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Route-following assistance for travelers with cognitive impairments: A comparison of four prompt modes

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Abstract

Navigational skills, which are fundamental to community travel and hence, personal independence, are often disrupted in people with cognitive impairments. Assistive technology, in the form of navigation devices, are being developed that can support community navigation by delivering directional information. Selecting an effective mode to provide route-prompts is a critical design issue. This study evaluated the differential effects on pedestrian route following using different modes of prompting delivered via an electronic device for travelers with severe cognitive impairments.

The research design used was a within subject comparison to evaluate potential differences in route-following performance when travelers received directions using four different prompt modes: (1) aerial map image, (2) point of view map image, (3) audio direction/no image and (4) text-based instructions/no image. Twenty travelers with severe cognitive impairments due to acquired brain injury walked four equivalent routes using four different prompting modes delivered via a wrist-worn navigation device. Navigation scores were computed that captured accuracy and confidence during navigation. Results of the repeated measures analysis of variance suggested that participants performed best when given prompts via speech-based audio directions. The majority of the participants also preferred this prompting mode. Findings are interpreted in the context of cognitive resource allocation theory.

Keywords: Navigation prompting; Cognitive impairments

1. Introduction

Navigation skills are fundamental to community access, personal independence and community integration (Doig et al., 2001). Unfortunately, navigational difficulties have been documented across a number of different populations with reduced cognitive abilities including elders (Wilkniss et al., 1997; Kirasic, 2000), people with mental retardation (Martin et al., 1982), and people with traumatic brain injury (TBI) (Newbigging and Laskey, 1995). Our work studying navigation patterns of people who have sustained brain injuries indicated that community travel is severely restricted. We will discuss this in more detail in the following section.

Spatial disorientation and reduced route finding ability have been described in the aged population (over 70) with and without cognitive decline (Wilkniss et al., 1997; Hunt and Waller, 1999; Kirasic, 2000), in people with mental retardation (Martin et al., 1982), and in people with acquired brain injury (ABI) (Dutton, 2003). One study showed that a route finding test was the one executive function task that differentiated people with cognitive impairments due to closed head injuries from non-injured controls (Spikman et al., 2000).

Obviously damage to brain regions directly responsible for spatial abilities affects navigation skills (Aguirre and D'Esposito, 1999). Less apparent and understood are the effects on navigation of impaired working memory, a pervasive cognitive condition across neurogenic populations. Working memory refers to the cognitive systems that allow an individual to hold and manipulate information before acting on it, as well as to retrieve information from

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his or her long-term memory store for a current need (Baddeley, 1986). These systems are thought to interface with a cognitive operation called the central executive that controls the allocation of cognitive resources and is responsible for choosing and carrying out different operations as required (Baddeley, 1999; Reisberg, 2001). Problems with cognitive resource allocation, working memory and reduced mental capacity are well described in the population of people with neurogenic disorders and have been implicated in skills critical for navigation (Goodman et al., 2005; Sohlberg et al., 2005).

Navigation represents a domain that, if supported, could make an impact on quality of life for many individuals. Technology offers a method to provide such support, particularly considering the developments in location-sensing (e.g., global positioning system) and personal electronics technology (e.g., personal digital assistants (PDAs)) (Goodman et al., 2005). There has been a proliferation of computerized navigation guides and aides to facilitate navigation in all travelers. While there are increasing numbers of devices becoming available, their designs do not typically consider the needs and abilities of users with cognitive impairments, the population of interest to our research group. For example, hand-held devices often place demands on working memory and require holding on to information viewed in an earlier screen display in order to know how to proceed in a subsequent screen view (Sohlberg et al., 2007). In terms of comfort and reliability, a PDA that must be carried in-hand during a trip, and not be dropped or lost, is not well suited for the population we are working with.

The neurorehabilitation literature suggests that external aids, including electronic devices, can be effective for prompting people with impairments in memory, attention, and initiation. Responsiveness to device prompting is documented across a wide spectrum of type and severity of impairments for a range of functional tasks (O'Connell et al., 2003; Sohlberg et al., 2003; LoPresti et al., 2004). Much of the work in this field calls for individualization of cueing and other design features of assistive tools (Goodman et al., 2005; Sohlberg et al., 2007); however, customization presents difficult scale issues for device developers. Regardless, simplicity and transparency are critical design features for assistive tools to be effective.

Navigation devices, in particular, utilize a number of different prompting mechanisms to support route following including text directions and maps. A few nascent studies have begun to evaluate the mode of prompting with respect to the usability of navigation devices. Goodman et al. (2005) showed that an electronic pedestrian navigation aide based around landmarks was more effective for older people than an analogous paper version. Their participants could use text, speech and photographic prompts, although preference and efficiency for specific modes differed between people. Another study compared people's performance using a displayless speech-based navigational system versus a multimodal interface that included visual-tactile map display. The results of this study suggested that the displayless mode placed significantly more cognitive load on the participants (Baca and Picone, 2005).

In the current study, we sought to further the fledgling work in navigation support for people with cognitive impairments. We compared the effects on pedestrian route following four different modes of prompting delivered via a PDA used by adults with severe cognitive impairments due to brain injury. The prompting modes included: (1) an aerial mode with navigation indicator arrow; (2) a point of view mode with navigation indicator arrow; (3) text-based step-by-step instructions; and (4) auditory-only step-by-step instructions (see Figs. 1–4). Our research questions were as follows:

(1) What differential effects on pedestrian route following (if any) will occur as a function of prompting mode delivered via a wrist-worn PDA for travelers with severe cognitive impairments?
(2) Will there be a trend in preferences for a particular prompting mode by device users with severe cognitive impairments?

Fig. 1.

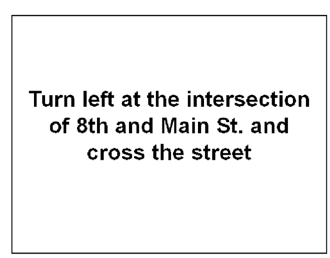

Fig. 2.

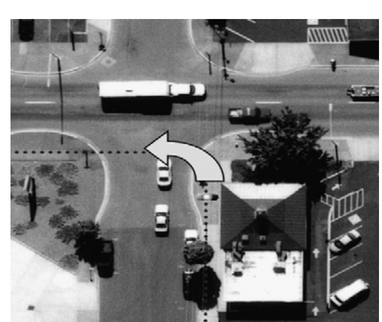

Fig. 3. Aerial image modality.

