A Pilot Study of a Wearable Navigation Device with Tactile Display for Elderly with Cognitive Impairment

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Abstract. It is typical for the older adults with or without cognitive impairment to manifest sensory declines. This indirectly affects their sense of direction and wayfinding ability as oriented search is linked with sensory, mainly the visual. The deterioration of spatial navigation skill due to aging and cognitive decline is well recognized. We present the conceptual design of a wearable navigation device with tactile display and its prototype development, aimed to assist the navigation of individuals with cognitive impairment. The results of a pilot test conducted on individuals with dementia using the working prototype are also presented and discussed. The experiment intended to verify the positive outcomes of using the haptic modality for navigation and its wearability. Results suggest that the haptic stimulus is a helpful signal for wayfinding. From the user assessment however, some limitations are traceable due to the wearable design of the device. This is needed to be improved and emphasized in our future works.

Keywords: Wearability · Haptic-feedback · Navigation · Cognitive impairment · Pilot study

1 Introduction

With the increasing aging population, the number of elderly with cognitive impairment due to dementia is simultaneously increased [1]. In parallel, although age is not the main factor of dementia, yet, most of the reported cases reside among the elderly [2]. It is very common for the older adults to be linked with the memory loss, cognitive decline and sensory changes, as they grow older [3, 4].

For the elderly with cognitive impairments, one of the ways to maintain the normal social functioning is the mobility skill [5]. In fact, mobility keeps the performance of activity of daily living and at the same time reduces the dependency. Nevertheless, individuals with cognitive impairment, mainly dementia are typically diagnosed with the decline of spatial navigation skill, the process of determining and maintaining trajectory from one point to another [6].

The declines of mobility, wayfinding and spatial ability according to age and severity of cognitive impairment have been recognized [7, 8]. Moreover, older adults with dementia also manifest sensory declines, similar to senescence (biological aging). These issues worsen their spatial ability in general, because oriented search is relatively connected with sensory acuity, mainly the visual [9] and at times auditory.

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Unfortunately, the most affected sensory for elderly with or without dementia are vision and hearing [10]. This initiates the idea of using alternative sensory/modality to assist their wayfinding. Thus, the paper aims to investigate how older adults with cognitive impairment mainly due to dementia perceive haptics a modality of navigation. A review on the selected existing studies is presented to highlight the potential of haptic/tactile applications for navigational purposes.

2 Related Works

Current navigational devices take advantage of the emerging technological applications, but the common methods of navigation are predominantly based on visual interactions and auditory support. While navigating in the actual environments, obliging to concentrate on the surrounding and visual display of the navigation device at the same time may be very distracting. In the case of dementia, one of the most important aspects to avoid during wayfinding is confusion [11]. Therefore, a possible alternative sensory that should be further explored for wayfinding purpose is the sense of touch.

Similar to vision and hearing, tactile perception is gradually diminished due to the age-related impairment of sensorimotor and cognitive abilities [12]. However, individuals with dementia maintained intact haptic priming, despite the weakened recognition performances [13]. Besides, although individuals with dementia have the difficulties to learn incipient things, the implicit recollection for haptically-explored objects is preserved in those in early stages [13].

There is a growing body of research at present on the use of haptic modality in a variety of applications, such as the system to sense the virtual objects, in surgical tasks, designing the human-computer interfaces and also for wayfinding/navigation purposes. As the focus of the study, the examples of haptic modality for navigation include: (i) a mobile navigational assistance with Microsoft Kinect and optical marker tracking to help the indoor navigation of individuals with visual impairments [11], (ii) a wearable navigation system using haptic directional display integrated with a vest [14], and (iii) a blind navigation system with a Kinect 3D sensor range camera and a vibrotactile helmet [15].

Nevertheless, like the abovementioned studies, the existing body of works often focuses on individuals with visual impairment or blind people, and not specifically for the persons with cognitive impairment. Closer to our goal, [16] investigate the applicability of tactile signals to assist the wayfinding of persons with dementia. They developed a wearable belt with vibrating motors and participants were asked to navigate in a series of routes with the assistance of the built-in vibrotactile signals. This study is a good example that highlights and proves the potentials of haptic stimuli to assist the wayfinding of individuals with cognitive impairments.

