Application of a Tactile Way-Finding Device to Facilitate Navigation in Persons With Dementia

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ABSTRACT

Persons with dementias, such as Alzheimer’s disease, have well-documented deficiencies in way-finding, which often renders these individuals house bound and/or unable to perform daily activities without significant frustrations. A wearable belt has recently been developed that may have the capability to facilitate navigation for this population. Through a series of four small, vibrating motors that are adjusted to the cardinal positions of front, back, right, and left, the belt provides wearers with a tactile signal indicating the direction to their destination. In this experiment, the applicability of the way-finding signals to persons with dementia was assessed. To do so, participants walked a series of routes through the corridors of a hospital while wearing the belt. The results suggest the way-finding belt has potential as a navigation aid for individuals with dementia. The participants displayed a few deficiencies in attending to the directional signals that led to way-finding errors in which the signal was ignored and the intended turn not made. The article concludes with recommendations that the system of signal delivery be modified in a way that captures and directs the wearer’s focus more prominently to the vibrotactile stimulus.

KEYWORDS

navigation, persons with dementia, vibrotactile information, way-finding

INTRODUCTION

Route navigation in spaces that are too large to view from a single perspective is achieved through comparison of perceptual information about our orientation and motion to memorial representations of relevant spatial landmarks (Allen, Seigel, & Rosinski, 1978) and the relationships between landmarks (Bestgen & Dupont, 2003; Ishikawa & Montello, 2006; Mallot & Gillner, 2000; Noordzij, Zuidhoek, & Postma, 2006; Rinck, Williams, Bower, & Becker, 1996; Seigel & White, 1975). Those who are older (Hess, 2005; Kirasic, 2000; Rogers, Meyer, Walker, & Fisk, 1998), visually impaired (Golledge, Klatsky, & Loomis, 1996), or with dementia (Pai, 2006; Rosenbaum, Gao, Richards, Black, & Moscovitch, 2005; Uc, Rizzo, Anderson, Shi, & Dawson, 2005) all, to varying
degrees and for different reasons, experience challenges in constructing and accessing accurate memorial representations of the environments in which they travel. Consequently, for these individuals, navigation can often be disorienting and frustrating.

A new device (Zelek & Holbein, 2008) has been developed that has potential as a navigational aid for persons with way-finding difficulties. The device is a wearable belt that is integrated with global positioning, three-axis compass, inertial sensor, power management, battery and algorithmic executive processor technologies, and operates to provide the wearer with direction-relevant cues through four small motors that are aligned to the front, back, left, and right positions of the wearer’s torso (Figure 1). The motors vibrate gently to provide tactile signals. The device has Bluetooth bidirectional networking capacity that allows users to upload desired destinations and area maps. With this information, the belt employs its integrated positioning system to locate wearers, identify their movement direction and speed, and determine the appropriate tactile cues to guide them to their destination. As wearers travel, the system monitors their progress and updates the directional cues in real time until they have arrived at their desired destination. Although other global positioning systems and navigational aids exist and are in widespread use already, this system is unique insofar as it does not require the use of vision or hands. That is, while providing spatially relevant directional information, the belt’s tactile interface permits the wearer to devote his or her visual faculties to the environment and perform manual tasks normally. This report describes a test of the new technology’s applicability to individuals with dementia of Alzheimer’s type.

A major assumption of the proposed system is that the wearer will orient him- or herself and travel in a manner congruent with the location of the sensed vibration. That is, when wearers feel a vibration on the left side, they know to turn and travel to the left. In previous laboratory research, this assumption was tested on groups of younger and older healthy persons (Grierson, Zelek, & Carnahan, 2009) in experiments of systematically increasing difficulty in which a priori way knowledge and belt assistance were manipulated as variables. The results of these experiments supported the conclusions that healthy humans, regardless of age, understand the system signals as intended and that the belt enhances way-finding performance.

Specifically, participants were always successful in reaching the route destination when wearing the belt; a lack of a priori route information notwithstanding. Furthermore, that participants only made directional errors in memory-guided conditions suggested that the belt’s advantage is exacerbated when navigating more complex routes.

