Conceptual Design of Haptic-Feedback Navigation Device for Individuals with Alzheimer’s Disease

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Abstract. Wayfinding ability in older adults with Alzheimer’s disease (AD) is progressively impaired due to ageing and deterioration of cognitive domains. Usually, the sense of direction is deteriorated as visuospatial and spatial cognition are associated with the sensory acuity. Therefore, navigation systems that support only visual interactions may not be appropriate in case of AD. This paper presents a concept of wearable navigation device that integrates the haptic-feedback technology to facilitate the wayfinding of individuals with AD. The system provides the simplest instructions; left/right using haptic signals, as to avoid users’ distraction during navigation. The advantages of haptic/tactile modality for wayfinding purpose based on several significant studies are presented. As preliminary assessment, a survey is conducted to understand the potential of this design concept in terms of (1) acceptability, (2) practicality, (3) wearability, and (4) environmental settings. Results indicate that the concept is highly acceptable and commercially implementable. A working prototype will be developed based on the results of the preliminary assessment. Introducing a new method of navigation should be followed by continuous practices for familiarization purpose. Improved navigability allows the good performance of activities of daily living (ADLs) hence maintain the good quality of life in older adults with AD.

Keywords. AD and dementia, haptic/tactile stimuli, spatial disorientation, navigational assistance, wearable device

1. Introduction

Dementia is an umbrella term describing a variety of diseases and conditions that develop when nerve cells in the brain (neurons) die or no longer function normally [1]. Of all the dementia types, Alzheimer’s disease (AD) is the most common [2]. The aging population increases each year and by 2050, the number of people above 65 years old is expected to be close to 2 billion [3]. Accordingly, with the increasing aging population, the number of AD and dementia cases is simultaneously increased [4].

AD often impairs individuals’ spatial cognition and representation that related to wayfinding abilities. In parallel, although age is not the main factor of the disease, yet, most of the AD cases reside among older adults [5]. Further, older adults with AD also manifest sensory declines, like the healthy older adults. This problem worsens their sense of directions, as oriented search is linked with sensory - mainly the visual [6]. Considering these limitations, conventional map and route-based navigations that rely predominantly on visual and sometimes with auditory supports may not be the best choice for older adults with AD.

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This paper is aimed to visualize a conceptual design of a navigation device with alternative and uncommon signals i.e. haptic/tactile to assist the wayfinding of older adults with AD. A review on the existing technological applications is presented to highlight the potential of haptic/tactile-feedback technology for navigational purposes. A preliminary validation is conducted in form of survey to understand the feasibility of the conceptual design. The analysis of the collected data is discussed further here and finally, a brief explanation on research future actions is presented.

2. Wayfinding Deficits in Older Adults with AD

One of the most important factors that help to maintain the normal social functioning in older adults with cognitive impairments is mobility skills [7]. It keeps the performance of activity of daily living, which at the same time reduced the dependency. Older adults without AD remain stable in terms of their spatial navigation skills: the process of determining and maintaining trajectory from one point to another [8]. However, this crucial skill is deteriorated by AD due to the cognitive function deficits. This problem is usually referred to as spatial disorientations, which is defined as the individual’s inability to orient in the environment as a result of focal brain damages [9][10].

The associative factor between aging and cognitive decline with wayfinding ability is well recognized. Typically, wayfinding deficits increased exponentially with the age and the severity of the AD [10] [11]. This inferred association is usually assessed by investigating the spatial/route navigation tasks. For instance, due to this wayfinding deficit, older adults tend to navigate only in the familiar routes or environments [12] [13], to avoid getting lost. Additionally, in navigating a route, older adults always take longer to reach the target destinations and made more mistakes as compared to younger adults [14][15].

However, since the cognitive domain is deteriorated in persons with AD, it worsens their spatial cognition in general. In fact, spatial disorientation is diagnosed early in the development of AD, which is during the Mild Cognitive Impairment (MCI) stage [16]. Although not every MCI case ends up with full-blown dementia, the possibility to develop it is suspected to be relatively high [17]. Consequently, as the disease progresses, the spatial navigational performances in individuals with AD gradually decrease [11].

