.**

I. Introduction

The growing complexity of the urban environment (e.g., the urban network, the diversity of users, the complex infrastructure, etc.) can cause orientation difficulties and therefore increase pedestrians' needs for assistance. To assist pedestrians, there are numerous navigational services on mobile devices (e.g., Google maps, HERE Nokia, Navigon, Wayfinder, etc.). However, these services were initially designed for in-car navigation and are not necessarily suited to pedestrians' needs [16, 19]. Mobile devices also require important visual and attentional resources, which are usually overloaded during navigation and can jeopardize safety. This is even more valid for older adults who tend to have more attentional difficulties.

Haptic technologies can be potentially useful in this context since they can provide information while freeing the older adults' hands, ears and eyes, which can be crucial for their safety [14]. Vibrotactile information has also proven to be very efficient in reducing reaction time and attentional load [15], and distraction [13]. Several haptic prototypes have been developed to assist people in their navigation through vibrotactile directional messages or alerts [3, 18, 12, 8, 6, 15] (see [10] for a more complete list). However, except for a few studies on the design of vibrotactile navigation displays for the elderly with memory disorders (e.g., [9]), few vibrotactile navigation aids have been designed and / or assessed with older adults aged 65 or over [5]. The same observation is valid for haptic messages adapted to older pedestrians. Therefore, studies need to be conducted in order to consider their specificities and diversity [17], in particular considering difficulties in extracting information [1] and abstract thinking [2].

To address older adults' needs, we adopted a user-centered approach to identify a number of design implications for a vibrotactile navigation aid. These implications are based on a user study evaluating the understanding and recognition of a set of haptic patterns designed in collaboration with older adults, using a metaphor-based approach to design. Two research questions were investigated, i.e. 1) Does a metaphor-based design facilitate the understanding and recognition of haptic patterns? And 2) Does repetition of a pattern facilitate these processes? For question 1) we hypothesized that intuitive metaphors would improve the recognition of the corresponding patterns whereas for question 2), we assumed that patterns repetition could be helpful in order to attract user's attention. The results of our study showed that a metaphor-based design was promising for improving patterns recognition and memorization. Conversely, repetitions of a pattern seem to cause memorization difficulties and confusion. Thus, our main contribution lies in these results, as well as in a number of recommendations for haptic patterns design directly derived from the study.

The paper is organized as follows. The first section presents the haptic device used in the study. Then, we describe the methodology of the user study and its results before concluding with preliminary recommendations for the design of vibrotactile patterns suited to the older pedestrians' needs.

II. The vibrotactile wristband

A. Wristband description

The vibrotactile wristband was developed at the Sensorial and Ambient Interfaces Laboratory at CEA. It was designed to provide basic navigational cues as well as other potentially useful or interesting information (e.g., points of interest [11]). The wristband contains three actuators strategically placed around the wrist (left, right and top), whereas the microcontroller and the power circuit are located under the watch face as displayed in Figure 1. The size of the wristband varies between ~19.5cm at maximum length and 16cm at minimum. Each actuator is composed of a commercially available coin motor (Precision Microdrives 310-113). As for the microcontroller, it not only regulates the actuation level and timing but also ensures the battery management and the Bluetooth communication with a

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mobile device. In this experiment, a tablet running Windows 7 was used to control the messages delivered to the participants and record their answers.

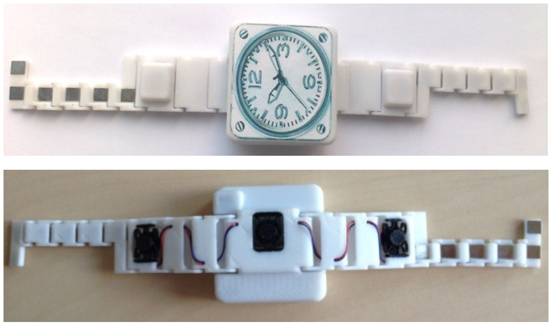

Figure 1. The vibrotactile wristband.

