Visual, Auditory and Haptic Navigation Feedbacks among Older Pedestrians

Angélique Montuwy
IFSTTAR – COSYS, LEPSIS
Versailles, France
TELECOM PARISTECH – I3
Paris, France
angelique.montuwy@ifsttar.fr

Béatrice Cahour
TELECOM PARISTECH – I3
Paris, France
beatrice.cahour@telecom-paristech.fr

Aurélie Dommes
IFSTTAR – COSYS, LEPSIS
Versailles, France
aurelie.dommes@ifsttar.fr

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Abstract
As worldwide population is aging and concentrating in cities, designing a pedestrian navigation aid adapted to elderly specificities and needs could help in preserving their autonomy, as their cognitive and perceptive abilities may decline with age. This study was aimed at comparing visual, auditory and haptic guidance feedbacks among older pedestrians, taking into account their navigation performance and user experience. A virtual environment was used to measure time to destination and rate of correct responses. Post-activity interviews were used to access participants' perceptions, feelings and hesitations in a qualitative way. Results showed great performance and user experience for visual guidance, whereas performance and user experience were poor for haptic guidance.

Author Keywords
Sensory modalities; navigation; pedestrians; aging; user experience; virtual environment.

ACM Classification Keywords
H.5.2. Information interfaces and presentation: User Interfaces.

Introduction
As worldwide population is aging and concentrating in urban areas [25], helping older pedestrians' mobility

User Experience: It concerns functional aspects such as usability (effectiveness, efficiency and satisfaction in a particular context of use) but also subjective aspects (emotional, hedonic and aesthetic dimensions).

Explicitation interviews: they aim at bringing back the participant to the situation s/he has lived in order to ask questions about her/his perceptions, thoughts, emotions and actions. These interviews consist in mentally re-viewing what happened, just like if the participant had rewound the film of the situation from her/his point of view. The interviewer asks for more details or for associated emotions, feelings, thoughts that occurred in the participant's mind when doing something specifically. This type of interview allows to focus on very precise moments, instead of a global appreciation of the use of a system or service.

has become a key issue for preserving their autonomy and quality of life. Pedestrian mobility is, indeed, a healthy and sustainable transportation mode, but also one of the most important one for the elderly in cities [19, 7]. However, cognitive, perceptive and physical declines associated with aging [16] can lead them to reduce their travels, especially in unknown environments. If some pedestrian navigation aids are available on the market, those ones rarely take into account older pedestrians' specificities, even if they could take advantage of such aids.

For the last decades, scientific research dedicated to navigation aids has studied pedestrians' navigation issues to design a system that better suits the pedestrian needs. Those studies often focus on the sensory modalities (visual [14, 3], auditory [8, 3], and more recently haptic [20, 21]) and the types of information that could be used to guide pedestrians, but rarely take into account perceptive and cognitive declines that occur with aging and impact the perception and interpretation of the directional messages. User experience is also a key element that should be considered when designing and evaluating navigation aids [22]. Studies dedicated to pedestrian navigation aids often focus on usability aspects and acceptance of the device after a short time of use through post-use questionnaires. If these questionnaires are standardized and easy to implement [15], they have some limits: Likert scales could be misinterpreted or interpreted very differently among participants [10]. Social desirability bias has also to be taken into account, especially when dealing with the elderly [5]. Moreover, factors affecting technology acceptance differ between young and older adults [13]. Technology Acceptance Model (TAM) has evolved since its first version to integrate dimensions such as pleasure and enjoyment in addition to functional aspects [24], but questionnaires of this type remain tedious to understand and fill in. Using interviews to question UX may help in accessing a more diversified range of dimensions of the UX than questionnaires, while limiting biases linked to social desirability and the use of Likert scales

This study was aimed at designing a navigation aid adapted to older pedestrians. Visual, auditory and haptic guidance feedbacks were compared. Performance was measured thanks to several navigation tasks performed on a virtual environment (VE). A VE was used to ensure the safety of the participants who may suffer from age-related declines, while experimentally controlling interference factors and allowing a clear and pure perception of guidance feedbacks. User experience was studied using post-activity explicitation interviews. This work was aimed at guiding the design of guidance feedbacks that will be tested in a real world environment in a further study.