In addition, the sense of direction is connected to cognitive mapping [18], comparable to the relation between sensory acuity to the visuospatial representations and oriented search [19][6]. Since the older adults experience sensory decline due to ageing, it affects their sense of directions indirectly. In older adults with AD, alongside with the decline of cognitive domain, they also manifest the sensory changes, as they grow old. This problem may gradually worsen their spatial cognition that is needed for precise wayfinding.

The decline in sensory acuity as a consequence of AD, are qualitatively similar to the sensory changes caused by senescence or biological aging. In vision for instance, despite the loss of color sensitivity and reduced depth perception and contrast sensitivity [20] [21], adults with dementia are significantly slower in motion search tasks [22], unable to sense movement [23], and also reduced control of spatial focus [24] due to deficits in their working memory.

Similarly, as mostly attributed to age-related loss of sensitivity, older adults with AD usually show mild-to-moderate hearing impairment. These deficits in central
auditory processing capacity and cognitive decline weaken the communication processes [25], as well as the visuospatial and auditory information [26].

Current navigation devices typically support predominantly on visual interactions, while the common additional feature is the integration of auditory support, i.e. speech instructions or sound cues. Nonetheless, in the course of navigation of both indoor and outdoor environments, to concentrate simultaneously on the surrounding and visual display of the navigation device may be very distracting, even for healthy people regardless of age. Additionally, environmental auditory (or soundscape) is also a crucial element in determining the successful navigation. Hence, obligating to both speech instruction and soundscape could add to wayfinding confusion.

The possible alternative sensory that should be further explored for wayfinding purpose is the haptic/tactile stimuli. Similar to vision and hearing, tactile acuity is progressively impaired due to aging [27] that contributes to the age-related impairment of sensorimotor and cognitive abilities. However, as proven by the assessment of speeded object identification task, individuals with AD maintained intact haptic priming, despite highly impaired recognition performances [28]. Furthermore, even though individuals with AD have the difficulties to learn incipient things, but the implicit recollection for haptically-explored objects is preserved in those with mild AD [28]. Thus, practicing a task (such as navigation task) as a daily habit could benefit them, since implicit memories are not consciously recalled.

Accordingly, the common method of navigations that rely only on the visual and also auditory devices may not always be the best choice for individuals with AD. This is because the navigational assistance should support the remaining abilities of older adults and avoid the confusion during wayfinding. Therefore, the use of haptic/tactile stimuli as a form of signals can substitute current wayfinding method for individuals with AD.

3. Haptic or Tactile-Feedback for Navigation

With the advance of technological applications, and with its rapid ubiquity, more sophisticated navigation devices may appear. The commercial map and route-based navigations that use Global Positioning System (GPS) for instance, is a very well established technique to meet the current wayfinding issues. However, as mentioned earlier, these GPS-based navigation devices often rely on visual modality (display maps or text instructions), while audio modality (sound cues or speech instructions) is the most frequently used sensory channel or signal options. For the older adults with AD, their most obvious sensory declines are both visions and hearings. Hence, these modalities may hinder the effective wayfinding.

Audio-feedback is a reliable form of wayfinding aids substituting the visuals, especially for those with visual limitations. Then again, audio-feedback signal might not be suitable in all situations, especially as continuous feedback (such as obstacle detections), since it distracts users from the environmental auditory [29]. Haptic/tactile stimuli in contrast, have the distinctive advantage that support the two-way communications between human and interactive systems that enable bidirectional interaction between users and environments [30].

Presently, there is a growing body of research on the use of haptic/tactile modalities in the domain of mobile human computer interaction. This unique modality has been explored in a variety of applications such as the haptic-feedback system to
sense of virtual objects [31], in surgical tasks [32], designing the human-computer interfaces [33], and for navigational instructions [29], [34], [35] [36]. Nonetheless, for wayfinding or navigational purposes, the existing body of works often focuses on individuals with severe visual impairment or blind people, and not for the persons with cognitive impairment.