B. Patterns description

Six messages, i.e. three directional messages (*Left, Right* and *Back*) and three informational messages (*Problem*, *Point of Interest* and *Arrival at Destination*) were encoded into patterns using different combinations of actuation parameters. Patterns were chosen for directional cueing instead of bearing information based on the rationale that continuous feedback would be required to indicate proper bearing, which in turn could increase the cognitive load (as confirmed by Pielot et al. [13]), increase annoyance and reduce battery life. The actuation parameters we varied were: 1) the vibration duration; 2) the pauses between the actuator activation; 3) the repetitions of a pattern; 4) the amplitude with six possible levels and 5) the position and number of activated actuators.

For the design of the patterns, we adopted a metaphor-based approach, which relied on the active participation of 25 older adults (more details on the adopted methodology can be found in [11]). The produced patterns and their corresponding parameters were analyzed and the most common user designs per message - in most cases two - were selected. These were subsequently refined into two final pattern designs per message leading to 12 patterns in total. They were then divided into two groups, Type 1 and Type 2, according to the following rules to ensure better discrimination (see Figure 2 for their description): within a group *Left* and R*ight* shall have the same symmetrical design; the designs of the directions should be as distinct as possible from the informational messages (e.g., if the directions are repeated, informational messages should preferably not be repeated or at least not the same number of times); and lastly similar rhythms for two different messages should be avoided (e.g., *Arrival* Type 1 and *Back* Type 2).

III. USER STUDY

A. Objectives and methodology

Our overall objective was to design discriminable, acceptable and intuitive vibrotactile messages for pedestrian navigation by involving older adults throughout the design process. The specific goal of the study described below was to assess the understanding and recognition of the haptic patterns designed during the initial participative design stage [11] and thus to find the optimal final set for further experimentation. Therefore, we compared the recognition of the two resulting sets of messages during a pedestrian navigation task outdoors. Outdoor navigation presents particular challenges such as changes in weather and traffic conditions, noises, etc. All these factors may have a direct impact on pattern recognition. A secondary goal was to assess the acceptability of the haptic navigation aid.

B. Participants

Fourteen participants (7m/7f), with various backgrounds (e.g., a manual worker, an employee, an engineer), aged 63 to 78 years (*Mean*=72, *sd*= 4.33), took part in the study. There were recruited through older adults' associations and they were not compensated for their participation.

C. Procedure

The evaluation lasted about two hours. Each participant started with a familiarization phase and then performed a navigation task. This process was repeated for each of the two sets of messages.

The familiarization phase occurred in a static seated position (e.g., on a bench outdoors). Each message was first played once along with a description of its meaning and parameters to help the user locate the actuators involved in the stimulation. Then, the message was repeated three times in order to help the participant memorize it. This process was repeated for each of the six messages. The participants could ask for an additional repetition if they judged it necessary.

During the navigation task, each participant had to walk two different outdoor routes (Figure 3), for about 20 minutes (depending on their walking speed and breaks). The participants wore the vibrotactile wristband on their right hand. One set of patterns was presented during one of the two outdoor itineraries. The presentation order of the two sets of patterns was counterbalanced between the participants, i.e. half of participants performed first route 1 with Type 1 patterns, while the other half performed it with Type 2, and inversely for route 2. For each route, all messages were presented five times. Participants were delivered the message and then asked to verbalize the message they recognized, which was immediately recorded by the experimenter through a graphical Python application. In order to ensure a relative ecological validity of the study, the messages were associated as much as possible to actual valid information in the environment. Obviously, directions were associated to the chosen itinerary, whereas points of interest corresponded to different landmarks (e.g., buildings) and similarly problems to potential dangers (e.g. ravines).

A questionnaire was administered after the navigation task. It was composed of 31 questions based on a 6-point Likert scale in order to avoid neutral answers. The questionnaire tackled the participant's demographics and navigation and orientation difficulties; their needs and expectations as far as vibrotactile navigation aids are concerned; their subjective appreciation of the vibrotactile patterns and device presented in this study.