Method

Population

Three groups of participants were compared in order to highlight possible age-related difference: 16 middle-age adults (M=58.3, SD=8.7; 9 women, 7 men) who still had a professional activity, 21 younger-old adults (M=66.7, SD=7.6; 8 women, 13 men), and 21 older-old adults (M=75.9, SD=7.5; 10 women, 11 men) who were all retired. The criteria of being retired was taken into account as daily mobility changes when retiring. Perceptual and mental-rotation tests were performed to ensure the participants did not suffer from a pathological aging.

Figure 1: Map showing street names, landmarks, a zoom onto the city center and the path to follow.

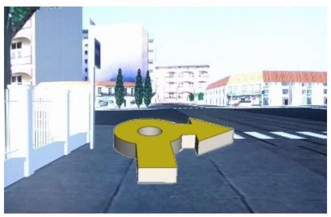

Figure 2: Arrow inlayed in the virtual environment.

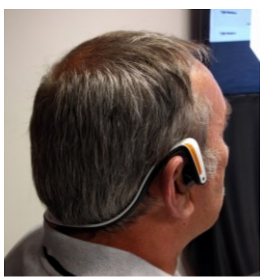

Figure 3: Participant wearing the bone conduction headphone.

Sensory guidance feedbacks

Four types of guidance feedbacks were designed and tested:

- An A3 paper map with the street names, the route to be followed and some landmarks written on (see Figure 1).
- Visual guidance feedbacks, consisting in directional arrows, were inlayed in the visual field of view, such as the ones used in augmented reality (AR) (see Figure 2). This choice was made because of the promising results of using arrows in an AR smartphone application for pedestrian navigation [23]. Using AR glasses for car navigation among older drivers also appeared to be relevant [12].
- Auditory guidance feedbacks, consisting in left/right ear panned stereo sounds, were transmitted through bone conduction headphones (see Figure 3). Non-verbal guidance has shown good results for navigation [18], and appears to involve few mental demands [17].
- Haptic guidance feedbacks, consisting in vibrotactile information, were delivered thanks to a wristband composed of 3 vibrators (see Figure 4). The use of haptics has been shown to reduce navigation errors in comparison to a paper map in the recent literature [6].
- For each type of guidance feedback (except the map), six messages were used to indicate whether the participant had to turn right or left at the next intersection, enter a roundabout to the right or to the left, make a U-turn and stop at arrival. Each message lasted two seconds. When no message was provided, the participant had to go straight on. The messages were designed according to the aging literature in order to be as simple as possible and well perceived even by people suffering from perceptual declines (arrows brightness, sounds frequency etc.).

Virtual environment (VE) for pedestrian navigation

The VE allowed participants to navigate in a city using a joystick (see Figure 5). The system included three 47-inch LCD screens displaying 3D visual data representing an urban environment with traffic, for a 130° field of view. The speed of walking was set at 3 m/s.

Navigation task

Each participant individually performed four navigation tasks in the VE. All participants were asked to navigate along four distinct (but similar) routes, each time using one type of guidance. Before each itinerary the participant could take time to learn the navigation messages. The experimenter explained where the participant was, and where to go. In the paper map condition, participants were asked to strictly follow the path drawn on the map (no detours, no shortcuts). In the other conditions, the feedbacks indicated the participants the directions to follow. Each route was preceded by a short practice trial. The routes were equivalent in terms of both distance and time (6 to 7 minutes), and the directions to take (3 right turns, 1 roundabout to take by the right, 3 left turns, and 1 roundabout to take by the left).

Post-activity interview

After each navigation task, a post-activity interview was performed with the participant, in order to gather her/his perceptions, emotions, hesitations during the navigation, but also her/his comments about the

Figure 4: Participant wearing the vibrotactile wristband.

Figure 5: Participant navigating the virtual city.

guidance's utility, innovation, adaptations to make, etc. (see side bar below).

First, each participant was asked about any spontaneous comment or observation about what s/he lived in the VE. Then, the method of the explicitation interviews was used to get details about the user experience from an embodied talk position. The participant was invited to take time in order to recall the route, and asked to give as many details as possible about the ten UX items. At the end of the study, the participant was also invited to rank the types of guidance tested from the most to the less preferred one.