For instance, Zöllner et al. [29] conceptualized a mobile navigational assistance with Microsoft Kinect and optical marker tracking to help the indoor navigation of individuals with visual impairment. They created a belt embedded with vibrotactile outputs that were used to detect obstacles during wayfinding tasks. Similar to another study by Ertan et al. [34], they described a wearable navigation system using haptic directional display integrated with a vest. The system gives haptic signals to the users’ back in the course of navigation. In a different study, Mann et al. [35] presented a blind navigation system using a Kinect 3D sensor range camera and a vibrotactile helmet. The vibrating actuators embedded inside the helmet convert depth information into haptic feedback, to allow the users in identifying depths for collision avoidances.

Close to our goal, Grierson et al. [36] investigated the applicability of tactile signals to assist the wayfinding of persons with dementia. In this study, they developed a wearable belt with vibrating motors. Participants were asked to navigate a series of routes within a hospital with the assistance of vibrotactile signals. This is the very idea where our design concept initiated. We found that it is important to highlight the potentials of haptic/tactile stimuli to assist or improve the wayfinding of individuals with cognitive impairment to serve their different needs and issues.

Another essential point is most of the navigational assistances described above are the wearable technologies/devices. This is most probably because designing devices to be wearable improve the practicality of handling and operating [37] [38]. Furthermore, haptic/tactile feedback as forms of signals 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 [39]. 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 [29].

Technological interventions that utilize haptic/tactile modality to assist wayfinding have shown positive results, though most of them were meant for visually impaired and blind people. Also, most of the existing wayfinding intervention strategies, which include the above-mentioned studies [29], [34], [36] focus on indoor navigations. This means, further research on navigational assistance for outdoor wayfinding purposes are highly recommended. The conceptual design that we propose employs the hybrid approach between; (1) the unique advantage of haptic/tactile, (2) wearability, and (3) outdoor navigation.

4. Conceptual Design

This non-visual and less-intrusive navigation device uses haptic stimuli as the signals, instead of reading a map display or listening to speech instruction in the course of navigation. For the ease and practicality of handling by the target users i.e. older adults with AD, this device is meant to be wearable. Since the concept employs a new technique of wayfinding even for many of us, it requires the continuous use for familiarization which at the end will hopefully results in promising outcomes of intervention.
The device provides the simplest possible information about the navigational instruction; left or right direction. The uncomplicated feature is crucial as to avoid distraction or confusion by the users when using this device during wayfinding tasks [29]. This is important because even a minor interference may cause misperception to the individuals with AD. For that, the navigation device is conceptually designed to be worn as a pair on both sides of appropriately chosen body parts.

The proposed positions to place the device are based on the recommendation by Gemperle et al. [40]. In the study, they presented the general areas (of body parts) that are most unobtrusive and suitable for wearable objects. Equally important, the built-in haptic signal will work most efficiently when it has the direct contact with users’ skins [41] hence, we proposed the integration with the clothes or underwear. Accordingly, the positions that we found appropriate for the integration are; shoulder, waist, thigh and feet. Figure 1(B) shows these possible positions to place the device.
As shown in Figure 1 that visualizes this proposed navigational concept, to go from point A (home) to point B (local supermarket), there are three routes the user can follow; #1 (Option 1), #2 (Option 2), and #3 (Option 3). In initiating the journey from point A, one may turn left or right and the haptic signals embedded in the navigational assistance will start immediately. If he/she turns right, #1 will be the choice of route, whereas left is for #2 or #3. In order to go back from B to A, the signal will initiate as soon as the user got out of the place (B), and direct him/her into the correct route (#1, #2 or #3). During wayfinding, the users need to travel within the estimated range. However (in some inevitable cases), if they happen to accidentally go beyond the range, a stronger signal will start immediately to guide them into the correct path.

The design concept is in a preliminary stage, thus the working prototype is yet to be developed. However, the system proposed should support its main functionality or features, as shown in Figure 3. The device consists of; (1) two sensors; directional sensor and GPS receiver, (2), microcontroller, (3) and the wearable haptic-feedback device. Technically, the sensors used to detect users’ real-time location and orientation, and the location information is sent to the microcontroller. The microcontroller is used to control vibrators and input data form the sensors, and communicating with the host PC. The output voltages data is converted using digital-to-analog (D/A) converter and allows the vibrators frequencies to be controlled.