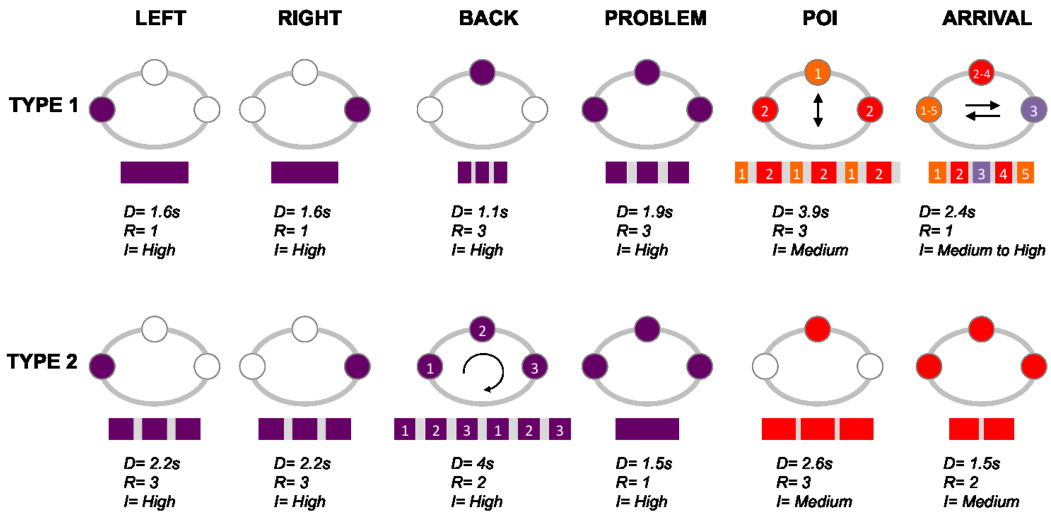

Figure 2. The haptic messages evaluated during the study, each depicted with their total durations (D), the number of repetitions constituting the pattern (R) and their vibration intensity (I) or amplitude. The colors correspond to the level of the amplitude, mainly purple for the highest values (dark and light) and orange and red for medium values. The bar beneath the representation of the pattern indicates the proportional timing values for each sequence (the colors indicate actuation with the level of amplitude whereas the intermediate grey bars indicate pauses).