Fig. 4. Auditory modality.

Consistent with (Baca and Picone, 2005), we hypothesized that the navigation prompting mode that placed the least demands on working memory would facilitate the most successful route following. This has rough correlation with the *perceived workload* for mobile devices discussed in Goodman et al. (2004). We anticipated that navigational prompting using text-based, step-by-step instructions would result in the least navigational errors and most efficient route following because it does not require the traveler to interpret and translate a map, and unlike auditory directions, written text is not transitory; it stays visible to the user, and hence, does not require working memory to hold on to the directions. For these reasons, we hypothesized that text-based instructions would be the preferred prompting modality.

2. Preliminary work

In an earlier study (Sohlberg et al., 2005), our group focused on the travel challenges faced by residents of an apartment complex that supports survivors of a traumatic brain injury (TBI, also called acquired brain injury or ABI). Since this earlier study led to the study reported here, it is worthwhile summarizing. Residents ranged in age from early twenties to mid-sixties with etiologies drawn from head trauma (traffic accidents being most typical), stroke, brain tumors and drug use. Residents lived semi-independently, being responsible for their own meals, finances and travel; a residence van is available for grocery shopping trips. Our study had two facets. First, we interviewed residents, staff and those in the community charged with public transportation. From this we learned that (a) residents had places in the community they would like to visit, but (b) did not attempt to travel beyond the limited routes that they knew. We validated this by having staff observe and record the comings and goings of a representative set of residents over a 3-month period. The end result was a clear picture that residents had travel goals that were currently unmet because of their cognitive impairments.

A second facet of the study was the detailed record of a resident's trip (accompanied by a researcher) as he or she attempted to travel to a destination that was known, but the route was unknown; because of memory impairments, most familiar routes quickly became unfamiliar to residents. We took this task in the belief that real-life tasks are better predictors of real-life functioning than standardized assessments (Nadolne and Stringer, 2001). Five different residents participated in the way-finding study, including one couple. Most trips involved using a bus with a transfer, but some also were pedestrian-only trips from the facility. Residents were given various forms of map directions to carry with them; there was no electronic device. Trips were designed to take 1 h max, but averaged from 2 to 5 h in reality. The researcher attempted to stay solely in the role of safety net, and not provide navigation help. None of the trips could be called fully successful. In one extreme case, a couple wandered the environs of a large shopping mall for 3 h searching for a place to cash a check to eat. Their original task was to visit a game store that they had heard about (a route-finding task). The check-cashing/eating task was added spontaneously by the couple (moving them to a way-finding task involving exploration of the environment). The accompanying researcher eventually felt compelled to intervene and guide them to a McDonalds and loan them some money. Another hour was spent looking for the bus stop for the return trip. The general findings were: (a) Use of a bus was typically non-problematic given the willingness of the bus driver to alert a person when their stop was near. However, locating unfamiliar bus stops, typically for the return journey, was a big problem. (b) Orientation was a large problem, e.g., knowing facing information when stepping off a bus at an unfamiliar stop. (c) Counting on a resident to self-manage directions, e.g., remembering to frequently glance at directions to follow along the route, was not reliable. (d) Both being self-aware that one is lost, and then carrying out effective problem solving were problematic.

We need to reiterate that the goal of much of the preliminary work described in this section was to guide the set of formal experiments we took on in the future. We mention the work here to motivate the study we describe next. We also discuss other experiments we are interested in, coming from our preliminary work, in the closing sections.

3. Methodology

3.1. Participants

Participants selected for this study consisted of 20 individuals with ABI from a variety of etiologies. They ranged in age from 24 to 67 years ($M = 46.95$, $SD = 11.79$) and consisted of 15 males and five females. Time post onset ranged from 4 to 37 years ($M = 18.55$, $SD = 10.37$). Table 4 provides more detail.

The participants were recruited from two local assisted living facilities by asking staff to refer potentially interested residents with cognitive impairments in the domains of attention, memory, and/or executive functions who experienced difficulty with navigation. Other requirements included the ability to walk or use a mobility device for a 1.5 km distance. A total of 22 participants were referred.

Of these, 20 were able to complete the navigation routes. One (Subject #7) was excluded due to a visual impairment that precluded her from reading the prompts, and one other participant (Subject #2) could not navigate due to physical impairments. Information was obtained from a combination of researcher observation and interview with the referring service provider. Recruitment and consent procedures were in compliance with the requirements of the university institutional review board.

3.2. Setting and materials

Participants followed route based directions presented on a Hewlett Packard iPAQ pocket PC as they navigated on foot (or in a wheelchair) in the downtown area of a small town. The town was selected because the downtown contained equal square blocks and none of the assisted living facilities were located in this town. Four equivalent routes were designated. Each route was approximately 300 m and was equated for the same number of choice points. A choice point was defined as a location requiring a directional decision. Intersections were examples of choice points whereas a driveway leading to one particular residence or building did not constitute a choice point. See Fig. 5 for a map of the routes.

We chose a wrist-mounted location for the iPAQ (see Fig. 6). The more typical alternative for navigation studies is to have a subject carry the device in his or her hand, either permanently or to fish it out of a pocket or bag. This was judged impractical for our study population: in real life such devices are dropped or left on bus seats. We will discuss in a later section the problems we had with the wrist-mounted device.

For one of the modes, audio, an iPod style earphone was used (see Fig. 4). In this mode, the iPaq displayed a blank screen to the subject: all information was transmitted through the earphone.

Each participant completed four routes using four different prompting modes delivered via the wrist-worn iPAQ: (1) aerial (bird's eye view) image, (2) point of view (from perspective of traveler) image, (3) audio direction/no image and (4) text-based instructions/no image. The two image prompts consisted of photos of the routes and surrounding environments with superimposed arrows to indicate the target direction. The audio prompts and the text prompts were identical in content and consisted of short phrases, no longer than 16 words (e.g., "Walk forward on the sidewalk"; "Turn right at the intersection of 6th and Main St. and continue walking on the sidewalk"). The audio prompt was delivered via an earphone connected to the iPAQ. All four types of prompts were delivered at the same points along the routes. The prompts were delivered just before the participant reached the choice point. There were a total of seven prompts for each route. The last instruction of each route was to stop at a specific business, e.g., a coffee shop.

Fig. 6. The iPAQ prompt delivery system.