Data collection and analysis

Route duration was measured, as the time between when the participant first moved the joystick to start walking and the end of the route. On this basis, the difference between the route duration and the optimal time to reach the destination was calculated, as the routes were not exactly identical. The percentage of correct responses at intersections was also calculated. The interviews were recorded and verbatim were fully transcribed, according to the ten UX dimensions shaping the interview. On this basis, percentages of responses for each UX dimensions were calculated.

Navigation data were studied using ANOVA with comparisons between groups of participants and between experimental conditions. Post-hoc comparisons were performed using Tukey's HSD tests. The final ranking was recoded into two modalities (positive vs. negative). Chi-square analyses were also used to study differences between final ranking and verbalizations.

Results

Navigation performance

TIME TO REACH DESTINATION

The data analysis highlighted a main effect of group ($F(2,55)=6.73$, $p=<.005$, $\eta^2=.20$), with older-old participants taking more time to reach the destination than younger-old and middle-age participants ($p<.01$). Analysis also showed a main effect of guidance type ($F(3,165)=57.94$, $p=<.0001$, $\eta^2=.51$). Navigating with a map required more time than the three other types of guidance ($p<.00001$). Among the other types of guidance, visual guidance required less time than haptic guidance ($p<.05$).

CORRECT RESPONSES AT INTERSECTIONS

The data analysis showed a main effect of group ($F(2,55)=10.84$, $p=<.0005$, $\eta^2=.28$), with older-old participants having fewer correct responses than younger-old ($p<.005$) and middle-age participants ($p<.0005$). A main effect of guidance type was also observed ($F(3,165)=20.66$, $p<.00001$, $\eta^2=.27$). The rate of correct responses was higher with visual and auditory feedbacks than with the map and haptic guidance ($p<.00001$). Finally, interaction between group and guidance type was observed $F(6,165)=3.57$, $p<.005$, $\eta^2=.11$), older-old participants having less correct responses with the map than the two other groups of participants ($p<.0005$). Moreover, there was no difference between the types of guidance among the middle-age group, while older-old and younger-old participants had more correct responses with the visual guidance ($p<.005$) and the auditory guidance ($p<.05$) than with the haptic guidance mode.

Ten UX dimensions: The interview dimensions were chosen based on some recent reflexive works and studies about measuring UX [15], the acceptance of mobile navigation devices [1], and the usability of applications for the elderly [9]. This benchmark led to identify ten UX dimensions to question specifically during the description of his/her lived experience by the participant: pleasantness, perception, understandability, attention to the environment, feeling of disorientation, reassurance, feeling of being autonomous, usefulness, innovation, and habituation.

User experience

Post-activity final guidance type ranking showed that participants preferred the visual guidance. Haptic guidance was the most depreciated one.

Visual guidance was the most often declared as pleasant, perceptible, understandable, compatible with paying attention to the environment and fostering the autonomy of the pedestrian, and the less often declared as a possible source of disorientation, whatever the group of participants (see Table 1). Despite the good experience they lived with the visual guidance mode in the VE, participants wondered about the potential embarrassment they may feel in using AR glasses in the real world. Nevertheless, visual guidance appeared to be obvious, familiar and natural.

User experience with auditory guidance was quite as good as with visual guidance. It was declared as the most reassuring and innovative guidance type (see Table 1). Using a bone conduction headphone appeared to be a good idea for the three groups of participants to guarantying their safety.

The haptic guidance was perceived as the less pleasant, the less perceptible, the less fostering autonomy and the less useful guidance whatever the group of participants (see Table 1). Older-old participants, in particular, declared having more difficulties to understand the messages than the two other groups ($\chi^2(1,58)=9.96$, $p<.01$). They did not perceive the vibrations on a precise side of their wrist, or had difficulties in memorizing the patterns of vibrations. Using a wristband was perceived to be more discreet than glasses or headphones, or than other vibrating devices (belt, insoles).

Finally, the paper map was the less understandable, the less compatible with paying attention to the environment, the less reassuring, the less innovative and the more disorientating type of guidance. However, surprisingly, the map was told to be the most useful guidance, probably because of its familiarity. Moreover, map was difficult to read for older-old participants in comparison to younger-old participants ($\chi^2(1,42)=4.84$, $p<.05$). They usually had two pairs of glasses, and had to use one for reading the map, and the other one to look at the VE screens. This type of guidance was very familiar to the participants, as 70% declared they still used paper maps when 30% had replaced maps by GPS.