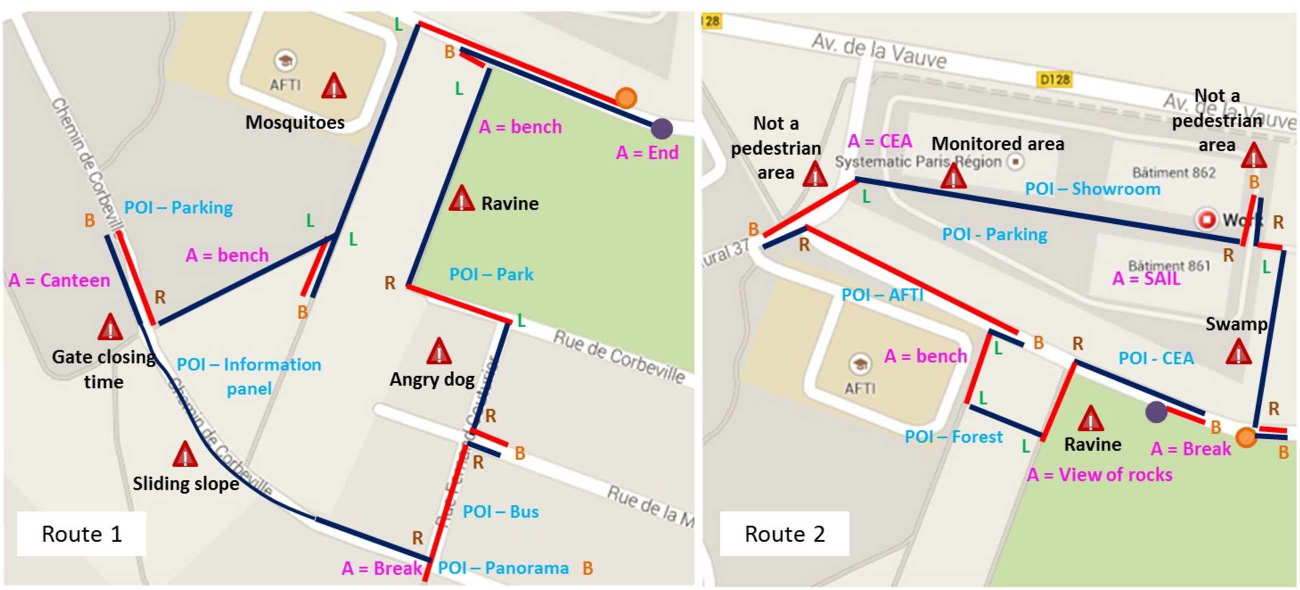

Figure 3. Routes description with the paths walked and the distribution of directional and abstract messages along the routes: *Left* (L), *Right* (R), *Back* (B), *Point of interest* (POI), *Problem* (⚠) and *Arrival* (A). The alternance of the route's color indicates a change of direction, either by turning or going back. The light colored circle indicates the start of the route whereas the dark colored one indicates the end.

IV. Results and Discussion

During the study, both quantitative and qualitative results were collected. These results are presented below and organized in three subsections, where the first presents the quantitative results about the recognition rates and the last two describe the qualitative results about the patterns design.

Since most of the data failed to meet the normality criterion, within-group comparisons were performed using Wilcoxon signed-rank tests. The Likert responses were numerically coded using the 1–6 values and were treated as ordinal data by means of nonparametric statistics [7]. For the frequency data (for instance, the preferred design), the chi-squared test was used to test the hypothesis of independence between participants' assessments. Percentages of responses were privileged when they appeared more informative or when a categorical approach focused preferentially on some responses (e.g., ''often'' and ''very often'' contrasted to the other responses).

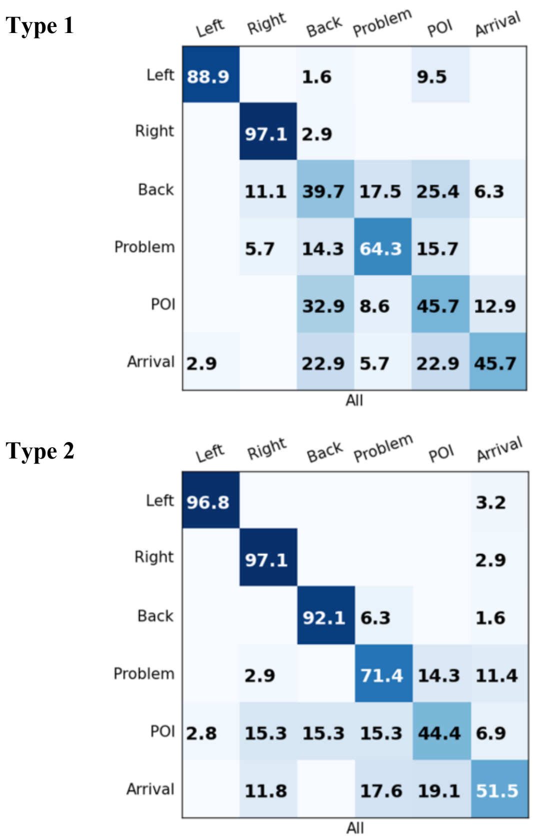

Figure 4. Confusion matrices with the average recognition rates for the two sets of messages (Type 1 and Type 2).