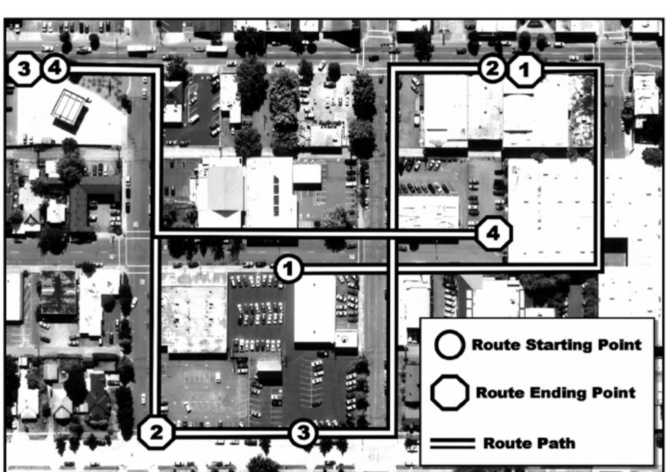

Fig. 5. Map of routes used in the trial.

The rationale for our choice of the four modes is based on others work with both the non-impaired and the visually impaired populations. Results show a distinction between people's ability in survey-knowledge, route-knowledge, and landmark-knowledge (Werner et al., 1997). Our preliminary work showed that normal street maps, which require survey-knowledge, were not a viable option. However, we also noticed that transit agencies (e.g., Portland's TriMet) were beginning to use aerial views in route visualizations they give to the public. We attempted to mimic this style for our routes under assumption that our participants might encounter them in transit-district media. And it gave us a survey-knowledge mode. The other three modes were based on route-knowledge. The point-of-view mode was motivated by our notice of commercial navigation applications using a similar interface. The instruction list, both written and audio, were typical of the instructions given to participants by residence staff, although typically in much less detail. Our omission of a landmark mode is discussed in the related work section (see Goodman et al. study).

3.3. Procedures

Two researchers (A and B) accompanied the participants during the experiment. Prior to beginning the route task, researcher A oriented the participant to the iPAQ and read the procedure script explaining the purpose of the study. Participants were told that they were going to be evaluating different types of directions and then provide feedback on what type of prompts they thought were the most useful. They were told to follow the instructions on their device and just do their best. They were informed that the researchers would accompany them, but not provide instructions. After making sure the participant understood the purpose of the study and was comfortable, researcher A oriented the participant to face the correct direction prior to receiving the first prompt.

In order to eliminate order effects, Latin Square (Denes and Keedwell, 1991) was used to counter-balance the four different prompt modes with the four different routes (see Table 1). The Latin Square used in this study was a 4×4 table filled with four different modes of prompts in a way that each mode occurred exactly once in each row and exactly once in each column.

After their orientation, participants received their first direction prompt and began the first route. During the trials, researcher A followed 5 ft behind the participant who was navigating. Researcher A controlled the pace of instructions by sending each successive prompt wirelessly from his own iPAQ at selected spots along the route. The prompts for each route were sent at the same place for all participants. An audio beep indicated the arrival of a new prompt on the participant's iPAQ.

Researcher B observed and recorded data on the participants' responses and behaviors during the trials. She too walked 5 ft behind the participant. If a participant asked a question, researcher B just encouraged the participant to do his or her best. If the person continued to feel confused and asked an additional question, the prompt was delivered for a second time. We hired a videographer (an undergraduate) who was solely responsible for video-taping the subject from a distance of approximately 5 ft. Following the completion of each route, the participant was brought to the starting point of the next route. Researcher A reoriented the participant to the iPAQ and positioned the participant to receive the first prompt of the next route.

After a participant completed the entire experiment consisting of the four routes using four different prompting modes, Researcher B interviewed the participant to determine his or her preferred prompting mode. The participant was asked to rank the prompting modes in order of how helpful they were and to share why they felt their top choice was the most helpful and why they felt the bottom choice was the least helpful. The participant was also given a chance to provide any feedback or comments on their research experience.

Table 1
The 4×4 latin square for counter-balancing the modes of prompt

	Route 1	Route 2	Route 3	Route 4
1	Text	Audio	Aerial photo	Image
2	Audio	Image	Text	Aerial photo
3	Image	Aerial photo	Audio	Text
4	Aerial photo	Text	Image	Audio

3.4. Measurement

The procedures used to measure performance on the route-following tasks were modeled after the method described by Lobben (2007) who studied navigation ability in people with visual impairments. In the current experiment, a navigation score was calculated that captured accuracy and confidence during navigation. The scoring system was developed and piloted on a group of participants not included in the study and found to have high inter-rater reliability and validity. The pilot participants who were rated as having the best navigational abilities by their caretakers received the best scores and those judged to have the most impaired abilities received lower scores.

Each route contained seven navigation choices. Five points were assigned for direct navigation to each choice point without error, extra cues or hesitation. Hence, the highest possible navigation score was 35 on each route. Points were deducted for missing a choice point, asking questions, and/or for hesitating. If the participant missed a choice point (e.g., did not turn left when prompted at an intersection), four points were deducted. This was determined when a participant went more than 15 steps past a choice point. If the participant asked a "content" question, a question whose answer would provide directional information (e.g., "Which way do I go?" or "Can you tell me what to do now?"), three points were deducted. If the participant asked a confirmation question (e.g., "Am I doing ok?" "Am I right?"), two points were deducted. Researcher responses to both types of questions consisted of verbal encouragement for participants to simply try their best. As noted, if a participant continued to be confused and repeated the question again, the prompt was delivered for a second time and the corresponding points deducted for that question. If a participant hesitated (defined by stopping, repeated looking around), one point was deducted. Finally, if a participant became completely disoriented to the navigation activity or to the surroundings and seemed to be wandering aimlessly, or the participant asked what they were doing walking around an unfamiliar community, they were taken back to the previous choice point, reoriented, and five points were deducted.

These procedures allowed us to provide frequent prompting in order to be able to evaluate navigation performance of participants with severe cognitive impairments. We note that we ran a pilot study that provided less frequent prompting by using more complex directions (e.g., omitting intermediate choice points, using multi-step instructions such as "do x and then y"). This was a general disaster, producing many more errors that were *uniform across modes*. In essence, we found that we were reconfirming that complex instructions are not useful for those with moderate to severe memory impairments, something well documented in the cognitive rehabilitation literature (Sohlberg and Mateer, 2001). Given our goal of eventually producing a usable navigation device for the population, we chose a simple and frequent prompting scheme to allow our participants to have a chance of success at the pedestrian navigation task.