The current project extends the efficacy testing of the device to include community-dwelling persons with dementia who attend clinical treatment at Sunnybrook Health Sciences Centre (Toronto, Ontario, Canada) and aims to contribute data that will guide specific recommendations regarding the device’s potential as a way-finding aid for this population. Although we are optimistic that these individuals will respond to the signals provided by the belt in a manner that is congruent with the idea that they can extract the intended meaning from the signal, some evidence suggests that individuals with dementia may have difficulty following the vibrotactile cues.

Navigational difficulty in persons with dementia has most commonly been attributed to loss of orientation and impaired memory function (e.g., Henderson, Mack, & Williams, 1989; Perry & Hodges, 1999). However, dementia has also been reported to impact attention and perception mechanisms (Bradshaw, Saling, Anderson, Hopwood, & Brodtmann, 2006; Filoteo et al., 1992; Parasuraman, Greenwood, Haxby, & Grady, 1992) in a way that may contribute to way-finding dysfunction, even if the belt is worn (Rizzolo, Anderson, Dawson, Myers, & Ball, 2000; Kavcic & Duffy, 2003; Golob, Miranda, Johnson, & Starr, 2001).

In a specific study of the impacts of cognitive impairment on subset mechanisms of attentional control, Baddeley, Baddeley, Bucks, and Wilcocks (2001) showed that persons with dementia have particular difficulty in performing control of attention tasks that require the capacity to resist distraction or to divide attention between two simultaneous tasks (see also Perry & Hodges, 1999). Because the proposed system requires wearers to devote attentional focus to tactile signals while also attending to the rich features of the visual environment, deficits such as these may have serious implications with regard to the efficiency with which individuals with dementia use the device. Therefore, although our previous tests of the belt (Grierson et al., 2009) provide good evidence that the device can provide a robust substitute for unavailable spatial memories, the meaning of the vibrotactile cues...
FIGURE 1  A rendering of the tactile way-finding belt (color figure available online).

may not be communicated to a wearer with dementia adequately. Specifically, the cognitive impairment may prevent the wearer from dividing focus in a way that allows him or her to attend to the signal. Thus, the belt’s overall applicability would be diminished. This study is a simple ecological test of the quality of the transfer and processing of the directional information that the belt provides individuals with dementia.

METHODS

Participants

Eleven community-dwelling persons with dementia of Alzheimer’s type and one community-dwelling person with mild cognitive impairment with a high probability of developing dementia of Alzheimer’s type, all patients at Sunnybrook Health Sciences Centre (Toronto, Ontario, Canada), participated in the study. Diagnosis of probable Alzheimer’s disease was based on the of NINCDS-ADRDA criteria (McKhann et al., 1984). The participants varied in terms of the progression of their dementia. Data on participants’ age, sex, and most recent Mini-Mental Status Examination scores (Folstein, Folstein, & McHugh, 1975), and, when available, their most recent scores on the Judgment of Line Orientation Test (Benton, Varney, & Hamsher, 1978) and Rey Visuospatial Immediate Copy (Rey, 1941) (two tests of visuospatial capability), appear in Table 1. All participants provided informed consent in accordance with the research ethics boards for Sunnybrook Health Sciences Centre, the Toronto Rehabilitation Institute, and the guidelines set out by the Declaration of Helsinki (1964). Participants received a $40 honorarium to cover the costs associated with parking and refreshments at the hospital.

Apparatus

The described four-motor way-finding belt was modified so that custom software and a wireless USB hub (Belkin Wireless USB 2.0 4-Port Hub, F5U302-HUB, Compton, CA) allowed the experimenter to control the vibration of the motors locally through the arrow keypad on a laptop. Such local control permitted the experimenter to control the directional signal rapidly and to stop and restart trials if necessary. Consistent with the previously reported parameters for optimal human vibrotactile sensitivity (Cholewiak, Brill, & Schwab, 2004; Jones & Sarter, 2008), the motors were set to provide a 255 Hz vibration for 300 ms every 700 ms. The apparatus was powered by a Xantrex Powerpack and Inverter modules (Xantrex Pocket Powerpack 100, 852-0081, Burnaby, British Columbia).