Furthermore, this modality as a form of signal provides a simple, yet a promising form of directional cues that allows users to concentrate on the surrounding with other senses (vision and hearing) during wayfinding [17]. Besides, the vibrotactile signals that created the haptic simulation are less disruptive as compared to the auditory instructions, which is a suitable substitute for continuous feedback.

Equally important, most of the navigational assistances described above are wearable devices. This is most probably because designing devices to be wearable improve the practicality of handling and operating. Also, the reason of the "wearable" choice is indeed, readable in the meaning of the word wearable: fully functional, self-powered, self-contained computer. It is worn on the body and provides access to information, and interaction with information, anywhere and at any time [18].

Wearable device refers to the electrical or mechanical systems, which are worn on the human body by means of incorporation into items of clothing, or as an additional apparatus, which is fixed, by straps or harnesses [19]. The advantage of making a device to be wearable is it blends between the technological applications with human body in a natural harmony. In next section, we present a conceptual design of a navigation device that employs the hybrid approaches between; (i) the advantage of haptic/tactile applications, and (ii) the device wearability. We posited based on the previous studies, that the use of haptic stimulus as a form of signal could be a good substitute to the current wayfinding modality for elderly with cognitive impairment.

3 Method

The apparatus for this pilot test is a prototype that integrates tactile displays, instead of the conventional graphic interface. Users are not required to read a map display and listen to speech instruction because the device uses haptic stimuli as the "input". Part from dynamic aspect, the device is designed to be wearable for our designated users since it may support the capabilities of the wearers while preserving personal privacy and functioning over a wide range of situations and contexts [20]. Other comfort issues to the wearers may occur if it is designed without considering their limitations [21].

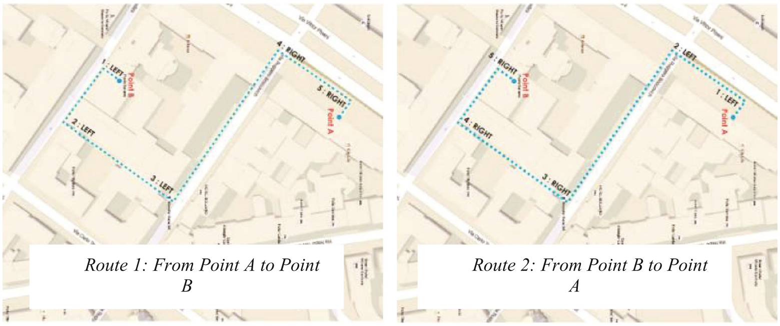
Similarly important, simplified interface is crucial to avoid distraction or confusion. For this reason, our device provides the simplest possible information of navigational instructions, which is: go to the left or to the right. The prototype system consists of; (1) the input that made of the sensor, (2) the process, and (3) the output which is the tactile display. The prototype is created as two main parts: the tactile display and the other built-in system's hardware (placed in a hard case), as shown in Fig. 1. This is to allow the tactile display to be adjusted for different (body part) positions.

Fig. 1. The two main parts of the wearable navigation device prototype

We previously conducted a preliminary assessment using a survey, mainly for the design concept of the device. Based on the results, two most preferred positions for the tactile display are: (i) waist and (ii) shoulder. Thus, this prototype is adjustable according to body size and the tactile display can be adjusted for these two positions. We adopt the wearable feature of the conventional backpack and body harness for this purpose. As shown in Fig. 1, the hard case that contains the hardware is connected to the adjustable and buckled straps. The tactile display is made of multiple mini vibration motors embedded onto the fabric to create the haptic-feedback. The built-in haptic stimuli from the tactile display are intended as the directional cues/signals in the course of navigation

The assessment of the pilot test is divided into two main sections: (1) navigation test using the device prototype, and (2) a questionnaire for the subjective assessment of the device prototype. Therefore, two substantial decisions were primarily made before starting the experiment: (i) the selections of the participants, and (ii) the methods to test the device prototype.