The video-tape from the trials was scored by a third researcher to assess inter-rater reliability. Inter-rater agreement for navigation score between the two coders was 89.9%.

Researcher B also recorded qualitative data on-route-following performance. If the participant indicated a reason for an error response (e.g., ‘‘I thought the direction said right not left’’ or ‘‘I forgot what the voice told me to do?’’) this was recorded. Other behaviors such as turning around the device, retracing steps and beginning again were also noted and coded.

A separate form was used on each route. We include an example, the form for route 2, as an attachment.

For those familiar with the field-based mobile-device evaluation procedures suggested in Goodman et al. (2004), we briefly summarize our study in their terms:

1. *Time to complete*: While we did collect timing information, it was not used in the final evaluation. Given that participants were sometimes ‘‘interfered with’’ by the observer, i.e., given feedback when confused or lost, timing information was deemed less than accurate.
2. *Errors*: Our focus was on errors. We developed an evaluation instrument around gradations of errors in navigation. The video-tape of each trial was analyzed (separately by two researchers) to provide an error grade.
3. *Workload*: This was reflected, indirectly, through post-hoc user questionnaires, and error analysis.
4. *Distance and route*: See discussion in section settings and materials.
5. *Percentage preferred walking speed (PPWS)*: As discussed in the preliminary results section, we found that most of our participants do not venture far from their facility; there is no baseline for them navigating in unfamiliar surrounds. In general, we felt that attempting to set-up a PPWS baseline that made sense with this study was a knotty problem, and one that was much less a concern than navigation errors. From working with the population on navigation issues for 3 years, our experience is that participants are much more anxious about getting lost than about how fast they travel.
6. *Comfort*: We obtained comfort measures, indirectly, through user questionnaires. See Table 3.

The Goodman evaluation metrics were developed for the non-impaired population. We discuss in later sections the ability (or lack thereof) to transfer results from the non-impaired world to that of the cognitively impaired population.

4. Results

4.1. Navigation score results

Twenty subjects completed all four trials. The results of the route-following performance are displayed in Table 2. A within subject comparison was computed to compare the navigation performance using the four prompting modes on the four routes. The performance of the navigation task in one mode (e.g., using the audio prompt) was compared with the navigation performance using the other prompting modes (e.g., text-based prompts, aerial image, and point-of-view image). Each subject served as his or her own control to assess potential differences in navigation performance based on mode of prompting.

There was one categorical independent variable (the prompt mode) with four levels (audio, text, aerial image, and point-of-view image) and one quantitative dependent variable (the navigation score). In order to operationalize the research question as a statistical analysis, a one-way, repeated measures analysis of variance (ANOVA) was used in this study. A significant difference was found between participants guided by audio-based ($M = 33.80$, $SD = 1.64$), text-based ($M = 32.05$, $SD = 2.95$), point-of-view-image-based ($M = 31.40$, $SD = 3.71$), and aerial-image-based ($M = 30.45$, $SD = 5.21$) route directions. There was a main effect between these four modes, $F(22, 57) = 3.46$, $p < .00$, $\eta^2 = .57$, indicating that statistical significant difference was found between these four prompt modes.

Follow-up tests were conducted to evaluate the pairwise differences. The pairwise comparisons were computed in order to discover which prompting mode worked most effectively for the participants. Tests of the four *a priori* hypotheses were conducted using Bonferroni adjusted alpha levels of .0125 per test (.05/4). Results indicated that the navigation scores were significantly higher when the participants were guided via the audio prompt ($M = 33.80$, $SD = 1.64$) than via the point-of-view image prompt ($M = 31.40$, $SD = 3.71$), $F(1, 57) = 13.44$, $p = .00$. Navigation scores were also significantly higher when participants were guided via audio-based prompts than when guided via aerial image prompts ($M = 30.45$, $SD = 5.21$), $F(1, 57) = 6.90$, $p = .0111$. Other pairwise comparisons did

Table 2
One-way, repeated-measure analysis of variance summary table

Source	df	F	n^2	p
Mode	3	4.78*	.11	.0049
Subject	19	3.25*	.46	.0003
Error	57			
Total	79			

*$p < .05$.

not reach statistical significance. There were no statistically significant differences in navigation scores when participants were guided by text versus point-of-view image, aerial image, and audio prompts or between point of view image prompts and aerial image prompts.

4.2. Preference ranking results

The results of preference ranking for the different prompt modes are presented in Table 3. Participants selected the "most helpful" and "least helpful" types of prompts. Twelve out of 20 participants (60%) reported that the audio prompt was the most helpful type of prompting. According to the qualitative feedback, there were three primary reasons for selecting audio prompts as the most helpful: (1) they were "easier" to follow; (2) this mode was more "straight forward", and (3) audio prompts do not require you to keep looking at the screen. Nine out of 20 participants (45%) reported that the aerial map was the least helpful mode. The rationale for ranking aerial maps as the least helpful mode consisted of two main problems: (1) it was hard to comprehend where the arrow was pointing, and (2) it was difficult to identify how the pictures related to where they were walking. Its poor results are consistent with other groups' findings (Kelley et al., 2006). This is discussed in more detail in following sections.

4.3. Observed problem behaviors

The navigation score is computed from observed problem behaviors (see the example form at the end of this paper). Table 2 presents an analysis of these numeric scores. In this section, we provide a summary of the problems that were observed in the field.

- Problems with left and right. Participants turning the wrong direction at a choice point. Little obvious consistency with this error. Sometimes all combinations—left for left, right for right, left for right, right for left—seen in the same person at different choice points and routes.
- Problems with missing a turn, i.e., continuing straight through a choice point. Related, failing to stop at the destination by continuing past it.
- Problems with making an uncalled for turn, e.g., turning right at a choice point where directions call for walking straight.
- Believing that destination reached when it was not.
- Problems with giving up at a choice point; unable to decipher what to do, so just stop without committing.

Table 3
The summary of ranking for most and least helpful modes of prompts

	Most helpful (%)	Least helpful (%)
Aerial photo	20	45
Image	20	10
Text	0	30
Audio	60	15

In essence, every type of error possible in the study was seen. We discuss how this relates to our follow-on studies in the following sections.