Procedure

Prior to initiating any walking trials, all participants engaged in an orientation session during which they were fitted and familiarized with the way-finding device. The experimenters helped each participant don the belt around the waist and adjust the motors so that they were aligned with the wearer’s cardinal left, right,
### TABLE 1  
Participants' characteristics and numbers and types of errors

<table>
<thead>
<tr>
<th>Participant</th>
<th>Sex</th>
<th>Age</th>
<th>MMSE (/30)</th>
<th>JLOT (/30)</th>
<th>REY (/36)</th>
<th>No. of errors</th>
<th>Type of error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>85</td>
<td>26</td>
<td>24</td>
<td>27</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
| 2           | F   | 81  | 22         | 12         | 24        | 3             | 1. Inattention  
2. Inattention  
3. Inattention |
| 3           | M   | 62  | 23         | 20         | 32        | 0             |               |
| 4           | F   | 74  | 17         | 16         | —         | 2             | 1. Inattention  
2. Inattention |
| 5           | M   | 61  | 18         | —          | —         | 0             |               |
| 6           | F   | 87  | 23         | —          | —         | 0             |               |
| 7           | M   | 69  | 25         | 28         | —         | 1             | 1. Inattention  |
| 8<sup>b</sup> | F   | 62  | 8          | —          | —         | 3             | 1. Inattention  
2. Inattention  
3. Inattention |
| 9           | M   | 78  | 17         | —          | —         | 0             |               |
| 10<sup>b</sup> | F  | 81  | 16         | 0          | 1         | —             |               |
| 11          | M   | 75  | 24         | 26         | 33        | 0             |               |
| 12          | F   | 68  | 28         | 24         | 27        | 0             |               |

<sup>a</sup>Information not available.  
<sup>b</sup>Participation was terminated.

Front, and rear sides. At this time, participants were delivered a random series of eight vibrotactile signals from the device and were asked to indicate whether they felt each signal, and where. They did this either verbally or by touching their hand to the location of the vibration. All participants included in our analyses performed this orientation test 100% successfully before proceeding to the walking portion of the study.

Following orientation, each participant walked four novel routes through the corridors of Sunnybrook Health Sciences Centre while receiving and following directional information from the way-finding belt. The order of the four routes was randomized across participants. For each route, the participants were instructed to walk at their normal pace and to be as directionally accurate as possible. The four routes were approximately 150 m long and contained six waypoints where directional decisions needed to be made. Each of the waypoints was located at a corridor intersection. The perimeter of each intersection was marked 3 m in all directions by small tabs taped to the corridor walls. The participants were not aware of these tabs. The experimenter initiated the vibrotactile signal as the participant crossed one of these tabs into the intersection area. Decision-making time was recorded and was deemed complete when participants initiated their choice of direction through the intersection. In some cases, the route required navigators to pass through intersections they had navigated earlier within the same route. This intersection reapproach always occurred from a different orientation and perspective than the first iteration and heightened route complexity (Mallot & Gilner, 2000).

Prior to commencing any trials, the experimenter walked the participants through the corridors relevant to the experimental environment. During this tour, the participants were informed that for each experimental route they would receive vibrotactile directional information for each intersection. At this time, participants were also informed that they would not receive directional information for unidirectional bends in the corridors and that they were to navigate these turns by continuing to travel in the direction the corridor afforded. The tour’s route did not replicate any of the experimental routes. It is important to note that the hallways used for this study were not closed to hospital patrons and staff and were subject to routine traffic during experimentation.

For each trial, the experimenter walked just behind the participants and recorded the number of directional errors made. On the occasion that a participant made a directional error, the experimenter stopped the participant by saying, “You have made an error.” Without deactivating the vibrotactile signal, the experimenter then asked the participant if he or she felt the signal, and where. The participant then returned to the
intersection’s perimeter and tried again. The participant continued through the route in this manner until it was completed successfully. Furthermore, for each error generated the experimenter made note of whether the error was an incorrect response (e.g., the participant turned right when cued to turn left) or whether the participant was inattentive to the signal (e.g., the participant did not make a turn and walked straight through an intersection he or she was signaled to turn at).