A. Patterns recognition

For both sets of messages (Type 1 and Type 2), the simplest messages (e.g., directional messages such as *Right* and *Left*) had the highest recognition rates (> 88%, see Figure 4). For these messages, the recognition rate was higher than for complex messages, no matter the design (only the comparisons between the simple message *Left* and the complex message *Back* for Type 2 is non-significant, T=4.00; Z=0.94; ns). Although *Left* and *Right* have the same recognition rate for Type 2 design, it differs significantly for Type 1 (T=0.00; Z= 2.02; $p<0.05$). Surprisingly, the message *Left* for Type 1 was not as well recognized as the similar message *Right* (T=0.00; Z= 2.02; $p<0.05$). Indeed, participants complained that the left actuator was not sensed as strongly as the right one for the same intensity. As this was not noted by all the participants, there could be different possible explanations. This could be due to anatomical differences on the wrist with the prominence of the ulna bone on the right side. Or perhaps it could be caused by an industrial dispersion of manufacturing between the actuators, thus impacting on vibration intensity. It could also be due to an unequal adherence of actuators on the skin. We hypothesized that this phenomenon is less pronounced for Type 2, due to the repetitions that could have increased the perception potential. In addition, we observed a high recognition rate for the *Back* message for Type 2 (92.1% versus 39.7% for Type 1; T=0.00; Z= 3.06; $p<0.01$), which was based on a "turn around" metaphor imitating the movement of turning back. The Type 1 *Back* on the other hand was not designed using a metaphor-based approach, but rather by simple opposition to the *Left* and *Right* messages with an alerting property. This result suggests a positive impact of a metaphor-based design in helping the understanding and recognition of haptic information. Another well-recognized message was the message *Problem* (71.4% for Type 2 versus 64.3% for Type 1; T=16.05; Z= 0.21; ns) where a long continuous signal was presented (Figure 4). The metaphors involved here were based on alarms, with two possible designs, a continuous or a repeating one.

The two remaining messages (*Point of Interest* and *Arrival at Destination*) were poorly recognized and often mistaken with each other or with other messages that constitute possible subsets of the patterns. A possible interpretation of these relatively poor results could be that these messages are quite abstract and require longer learning to be memorized. These poor recognition results could also be due to a learning time too short for a large number of messages - participants learned 12 messages in total. Another explanation could simply be that the learning time of more complex messages was too short to allow participants to remember all the messages. Priority was given to what participants considered the most important messages, i.e. directions and problems. This is also confirmed by observations done by the experimenter and qualitative feedback further detailed in the following subsections.

B. Patterns preference

At the end of the user study, the participants were asked which of the patterns they preferred for each message. Concerning the directional messages (*Left* and *Right*), there was no major difference in preferences, though Type 1 had a slight advantage compared to Type 2 (57% of participants for Type 1, $\chi^2(1, 14) = 0.54$, ns; see Figure 5). Regarding the other messages, the preferences were more strongly pronounced. Participants largely preferred the second set of patterns (global comparisons between Type 1 and Type 2 $\chi^2(4, 14) = 24.38$; $p<0.001$, with for *Back*, $\chi^2(1, 14) = 28.00$, $p<0.001$, and for *Problem*, *POI* and *Arrival*, the same significant-different pattern of responses $\chi^2(1, 14) = 20.57$, $p<0.001$; see Figure 5). It is noteworthy that all participants preferred the message *Back* which was based on the natural analogy with turning back on oneself (Type 2: vibrations in clockwise rotation) rather than the design relying on a simple opposition with directions. They found it more "intuitive".

For Directional or "simple" messages, more than half of the participants estimated that it is not necessary to repeat, within a given message, the vibrations for simple messages such as *Right* and *Left* (global comparisons of the 6 Likert scale's values, $\chi^2(4, 14) = 22.54$, $p<0.001$; and comparisons between "1", "2", "3" responses meaning "no repetition" and "4", "5", "6" responses meaning "repetition": $\chi^2(1, 14) = 14.28$, $p<0.001$). These participants thought that such a repetition would require more cognitive resources to process and memorize the haptic information. They were also afraid of confusions with more abstract and complex messages (i.e. informational messages). The participants required repetition "on demand", when judged necessary.