5. Related work

Goodman et al. (2005) ran a study of navigation assistance for older people. In their study, participants were chosen from two age groups: 63–77 and 19–34. No further filtering or pre-testing is reported. Participants were asked to navigate using landmarks in an urban setting. The results were that landmarks were more useful to the older age group than the younger group. Our group was also interested in landmarks as a navigation aid, in particular because of the large literature that suggests they are valuable for the non-impaired population (Lobben, 2007). Through pilot studies similar to those carried out by the Goodman team, we looked at landmarks as a potential navigation mode for cognitively impaired travelers, i.e., as a fifth mode to use in our studies. Unlike the Goodman group, we had mixed results. First, landmarks that could be viewed as distinct in a light-urban environment were often lacking on large parts of a route: our subjects could not locate any of the alternatives we chose. It is an open question to us on whether our subjects would have performed better with the type of landmarks used in the Goodman study, or conversely, they suffered from a form of landmark agnosia as seen in brain-injured patients studied by Aguirre and D'Esposito (1999). Second, while most (but not all) of our participants showed little difficulty with directions to *turn* left or right, they were often stymied by directions to place themselves relatively to the left or right of an object/landmark. For these reasons, we did not attempt to use landmarks as one of our modes. On a more general note, it appears that the participants in the Goodman study were currently active walkers: Goodman's group was able to gather PPWS from them as a baseline. Our participants shared a problem seen in the cognitively population at large: social isolation. None ventured much beyond the known surroundings of their living facility. Time to complete was less an issue than anxiety about getting lost (making errors). Finally, while 21 out of 32 participants in the Goodman study were regular map users, none of our participants were map users. In a pilot study, we gave six individuals a personalized walking map to a destination within walking distance of their apartment/facility; our interest was in their ability to use a simplified map that incorporated information that they were familiar with and the route indicated clearly; in essence, a map tailored to both their personal knowledge of an area and to a specific destination. In this pilot study, we did not correct errors, hoping that participants would recognize their errors from their map and self-correct. Participants missed turns and quickly wandered from their goal. The map did

Table 4
Participant profiles

Subject code	Gender	Age (years)	Education (years)	Etiology[a]	TPO (years)	Primary cognitive-communicative; psychosocial impairment[b]
#1	M	51	12	TBI + stroke	10	MEM, aphasia, AOS
#2	M	50	12	MVA	24	MEM, DES
#3	F	36	12	MVA	15	MEM, affective disorder
#4	M	55	13	CVA	6	ATT, MEM, DES
#5	M	63	12	TBI	18	ATT, MEM, DES
#6	M	45	9	MVA	32	MEM, DES
#7	F	44	12	MVA	14	ATT, MEM, DES
#8	F	39	12	MVA	19	MEM, DES, Anxiety
#9	M	27	12	TBI	25	ATT, MEM, DES
#10	M	46	12	MVA	27	ATT, MEM, DES
#11	M	55	12	TBI	5	MEM, DES
#12	F	45	15	MVA	20	ATT, MEM, DES
#13	M	32	12	TBI	5	ATT, MEM, DES
#14	M	67	18	CVA	18	MEM, DES
#15	F	58	16	MVA	28	MEM, DES, anxiety
#16	M	62	16	MVA	37	ATT, MEM
#17	M	54	16	MVA	25	ATT, MEM, DES
#18	F	40	12	MVA	13	ATT, MEM, DES
#19	M	24	11	MVA	5	MEM, DES
#20	M	44	10	MVA	30	MEM, DES
#21	M	52	12	MVA	29	MEM, DES
#22	M	43	12	MVA	4	MEM, DES

[a]TBI = traumatic brain injury (details unknown), MVA = motor vehicle accident, CVA = cerebrovascular accident.
[b]MEM = memory impairment, AOS = apraxia of speech, DES = dysexecutive syndrome, ATT = attention deficit.

not aid them in discovering their mistakes. This leads us to a supposition: we believe the map-reading skill (seen in a majority of Goodman's participants) is a telling separator from our participants. We also believe there is much interesting work to be done in the area of map-making for special populations.

Work by Tyler and Wainstein (2007) suggests a set of phone-interface guidelines for navigation applications that target the learning-disabled population. Through a story-boarding-style session, they received feedback from users on content and layout. In general, the guidelines and examples used in the paper appear overly complex for our target population. We could neither determine if field trials were actually carried out with devices following the guidelines (similar to our study), nor what were the etiologies of the participants in the study. Without this information, it is difficult to comment further on differences between our findings and theirs. More generally, there are several groups looking at navigation for the cognitively impaired population for which we could not find comparison data, e.g., Patterson et al. (2004) and Carmien et al. (2005). Without knowing the details of a group's experimental set-up and results, we can offer little in way of discussion of convergence or divergence from our own work.

Other work has concentrated not on specific populations, but on general means of delivering information in a mobile environment. Chittaro and Burigat (2005) report on a tourist guide device. The application is a guided walking-tour of a city-center while carrying a PDA device with earpiece. The tour area is traffic-free, removing one of the distractions on our study: pedestrian safety, i.e., staying alive. Twelve subjects ranged in age from 20 to 40. Half had map-reading experience. Only two had used a PDA. The PDA was used to guide subjects to spots of interest roughly 10 m apart, with a total of 23 spots on each route. Once at the spot, audio would play that described the spot. The modes of presentation were as follows in terms of navigation information: (1) map, (2) map and photographs, and (3) arrow and photographs, the arrow replacing the map. Subjects were required to tap the screen when they stopped at a spot and when they restarted their tour. Related to our study, Chittaro and Burigat (2005) studied errors made with the three modes. They did not obtain significant results: across all subjects a total of three errors were made with map, one error with map + photographs and 0 errors with arrow and photographs. For time to complete the tour, the map mode was significantly worse than the other two modes. In terms of similarity to our study, Fig. 1 roughly correlates with the photographs used by Chittaro and Burigat (2005). Our use of an aerial-overhead map (Fig. 3) is somewhat similar to their more traditional route-map. Significantly, Chittaro and Burigat (2005) did not attempt to use either a text only mode (Fig. 2) or an audio only mode (Fig. 4). This is as might be expected for their study of a different population and a different application. Most telling, they expected subjects to be distracted: that is the point of a tourism-guide. For our study, we used the cognitive rehabilitation literature as the basis for minimizing distractions: distractions cause loss of set and forgetting what the task is (Sohlberg and Mateer, 2001). In particular, we cannot think of many worse examples than having one of our subjects stopped 23 times on a 230 m route, distracted, then expected to reinitiate the trip from that point.