The experiment was conducted with the cooperation of Fondazione Manuli, a dementia therapy center in Milan, Italy. The experiment started with the orientation or training phase to get the subjects familiarized with the device system and experimental procedures. Since the navigation test could be difficult for the elderly with dementia, we needed to identify the appropriate subjects. First, experimenters put on the wearable device onto the subjects' body and observe their reaction or acceptance. Afterward, only if the subjects reacted well to this wearable device, they will be then asked if they can feel and indicate which side (left/right) of the haptic signals on both waist and shoulder positions. Only the subjects who succeeded this orientation phase were allowed to proceed to the next phase (navigation test). For the test, two routes with same difficulty (same number of turns and distance) level were created, as shown below (Fig. 2).



Route 1: From Point A to Point B

Route 2: From Point B to Point A

Fig. 2. The navigation routes with same difficultly level

The severities of cognitive impairment of the subjects are varied and based on their cognitive-based ratings of Mini Mental State Score (MMSE). The MMSE scores ranged from the minimum of 17 and maximum of 27, with average of 21. Those who passed the first phase are able to walk properly with no serious mobility issues. Subjects ranged in age from 74 to 81 years old, with the average age being 78.5. In total, ten subjects partaken in the first phase (three of them are male). From the total of ten, six of them succeeded the first phase (orientation) and recruited for second phase (navigation test). During the test, subjects were required to make the left/right turns at the junctions accordingly, whenever they sense the haptic stimuli from the device. Each subject travelled in both routes, but with the different positions of the tactile display. The test started with the first route (from point A to point B in Fig. 2), but the position of tactile display was randomly decided. If they started on shoulder in the first route, they continued with the waist positions for the second phase, and vice versa.

One important data to be recorded before starting the navigation test was the walking speed of each subject. The recorded walking speeds (m/s) are to be compared with the walking speed while navigating with the device. This justifies the effective walking (based on the walking speed or time taken) when and when not using the device during navigation. In the tests, haptic signals were initiated before subjects reached the junctions, and stopped after they were in the correct turns. We set the constant length of as 6 m for this haptic signal to be stimulated in every junction. For comparison, the subjects' walking speeds, which were recorded beforehand, were calculated as the travelled distance (of 6 m) divided with the time taken. During the navigational test of each subject, experimenters recorded the: (i) Decision making time in making the turns, (ii) Numbers of direction errors made, and (iii) time taken to finish the task. After each navigational test, subjective assessments were carried out.

4 Results

The recorded walking speeds of each subject were compared with the walking speed while navigating with the device. Subjects tended to make mistakes (especially in the first route) when making the turns. This is probably because they were not able to perfectly understand the function of the device. Thus, it is necessary to determine the effective walking of the navigation. The time taken to make every turns and the overall time to finish both routes were also recorded. Table 1 below presents these data of each subject's speed, control time, average time taken to make the turns and to finish both routes. The shown average time taken was based on the cumulative time taken for each turn of both routes. The score was somehow influenced by the number of mistakes (or direction errors) while navigating with the device. However, the justification on average time influences the overall time taken is not necessarily accurate. This is falsified when comparing these data in both routes. What we can primarily highlight here is, even if the subjects took less time to finish the routes as compared to the others, it does not mean they scored the highest effective walking while navigating with the device. This depends on their walking speeds and the hesitation before making the turns.