Using Pearson’s methodology, the number of errors for each participant was correlated independently with that participant’s MMSE score, JLOT score, and Rey Copy score. Correlations were determined as significant at an alpha level set to $p < .05$. The numbers and types of errors made by each participant appear in Table 1.

After taking part in the way-finding walking trials, participants removed the device and completed a simple questionnaire that asked them:

1. How easy was it to use the navigation belt?
2. How comfortable was the belt?
3. How confident in your ability to navigate do you feel when you walk without the belt?
4. How confident in your ability to navigate do you feel when wearing the belt?
5. How useful do you think the belt was?

**RESULTS AND DISCUSSION**

As noted, data on participants’ characteristics and their numbers and types of errors are presented in Table 1.

**Participants for Whom the Experiment Was Terminated**

Of the 12 individuals who participated in the study, 10 were able to complete all four hallway routes. On two occasions, experimentation was terminated because the participant showed consistent inability in understanding and performing the experimental procedures. It is noteworthy that these two participants were the lowest in the sample with regard to MMSE score (Participant 8: MMSE score of 8; Participant 10: MMSE score of 16). Specifically, Participant 8 exhibited difficulty with the instructions and problems in identifying the signals and relaying the directions. During orientation, this individual confirmed she was appropriately feeling the signals by touching her hand to the correct location. During the walking trials, however, she did not respond to the tactile cues and was easily distracted by the hallway signage and pedestrian activity. The walking portion of the study was terminated immediately. Participant 10 was able to navigate through 14 of the experiment’s 24 waypoints. Initially, this participant followed the belt directions successfully, without error. However, as the protocol progressed, she appeared to tire and eventually ceased to provide any directional response to the signals at all.

If we consider the performances of the individuals for whom experimentation was terminated early as errorful and include their data in the statistical analysis (i.e., Participant 8 with 24 errors and Participant 10 with 10 errors), extremely strong inverse correlations are exhibited that suggest that the belt’s applicability is directly related to the wearer’s level of cognitive and cognitive-spatial impairment. Specifically, this analysis revealed a significant correlation between number of errors and MMSE score ($r = -.83$, $n = 12$, $p = .001$), JLOT score ($r = -.92$, $n = 7$, $p = .004$), and Rey Copy score ($r = -.99$, $n = 5$, $p = .003$). However, although the performances of these two individuals were obviously inaccurate, including their terminated data in the analysis is not particularly helpful with respect to dissociating the applicability of the device for the individuals with dementia who were able to complete the protocol. That is, it is possible that the inaccuracy displayed in the terminated trials is not due to the participants’ inability to process the vibrotactile signals efficiently; rather, their cognitive deficit precludes them from understanding the procedural instructions and/or the experimental context. In either case, these two individuals’ inability to participate does suggest that orientation with respect to vibrotactile stimulation requires a certain level of cognitive capability, and raises questions about the device’s usability for individuals in the low MMSE range if they begin wearing and using it when their cognitive ability is less deteriorated.

**Correlation Statistics**

Pearson product-moment correlations were computed for those participants who completed the course to assess the relationships between number of errors and MMSE score ($r = -.56$, $n = 10$, $p = .095$), number of errors and JLOT score ($r = -.77$, $n = 6$, $p = .074$), and number of errors and Rey Copy score ($r = -.79$, $n = 5$, $p = .003$). These results suggest a strong inverse relationship between the number of errors and the participants’ cognitive abilities. The results also indicate that the MMSE score is a better predictor of the participants’ performance than the JLOT score, which is also consistent with previous findings. The Rey Copy score, on the other hand, showed a weaker but still significant correlation, suggesting that this measure may be less sensitive to changes in cognitive ability than the other two measures.

**Table 1.**

<table>
<thead>
<tr>
<th>Participant</th>
<th>MMSE Score</th>
<th>JLOT Score</th>
<th>Rey Copy Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>8</td>
<td>8</td>
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<td>3</td>
<td>16</td>
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<td>8</td>
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<td>1</td>
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<td>9</td>
<td>16</td>
<td>0</td>
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<tr>
<td>10</td>
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<tr>
<td>11</td>
<td>16</td>
<td>0</td>
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<tr>
<td>12</td>
<td>16</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

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There were no statistically significant correlations between any two variables assessed.