Chewar and McCrickard (2002) discuss the issue of personalized information display in secondary displays, i.e., displays that are not the primary focus of a user performing a task. They argue, and we agree, that navigation displays fit this model: the user is attempting to focus on the physical task of navigation with the display providing secondary information. Chewar and McCrickard (2002) set out to explore if dominant brain lateralization can be used to assess the style of an individual user, and then use that style description to customize the user's display mode, chosen from six different modes available: (a) an arrow, (b) text (next step to take), (c) audio (same as text but spoken as opposed to displayed), (d) text list (next seven steps to take), (e) map placement (position and heading of user), and (f) map placement with solution path (position and placement, but also path to goal). The navigation problem was based on a virtual reality set-up. Users were shown the walls of a maze in 3D, similar to the early computer-based dungeon games. The navigation display was on the side of the maze graphic as a secondary display. Attention to this display, as opposed to the actual maze, was indirectly calculated by asking the user to press the spacebar. This request showed up in the maze graphic. It was assumed that if the request was not carried out by the user, they were attending to the secondary navigation display, and hence did not see the request. Thirteen subjects, aged 22–60, participated. Gender mix was not reported. All subjects used a computer at least occasionally. The program Brain Works (Synergistic Learning Inc.) was used to assess dominant brain lateralization. Results of this assessment found subjects relatively evenly mixed. Looking at navigation error results, there was similarity with the results reported in this paper: audio was among the top three under all conditions. The other two were graphics (roughly corresponding to our point-of-view) and text list (which we did not attempt). Like our aerial image, Chewar and McCrickard (2002) found their map modes weak alternatives. When they looked at the dominant brain lateralization assessment, no significant results were reported in terms of errors. Frankly, we are less interested in the lateralization question, and more in the use of VR to replace field studies. This paper leads us to speculate on whether our trials could be carried out in a VR environment. Given the time-consuming nature of field trials, a VR approach could be a huge benefit to researchers. However, we see problems. In particular, can we transfer results from virtual reality to the real world. Will their same subjects get repeat results when moved to a field situation? How will the virtual reality display be implemented as a secondary display in the real world? We remain interested in work like that reported by Chewar and McCrickard (2002), which focuses on assessment to predict display modes. However, a rigorous study of the relation between VR and field experiments is lacking.

6. Discussion

This study provides preliminary direction for designers of assistive navigation devices for the cognitively impaired population. It appears that audio-based prompts can be an effective form of navigation guidance for people with moderate to severe cognitive impairments. They are clearly superior to image-based prompts and slightly more effective than text-based prompts. These findings ran contrary to our hypotheses. We had predicted that the text-based prompt mode would be correlated with superior navigation scores, and that it would be the preferred method for guiding route following. Our hypotheses were based on the cognitive rehabilitation literature supporting the use of checklists and step-by-step instructions to guide completion of multi-step tasks, and assumption that this mode demands less working memory especially compared to auditory prompts (Sohlberg and Mateer, 2001; Wilson et al., 2001).

Our findings encourage us to consider the notion that the effectiveness of prompt mode may be intricately linked to the cognitive requirements for an individual task. It may be that the cognitive demands of navigation or route following are better matched to auditory prompts. The human factors literature suggests a possible explanation for why the transitory auditory prompts appeared to be the most effective and preferred guidance modality for route following. For people without cognitive impairments, speech-based interaction has been recognized as appropriate for "hands-busy, eyes-busy" multitask situations such as driving while using navigation devices (Lee et al., 2001; McCallum et al., 2004). For example, one study (Parush, 2005) used a dual task paradigm requiring participants to complete a primary visual tracking task using a joystick and computer screen and a secondary data entry task involving inputting destinations into a hypothetical navigation device. The data entry task had two conditions, a visual prompt and speech-based prompt. The purpose of their study was to assess the best modality to guide the users when they were completing the complex dual task. Their findings suggested that the use of spoken prompts, as compared to visual prompts provided better overall support on the performance of the primary visual task. They suggested that cognitive resource allocation may account for performance differences. The visual prompts may have competed with the cognitive demands of the primary visual (tracking) task. This theory may also account for the findings in the current experiment. It may be that the audio prompts did not compete with the visuomotor demands of the navigation task as much as the image-based and text-based prompt modalities.

It is possible that text-based prompts (e.g., checklists or written instructions) may be more useful for completing linear tasks that do not require an individual to move around in space and continually evaluate one's environmental location and direction. For example, text-based prompts have been shown to be useful for carrying out functional home tasks such as cooking (Yasuda et al., 2002) or vocational tasks (Kirsch et al., 1992). The nature of these tasks may differ substantially from route following while walking in the community, and thus be best assisted by different types of prompts. More research is needed on the correlation between the completion of different types of complex tasks and the relative support provided by different prompting modes.

Specific to our area of interest, community navigation by people with cognitive impairments, the current study encourages further examination of the effects of auditory and text versus visual or image-based prompts. One might argue that the aerial view we used, if overlaid with map-like text (e.g., cardinal directions, street names), might have proven more effective. While we suspect not, the current study offers an experimental paradigm for testing such a claim.

7. Follow-on work

We attempted to address ecological validity by having participants navigate in a real community where they walked on sidewalks in a downtown area and crossed actual intersections. This allowed us to look at the use of the navigation device in an authentic environment where environmental variables such as traffic noise and visual distractions could potentially affect performance. One factor that we did not keep authentic, however, was the initial orientation. Participants were not able to orient themselves independently in any prompt mode to receive the first direction; a researcher was required to tell them what direction to face prior to beginning the experiment. For a navigational device prompt system to be useful, it would be critical to develop a prompting method to orient travelers as they begin a route, and be able to reorient them if they become confused on-route. We are beginning to study this difficult problem as part of our future work. More generally, we find the issue of error-correction while navigating a fascinating and under-studied topic. Can the current car navigation (e.g., OnStar in the US) approach of continuous rerouting be effective in a pedestrian setting? Or can a person reorient themselves back to the last choice point and then make the right decision?