Is the guidance?	Visual	Auditory	Haptic	Map
Pleasant	93% (55)	79% (56)	50% (56)	62% (52)
Perceptible	100% (48)	84% (56)	22% (58)	64% (58)
Understandable	95% (56)	86% (57)	41% (58)	39% (36)
Compatible with paying attention	79% (48)	65% (49)	69% (49)	45% (51)
Disorientating	2% (58)	7% (58)	12% (58)	30% (58)
Reassuring	81% (42)	91% (43)	73% (37)	68% (41)
Fostering autonomy	84% (51)	74% (46)	59% (46)	66% (44)
Useful	80% (56)	83% (57)	73% (58)	93% (43)
Innovative	77% (53)	86% (51)	83% (52)	6% (48)

An example of verbatim:

When entering a roundabout with the haptic guidance, a middle-aged male participant said: *"I was waiting for the message. I was thinking to myself: "is it going to prickle?" At this moment, when it vibrated, I went to the left side of the roundabout, but I wasn't sure of me at 100%. It wasn't hazardous, but I had a doubt at this moment".*

This kind of information could not be collected by the only use of questionnaires like the TAM, both in terms of precision and in terms of vocabulary used to describe the perception.

Is the guidance?	Visual	Auditory	Haptic	Map
Habitual	78% (58)	43% (58)	43% (58)	70% (56)

Table 1: Percentage of participants characterizing each type of sensory guidance in accordance to the interview topics. The total number of participants who expressed opinions about each topic is indicated in parentheses.

Data analysis showed that the general pleasantness and usefulness were the two UX dimensions that significantly influenced the ranking for almost all types of guidance feedbacks.

Discussion, limits and future works

This study aimed at comparing four types of guidance feedbacks among three groups of participants, taking into account navigation performance and user experience. When using a map, older-old participants made more errors and had a tendency to take a longer time to reach the destination. These findings were congruent with other studies [20, 23]. These results highlighted the benefit of using a navigation aid instead of a map for older people. Older participants also showed poorer navigation performance with the haptic feedbacks than with the visual and the auditory ones. These findings suggested that a visual or an auditory guidance system may be more adequate to the elderly needs than a haptic guidance system.

Results about the map have to be questioned: performance was low and user experience rather poor, but the map was perceived as the most useful guidance type. This is a common result in the literature dedicated to navigation aids, participants appreciating the global overview provided by a map or being more familiar to maps [22]. In this study, participants also evoked the absence of battery in the map as a gage of usefulness, as this one could not break down. This may be seen as a sign of technology anxiety, which could affect acceptance of the system, especially among elderly [4].

Visual and auditory feedbacks were well perceived and well understood by all participants. This fosters the hypothesis that visual and auditory modalities displaying adequate types of feedbacks could help in compensating the deleterious effects of aging, even if visual and auditory perceptions are affected when advancing in age [7]. Haptic feedbacks were difficult to use when navigating the virtual environment for younger-old and older-old participants. This could be explained by a poorer haptic perception among older participants [11]. The design of the vibrotactile messages should also be modified, even if it was based on previous studies [2].

Using interviews based on the explicitation method was a way to highlight the difficulties related to the perception and the comprehension of the sensory messages (see side bar). Beyond statistics analyses, those data help in understanding what lies behind the observed behaviour. If differences related to the age groups are important in the quantitative results, there are quite no age-related differences in the qualitative results. This fosters the need of questioning user experience: a great performance could hide difficulties which are not observable directly. Pleasantness and usefulness are two key elements in explaining the preference for a type of guidance. These two UX dimensions are traditionally associated with behavioural intention in the acceptance theory [24]. In the present study, the explicitation method also helped us in explaining the difficulties that the participants had in learning some messages, ease of learning being a key element in acceptance among elderly [13].

Of course, the context has to be taken into account in analysing data. Using a VE may have influenced the feeling of being reassured or accentuated some difficulties among participants (perception and navigation). If interesting dimensions of the user experience are questioned, this user experience is incomplete and limited by the use of a VE. Kinaesthetic (body movements, displacement and hands' occupation) and environmental aspects (sounds, smells, crowd, traffic density, glare etc.) which are important in the activity of navigation [11] could not be questioned in this experiment. A second study in a real environment should help in answering these questions.

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