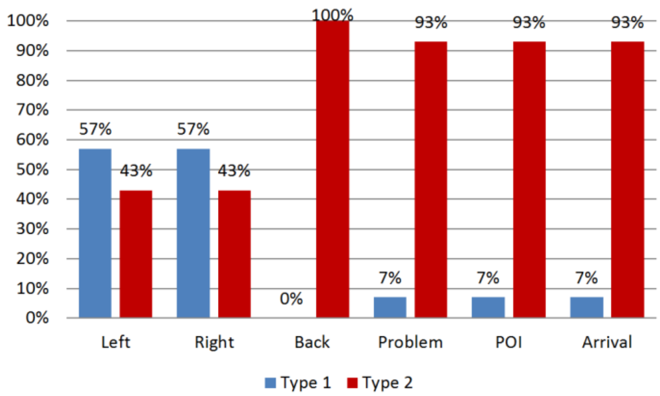

Figure 5. Haptic patterns preference for each message.

Similarly, for abstract or "complex" messages, though not significantly, more than half of the participants reported again that changes in the number of vibrations and internal repetitions caused memorization difficulties and confusion between abstract messages. Contrary to our expectations, repetition was not perceived as an aid to recognition; it makes messages "more complex". Moreover, 78% of participants considered that repetitions would be mainly useful in an emergency situation to emphasize the imminence of an event or to stress a problem.

C. *Overall acceptability questions*

The other questions of the questionnaire enquired about the general acceptability of the haptic aid. First, concerning the learning and recognition of the messages and whether each was mentally demanding, the participants' feedback showed that Type 1 and Type 2 patterns were not significantly different concerning learning ($\chi^2(20, 14) = 29.70$, ns). In contrast, it was for recognition ($\chi^2(12, 14) = 29.16$, $p<0.01$) with Type 2 performing slightly better. However when enquired about the ease of learning and recognition, there was a significant difference for learning between Type 1 and Type 2 ($\chi^2(16, 14) = 25.00$, $p<0.05$) but not for recognition ($\chi^2(12, 14) = 15.84$, ns) with Type 2 leading to a better learning facility. Nevertheless, data showed it was still a rather easy and acceptable task. The difficulties participants faced stemmed primarily from the more complex messages (i.e. *POI*, *Arrival* and *Problem*).

When asked about the general satisfaction of the design of the messages for each type, only 14% of the participants were not satisfied with Type 1 design and no participant was unsatisfied with Type 2 design. The satisfaction degree did not differ significantly between the two designs ($\chi^2(12, 14) = 15.84$, ns). All the data indicated that overall participants were satisfied, particularly so with the second design, but left some room for improvement. In particular such improvement was suggested by recombining the two sets, according to the results presented in Section B.

As for the irritation caused by the vibrations, all participants but one did not find the sensation irritating at all. Furthermore, only 14% of the participants did not appreciate the sensation caused by the vibrations. Interestingly, 57 % of the participants found it useful to wear such an aid for navigation. They found it particularly useful for indicating directions and problems. Concerning the potential improvements, the suggestions tackled primarily missing functionalities such as the possibility to have a volume button (for discretion as well as perception purposes, 71% of the participants), a "repeat message" button (all participants) and a stop message (93% of the participants). The other improvements concerned the esthetics (size of the wristband, a look more similar to a real watch) with 21% of participants, as well as the improvements of the design of the more complex informational messages.

Overall participants reacted well to wearing the haptic wristband and its sensations and were not displeased with getting information haptically. On the contrary, they were satisfied and found it useful and securing. Their feedback highlighted the importance of designing simple messages with the worry of inattention and memorization issues and having a functional yet esthetical device.