Once we obtained the error results, a logical question is *why* did a specific mode fail for a specific subject. A place to start is to hypothesize that a subject had difficulty aligning screen/audio information with reality, being unable to align at all, or just as problematic, do a misalignment. Unfortunately, we do not have the type of detailed information we need to study this question. We do have video at a distance, but this was used to verify observer field-notes, and only captures data for our behavior checklist (see Appendix A). We have begun a new study that uses webcam-in-glasses to capture where a subject is gazing (or at least where the glasses are pointed). We hope to integrate this with video at a distance to begin to make headway on the cause of errors in various modes.

It is frequently the case that one is walking outside to get to an inside destination (Sohlberg et al., 2005). For instance, one of the destinations on the wish list of some of our participants was a local (enclosed) shopping mall. We have just begun to ask what, if any, of the results from our outdoor navigation study can transfer to an indoor environment like a mall. We have run some very preliminary wizard-of-oz type studies in the local mall using audio directions through a cell-phone earbud. At this point we feel that much more work is called for in terms of helping the cognitively impaired navigate in chaotic, dynamic, and (purposely) sensory overloaded places like malls (with confusing medical complexes falling not far behind).

Finally, we note that our study and discussion are based on one-way communication, from device to participant. We have just started to look at two-way communication, again using a wizard-of-oz approach. Participants are given a cell-phone earbud with which to talk with a researcher back in our laboratory users are given a set of directions, but with a foil (i.e., an errorful or missing direction) to insure uniform navigation problems. Our goal in this study is to (a) understand how participants describe problems, and (b) explore scripted means of getting them back on track. Full automation of a computer-based assistant to replace the researcher in this study remains a future dream.

8. Final notes on our hardware set-up

We made several decisions early on in setting up our study. First, we chose the device-on-arm approach to avoid (a) a participant having to carry something in his or her hand over the routes, or (b) having to pull the device in and out of a bag or pocket constantly. However, we observed, and our participants commented on, the problems with a device strapped to their arm. It grew heavy over time. It was difficult to position so to be clearly seen in bright sunlight (although this was observed to be true even when being held in the hand). Our goal was to allow participants to look away from the device (for instance, to watch for traffic), and only glance at it when a new instruction arrived. We did this by beeping on arrival of new directions before they reached a potentially unsafe intersection. Nevertheless, most participants monitored (looked down at) the device more than we would have liked, commenting that they were worried they would miss a direction or not hear the beep. Chewar and McCrickard (2002) reported similar issues of participants being extremely cautious of not missing a choice-point direction. Of course this is a difficult problem for secondary displays, where too much attention to the display distracts from the actual task.

Another problem with the wrist-worn approach is the lack of freedom in orienting the device to the user's tastes.

Several participants did comment that the orientation we used for the aerial view (see Fig. 3) was hard to use and that they would have liked to rotate the image. This fits with the general literature: rotation of a map is effective for some and not for others (Seager and Fraser, 2007). Like Chewar and McCrickard (2002) and Lobben (2007) is looking at means of determining a user's navigation skills through assessment. This has potential to tailor a device, e.g., rotate maps, to fit the user's style and skills.

The audio mode did not fall prey to the above problems. Further, wearing an earpiece (e.g., cell-phone or iPod earbud) is inconspicuous in a way that wielding an iPAQ-like device in public is not, whether in your hand or on your wrist; this is a vulnerable population, and geeky or conspicuous clothing, accessories or devices are to be avoided. The major problem with audio was one of volume: participants said they sometimes could not hear it over traffic noise. Turning the volume up caused complaints that it was too loud on quieter sections of a route. We speculate that a volume modulator based on ambient noise could solve this problem, and are working on such a solution for our follow-on studies.

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Appendix A

PARTICIPANT BEHAVIOR CHECKLIST FOR ROUTE 2

(Begin at the entrance to Terese's Place on Main St. between 6th and 7th Ave.)

Participant's ID_______ Route #_2_____ Trial #______ Mode:_________

Total time for this route ______ Observer________ Date_________

Codes for Problem Behaviors		Codes for Error Responses
A-- Keeps turning device around	**E-- Look around or try to find street signs**	**a-- Didn't hear the direction**
B-- Stopping	**F-- Walk pass the choice point**	**b-- Participant thought the direction meant something else**
C-- Pushing buttons on device	**G-- Go back to the previous choice point**	**c-- Participant forgot the direction**
D-- Ask questions	**H-- Stop and Discontinue**	

Observer's response when an error happened	
First step-- Open Questions	**How is it going?**
	Any problems?
Second step	**You missed a choice point/direction**
	I'll take you back.
	Face this way. The device is going to give you directions again

Choice Point	CUED DIRECTIONS (AUDIO AND TEXT MODES)	ACCURACY	POINTS	OBSERVED/PROBLEM BEHAVIORS	RESPONSE TO ERRORS	
		(D) DISORIENTATION (M) Missing (Q1) Content Question (Q2) Confirming Question (H) Hesitation (+) Accurate	-5 -4 -3 -2 -1 -0		AWARENESS (+/-)	RESPONSE
0-1						
1	Walk forward on the sidewalk					
1-2						
2	Turn left at 7th and Main					
2-3						
3	Cross the street					
3-4						
4	Walk forward on the sidewalk					
4-5						
5	Turn right at 7th and B St.					
5-6						
6	Walk forward on the sidewalk					
6-7						
7	Stop at the corner of 8th and B					

Total Points (35 max)=

References

Aguirre, G.K., D'Esposito, M., 1999. Topographical disorientation: a synthesis and taxonomy. Brain 122, 1613–1628.

Baca, J., Picone, J., 2005. Effects of display less navigational interfaces on user prosodics. Speech Communication 45, 187–202.

Baddeley, A.D., 1986. Working Memory. Clarendon Press, Oxford.

Baddeley, A.D., 1999. Essentials of Human Memory. Psychology Press, East Sussex.

Carmien, S., Dawe, M., Fischer, G., Gorman, A., Kintsch, A., Sullivan, J.F., 2005. Socio-technical environments supporting people with cognitive disabilities using public transportation. Transactions on Human–Computer Interaction (ToCHI) 12, 233–262.

Chewar, C., McCrickard, S., 2002. Dynamic route descriptions: tradeoffs by usage goals and user characteristics. In: Proceedings of the Smart Graphics '02, 2002.