Table 1. The summary of recorded data for the navigation tests

Subjects	MMSE score	Walking speed (m/s)	Number of errors	Control time (s)	Average time taken to make the turns (s)	Overall time (s)
Route: 1						
6	20	0.79	3	7.56	18.85	776.43
8	17	0.68	3	8.86	23.55	956.43
4	21	0.78	3	7.74	17.62	733.81
9	20	0.51	1	11.08	16.34	682.27
3	27	1.08	–	5.53	6.24	337.82
10	–	0.73	2	8.15	16.56	602.05
Route: 2						
6	20	0.79	2	7.56	11.52	567.01
8	17	0.68	2	8.86	16.23	797.92
4	21	0.78	1	7.74	10.41	526.07
9	20	0.51	1	11.08	14.67	647.72
3	27	1.08	–	5.53	6.19	321.43
10	–	0.73	1	8.15	11.81	512.45

We compared the number of direction errors made by each subject for both routes. The comparison showed that the numbers of direction errors for all the subjects decreased when navigating in the second route. This is indeed an interesting indication, where it is possibly suggests that the participants have started to learn and understand how to navigate with the assistance of the device in the second route.

Subject 9 demonstrated the best navigational performance amongst others. It is mostly related to the fact that he has the highest score of MMSE. For the other participants, the MMSE score are varied from 17 to 21, which is way lower than subject 9's score. According to [22], comparing the MMSE score in terms of description and stage, (i) 26 to 30 could be normal, (ii) 25–20 is mild and in early stage, and (ii) 19–10 is moderate and middle stage. Hence, Subject 4, 6 and 9 have the similar range, which is in the mild condition and only Subject 8 is in the moderate conditions. Nevertheless, we cannot simply justify that subjects in early stage has better navigational performance with or without the device than those in middle stage. This is because Subject 6 who has the MMSE score of 20 did the same number of directional errors with subject 8 with the MMSE score of 17. But then again, the other participants (with mild condition) demonstrated average or moderate navigational performances. A subjective assessment based on user perception was carried out as well. Here after the Table 2 shows the results.

The subjective assessment proved that patients can appropriately sense the vibration and the most preferred position for the tactile display is the waist (4 out 6 subjects). 83.3% agreed that they were comfortable wearing the device as they rated 3 over 3. This is in contrast with subjects' perspective on the device's usefulness, where they mostly gave a lower score to Q3 and moderate to Q4. The average score for Q3 is 1.67 shows that they are not so keen to have and use the device. Meanwhile for Q4, 4 subjects

(66.7%) rated 2 over 3. The data from the last two questions may explain the preceded scores. Indeed, it shows that the user familiarization is a crucial.

Table 2. The Subjective Assessment Questions and the Scales given by subjects

Questions (Scale of 1 to 3)		Subjects and Scale					
		6	8	4	9	3	10
Q1	Do you properly sense the vibration?	3	3	2	2	3	3
Q2	Are you comfortable wearing the device	3	3	2	3	3	3
Q3	Would you like to have the device and use it?	2	2	1	2	1	2
Q4	Do you think the device is useful?	2	2	2	3	3	2
Q5	Do you need more time to learn to use it?	3	3	3	2	1	3
Q6	If you are given more time to use it, will you perform better?	2	3	3	3	3	3

5 Conclusions and Further Development

In this paper, we proposed a new wearable navigation device with tactile display and we developed its prototype systems. We used a working prototype to evaluate the possibilities for practical use by conducting the pilot test on the actual participants (i.e. elderly with dementia). The analysis of the test results proved the potentiality of haptic modality in supporting the target users' wayfinding, despite several noticeable weaknesses of the prototype that leads to the efficacy and practically issues. These positive outcomes from the pilot test lies mainly on the decreasing of (i) overall time taken and (ii) the numbers of errors, when comparing subjects' navigational performance in both routes accordingly. Nonetheless, a new intervention should be appropriately introduced to avoid the misconception and for the familiarization purpose [23]. The wearable form of assistive navigation device is totally new for our participants. Thus, the importance of proper training is proved when subjects demonstrated better navigational performance in the second route. It is supported by the analysis of subjective assessment where the subjects needed ample time to learn to use the device. The responds from the subjects also suggest that the physical appearance of the device needs some improvement since it caused the wearability issues. In our future works, we will develop an improved version of the prototype mainly from wearable point of view. Once the new prototype is developed, we will conduct a following test to the same population but with bigger samples and use the similar experimental procedures in this study. This further development is essential in shaping the wearable form of haptic-feedback technology, making it desirable, acceptable, and pleasurable for the final users.

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