V. RECOMMENDATIONS FOR DESIGNING HAPTIC NAVIGATION AIDS SUITED TO OLDER ADULTS NEEDS

Haptic technologies can open up new avenues for assisting older people in navigation and orientation tasks. However, key factors for a successful haptic aid lies not only in the discrimination and intuitiveness of the haptic language but also its acceptability along with the one of the device. In this section, initial recommendations resulting from the study are described for designing vibrotactile navigation aids suited to the older pedestrians' needs.

Recommendation 1: **Design task-specific messages, on the basis of the priorities given by older adults.** Thus, in this study, the older adults considered the directional patterns crucial for the navigation task, while the other patterns were considered of secondary importance. This could be influenced by the outdoor setting and the experimental conditions which did not offer and promote exploration through interesting points of interest or convey problems related to real dangers. Consequently, task-specific messages, in this case directions related to the primary task of navigation, should be designed as the most intuitive and easy to recall as possible. Also the design should be different between a set of messages considered as crucial to the primary task and others as of secondary importance.

Recommendation 2: **The design of the important messages should be the simplest possible.** In our study, the preferred and better recognized design involved continuous strong signals, without too many repetitions. Such patterns were considered "most intuitive", requiring less memorization efforts. Therefore, various combinations of parameters (such as repetitions, as well as variations on the durations and the amplitude of the stimulations) should be avoided as much as possible for such messages. In general, for such messages, in our case directions, a single repetition with the highest possible amplitude was preferred.

Recommendation 3: **Use "internal" repetitions of a sequence with care.** We hypothesized, given attentional issues, potential memory declines and possible distractions from the environment, that having "internal" repetitions within a message would help its recognition. Indeed, even if the first signal were missed, the following signals would still enable its recognition. However, in a set containing at least 6 messages, each with repetitions and different combinations, this brought confusion. By missing the first signal, participants were unsure of how much they had missed and could not discriminate properly amongst similar messages.

Recommendation 4: **Using a metaphor-based design is a promising lead.** Indeed, the recognition rates were rather high for the messages *Back* of Type 2 based on the movement of turning back and for *Problem* where the underlying metaphor is an alarm (either repeated or not). On the contrary, for the messages where the metaphors were less significant, i.e. intuitive and natural (*POI* and *Arrival*), the recognition rates were quite poor, less than average in fact. Such a methodology has proven effective for a younger targeted population [4] and should be further investigated and applied for older adults where strengthening the link between the vibrations and the signification of the message is of outmost importance for recall.

Recommendation 5: **For any success of a haptic aid, its acceptability should be tackled as seriously as the development of the language itself.** Given some reticence of the older adults towards technological accessories, it is important to take into account the esthetics, comfort and portability of the navigation aid. We chose the form factor of a wristband resembling a watch to aid its acceptability. Through the qualitative answers, this design choice has proven fruitful as participants did not reject this design and felt comfortable with the device. Often they would forget to remove it when starting to answer the questionnaire.

VI. CONCLUSION

In this paper, we presented an evaluation study conducted to assess the recognition and the understanding of haptic patterns for a navigation task in ecological conditions with older adults. Six messages (*Right*, *Left*, *Back*, *POI*, *Problem* and *Arrival at Destination*) were evaluated with two different design sets in order to identify successful combinations of the parameters to reach intuitive and pertinent messages for the elderly. The various findings concerning the usage of a metaphor-based design or repetitions within a message highlighted the necessity to take into account the specific needs of this targeted population, for whom for instance focus should be given to simplicity and messages considered crucial to the task. These findings are summarized into recommendations for designing an efficient aid accepted by the older adults.

This study is a first step in designing and validating efficient haptic aids for older adults. In particular, the patterns will be further refined and evaluated for testing long-term recall and acceptability. Differences with younger users will also be investigated to further highlight the possible design differences stemming from different needs and population specificities. Finally, the integration of such a navigation aid into the current smartwatch trend will be explored along with other useful haptic information that can be provided (e.g., information from calendars, health-related alerts, etc.).

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