Chittaro, L., Burigat, S., 2005. Augmenting audio messages with visual directions in mobile guides: an evaluation of three approaches. In: Proceedings of the Seventh International Conference on Human–Computer Interaction with Mobile Devices & Services, pp. 107–114.

Denes, J., Keedwell, A.D., 1991. Latin Squares: New Developments in the Theory and Applications. North-Holland Publishing Co., Amsterdam.

Doig, E., Fleming, J., Tooth, L., 2001. Patterns of community integration 2–5 years post-discharge from brain injury rehabilitation. Brain Injury 15, 747–762.

Dutton, G.N., 2003. Cognitive vision, its disorders and differential diagnosis in adults and children: knowing where and what things are. Eye 17, 289–304.

Goodman, J., Brewster, S.A., Gray, P.D., 2004. Using field experiments to evaluate mobile guides. In: HCI in Mobile Guides Workshop at Mobile HCI 2004, Glasgow, UK.

Goodman, J., Brewster, S.A., Gray, P., 2005. How can we best use landmarks to support older people in navigation? Behavior & Information Technology 24, 3–20.

Hunt, E., Waller, D., 1999. Orientation and Wayfinding: A Review. Office of Naval Research, Arlington.

Kelley, M., Lawrence, M., Groshon, L., McConnell, J., Lobben, A., 2006. Route planning strategies using different environmental representations. Presented at the Annual Meeting of the Association of American Geographers, March 2006, Chicago, IL.

Kirasic, K.C., 2000. Aging and spatial behavior in the elderly adult. In: Kitchin, R., Freundschuh, S. (Eds.), Cognitive Mapping: Past Present and Future. Routledge, London, pp. 166–178.

Kirsch, N.L., Levine, S.P., Lajiness-O'Neill, Schnyder, M., 1992. Computer-assisted interactive task guidance: facilitating the performance of a simulated vocational task. The Journal of Head Trauma Rehabilitation 7, 13–25.

Lee, J.D., Caven, B., Haake, S., Brown, T.L., 2001. Speech-based interaction with in-vehicle computers: the effect of speech based e-mail on driver's attention to the roadway. Human Factors 43, 631–640.

Lobben, A., 2007. Navigational map reading: predicting performance and identifying relative influence of map-related abilities. Annals of the Association of American Geographers, March, 2007.

LoPresti, E.F., Mihailidis, A., Kirsch, N., 2004. Assistive technology for cognitive rehabilitation: state of the art. Neuropsychological Rehabilitation 14, 5–39.

Martin, J.E., Rusch, F.R., Heal, L.W., 1982. Teaching community survival skills to mentally retarded adults: a review and analysis. Journal of Special Education 16, 243–267.

McCallum, M.C., Campbell, J.L., Richman, J.B., Brown, J.L., 2004. Speech recognition and in-vehicle telematics devices: potential reductions in driver distraction. International Journal of Speech Technology 7, 25–33.

Nadolne, M.J., Stringer, A.Y., 2001. Ecologic validity in neuropsychological assessment: prediction of wayfinding. Journal of the International Neuropsychological Society 7, 675–682.

Newbigging, E.D., Laskey, J.W., 1995. Riding the bus: teaching an adult with a brain injury to use a transit system to travel independently to and from work. Brain Injury 10, 543–550.

O'Connell, M.I., Mateer, C.A., Kerns, K.A., 2003. Prosthetic systems for addressing problems with initiation: guidelines for selection, training & measuring efficacy. Neuro Rehabilitation 18, 9–20.

Parush, A., 2005. Speech-based interaction in multitask conditions: impact of prompt modality. Human Factors 47, 591–597.

Patterson, D.J., Liao, L., Gajos, K., Collier, M., Livic, N., Olson, K., Wang, S., Fox, D., Kautz, H., 2004. Opportunity Knocks: A System to Provide Cognitive Assistance with Transportation Services. Springer, Berlin/Heidelberg (In UbiComp 2004: Ubiquitous Computing, volume 3205 of Lecture Notes in Computer Science, pp. 433–450).

Reisberg, D., 2001. Cognition: Exploring the Science of the Mind, second ed. W.W. Norton, New York.

Seager, W., Fraser, D.S., 2007. Comparing physical, automatic and manual map rotation for pedestrian navigation. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 767–776.

Sohlberg, M., Mateer, C., 2001. Cognitive Rehabilitation: An Integrative Neuropsychological Approach. Guilford Press, New York.

Sohlberg, M., Ehlhardt, L., Fickas, S., Sutcliffe, A., 2003. A pilot study exploring electronic mail in users with acquired cognitive–linguistic impairments. Brain Injury 17, 609–629.

Sohlberg, M.M., Todis, B., Fickas, S., Hung, P., Lemoncello, R., 2005. A profile of community navigation in adults with chronic cognitive impairments. Brain Injury 19, 1249–1259.

Sohlberg, M., Kennedy, M., Avery, J., Coelho, C., Turkstra, L., Ylvisaker, M., Yorkston, K., 2007. Practice guidelines for external aids for memory rehabilitation. Journal of Medical Speech Language Pathology 15.

Spikman, J., Deelman, B., van Zomeren, A.H., 2000. Executive functioning, attention and frontal lesions in patients with chronic closed head injury. Journal of Clinical and Experimental Neuropsychology 22, 325–338.

Tyler, N., Wainstein, M., 2007. An accessible interface for a mobile phone-based travel information system. In: Proceedings of the First International Conference on ICT & Accessibility, April 12–14, Hammamet-Tunisia.

Werner, S., Krieg-Brückner, B., Mallot, H., Schweizer, K., Freksa, C., 1997. Spatial cognition: the role of landmark, route, and survey knowledge in human and robot navigation. In: Informatik '97, pp. 41–50.

Wilkniss, S.M., Jones, M.G., Korol, D.L., Gold, P.E., Manningal, C.A., 1997. Age-related differences in an ecologically based study of route learning. Psychology and Aging 12, 372–375.

Wilson, B.A., Emslie, H.C., Quirk, K., Evans, J.J., 2001. Reducing everyday memory and planning problems by means of a paging system: a randomized control crossover study. Journal of Neurology, Neurosurgery and Psychiatry 70, 477–482.

Yasuda, K., Misu, T., Beckman, B., Watanabe, O., Ozawa, Y., Nakamura, T., 2002. Use of an IC recorder as a voice output memory aid for patients with prospective memory impairment. Neuropsychological Rehabilitation 12, 155–166.