The haptic stimuli are created with multiple vibrators or tactors that are embedded with the fabric; Figure 1(A) at regular intervals of mean threshold (20mm to 50mm), according to body positions [42]. Since there is a dearth on outdoor wayfinding strategies, we hope that our proposed conceptual design of wearable navigational assistance may fill the gap. This navigational device is expected to improve the navigability of older adults with AD, mainly in an outdoor environment. Then again, as implicit memory for haptically-explored objects is preserved in those with mild AD [28][11], only continuous practice gives an encouraging result. Therefore, before the development of a functioning prototype, it is necessary to understand the potential of this conceptual design from the perspectives of the (AD and dementia) experts in its initial stage. The next sections discussed on the aims, method, and results of the preliminary assessment.
5. Preliminary Assessment

A survey was conducted as a preliminary assessment to investigate the feasibility of the design concept in terms of; (1) acceptability of intervention, (2) usability on users, (3) wearability of the device, and (4) setting suitability of interventions. Although this intervention concerns individuals with AD, attaining feedbacks from them could be insubstantial due to their disability of decision making. Thus, the target respondents of the survey were; (1) caregivers and (2) clinical/medical experts of AD, since they have the most knowledge base about patients’ behavioral and caregiving needs [43].

The total number of respondents was forty-two, where most of them were the clinical/medical experts; therapists, gerontologists and neurophysiologists. In terms of wearability, the most preferred positions to place the device (or to trigger the haptic/tactile stimuli) are waist and shoulder (both 26.2%), while thighs and feet are the least favored. Most of respondents agreed to integrate the device with either users’ clothes or underwear. Accordingly, they mostly preferred the singlet (35.7%) and secondly the briefs (26.2%) to be integrated or attached with the device. This validates the preferred body-part positions as justified earlier.

For the device’s usability, most of the respondents prefer this navigational assistance to be a standalone, without integration of another device, such as mobile applications. However, when they were asked if additional features are needed, 42.9% were unsure, and 33.3% prefer the additional features. The following question rectified this dispute. Accordingly, the essential additional features to the device are; speech instruction and both speech and visual instructions.

As agreed by most of the respondents, this intervention strategy is best be implemented mainly in an outdoor environment. They also agreed that the device is useful to assist wayfinding of persons with AD within the neighborhoods they live in. Accordingly, they recommended that the users should not be allowed to travel alone too far with this device; 1 to 4km.

The qualitative analysis also raised some concerns as to improve the design concept. These include the use of suitable materials for the wearable device that is appropriate for long hours of use and for different environmental and contextual climates. Also, they suggested that this intervention should be targeting to individuals with early dementia, since those in the severe stage might not be able to perceive the haptic stimuli as forms of wayfinding signals.

In general, results demonstrate that positive feedbacks on the overall concept and suggested that this intervention is acceptable certainly due to its uncomplicated features. This device is believed to be practical to use by the target users and the concept has a great potential to be implemented in real-world applications.

6. Conclusion

The analysis of preliminary assessment proves that it is important to investigate if the device is practical and effective to be used by target users only with haptic/tactile modalities. Although the main research aim is to highlight this modality as alternative signals for wayfinding, this feasibility is still need to be proven quantitatively. Therefore, another assessment; Usability testing using the functioning prototype will be carried out soon to evaluate the feasibility of the conceptual design on the real target
users. For that, some modifications on the design concept are to be made based on the results of this preliminary assessment before the prototype can be developed.

In sum, introducing a new navigational system could be a challenge even for many of us since we might be used with reading a map and/or listen to speech instruction. Thus, a continuous practice in form of training to get persons with AD familiarized with the new system is appropriate. Since spatial navigation is related to mobility and autonomy, improved navigability allows persons with AD to perform and maintain the activities of daily living. This will result in keeping their good Quality of Life (QoL).

References