Perusal of Table 1 shows that the lack of any significant correlations can be accounted for by the low number of errors across the sample, with six participants making none. This is promising evidence in support of the belt. Unfortunately however, unlike the healthy older and younger participants in our first tests of the belt (Grierson et al., 2009), the participants in this study did not perform error free. Accordingly, the nature of the errors performed was examined.

**Types of Errors Observed**

Each of the way-finding errors observed shared important characteristics. First, the errors were never manifested in the form of the participant responding to a cue in the wrong direction. Rather, in each instance, the only errors were when participants proceeded through an intersection in the same direction as they entered, despite the belt signaling them to turn. Secondly, when stopped just after making the error and asked to indicate if and where they felt the vibrotactile signal, participants always did so correctly. Given that all participants displayed accurate understanding and sensation of the device in orientation, and for the greater portion of the way-finding walking trials, we deemed each of these mistakes as errors of inattention. As such, it seems that persons with dementia may make way-finding errors while wearing the belt as it is presently constructed because of distractions to their perceptual focus. In fact, Participant 5 indicated at the end of the experiment that he “had to focus attention completely on the belt and this made it difficult to also pay attention to [the visual stimuli] in the corridors.” Overall, it appears that visual stimuli, like those present in the hospital corridors for example, may work to suppress and/or interfere with attention devoted toward the vibrotactile stimulus (Baddeley et al., 2001; Drzezga et al., 2005; Mohr, Cox, Williams, Chase, & Fedio, 1990; Posner & Peterson, 1990).

**Participants’ Subjective Experiences**

Participants answered each question posed by the exit questionnaire on a 5-point Likert scale. Answers for Question 1 ranged from not very easy (1) to very easy (5), answers for Question 2 ranged from not very comfortable (1) to very comfortable (5), answers for Questions 3 and 4 ranged from not very confident (1) to very confident (5), and answers for Question 5 ranged from not very useful (1) to very useful (5). Participant 8 did not complete the questionnaire; however, Participant 10’s responses are included in the mean values presented here.

Notably, the participants’ mean ratings of the belt’s ease of use (4.9 ± 0.3) and comfort (4.5 ± 1.0) suggest that the device does not pose any perceived difficulty or discomfort to use. Moreover, the group deemed the device to be extremely useful as a navigational aid (4.9 ± 0.9). Interestingly, although the participants’ subjective ratings of the belt’s perceived usefulness are further highlighted by their confidence ratings when wearing the belt (4.7 ± 0.6), that they report confidence in unassisted navigation (4.5 ± 0.7) suggests that there may be some hesitation in acknowledging a need for assistive navigation technology.

**RECOMMENDATIONS**

In conclusion, the results of this study are promising with regard to the applicability of the way-finding belt for many community-dwelling persons with dementia. Overall, the data suggest that individuals with mild dementia are generally capable of following the vibrotactile signals appropriately, feel confident in doing so, and are comfortable in the device. However, we propose further development of the belt to include a system of attention capture. For example, the belt may be modified so that the vibrotactile signals increase in intensity and frequency as the participant approaches a waypoint. Such variable signal delivery may be a means to protect the vibrotactile stimulus from achieving some unnoticeable or ambient status for the wearer. The power of attention capture systems should be subjected to more population-specific efficacy testing.

Also, the present study suggests that the device is not functionally relevant to those community-dwelling persons with dementia that has progressed into more moderate stages. The individuals with more progressed dementia described in this report had difficulty participating in the experiment in a way that allowed for meaningful evaluation of their ability to use the vibrotactile information. This may have been a function of a lack of understanding the experimental context, an impact of the dementia on the sensory-perceptual and/or perceptual-motor processing of the vibrotactile signals, or a lack of earlier learning on how to use the...
device. That is, it is possible that individuals who begin using the device early in dementia onset may be able to use it longer into dementia progression. We recommend that longitudinal supervision be conducted with the first in-home users of the device with the aim of determining how device applicability changes as dementia progresses.

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