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User Requirement Analysis for Smart Voice Technology for Older Adults with Visual Impairments

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ABSTRACT
Although many users adopt voice-enabled technology today, there is lack of understanding on voice technology designs suitable for older adults with visual impairments. This study aims at investigating the auditory information processing capability of older adults with visual impairments and their preferences for voice user interfaces and interactions. A convenience sampling method recruited 20 older adults with visual impairments. The auditory information processing capability was measured with a word memory span task, and the Wizard-of-Oz method helped to explore user requirements for voice technology. The word memory span was 3.00 ± 0.34, which leads to the recommendation that information architectures include no greater than three layers of horizontal or vertical menu structures. The majority of the participants (75%) preferred the combination of inbound and outbound calls to interact with the system, and 65% appreciated the interactive, structured navigation menu user interfaces that empower the user to control the system. The study contributes to user-friendly voice technology for older adults with visual impairments.

1. Introduction

1.1. Voice-enabled technology

Today, the popularity of voice-enabled technology such as smart speakers and smartphone voice assistants emerges and is expected to continue to grow. A recent report (Newman, 2019) indicates that 14% of U.S. households have one or more smart speakers such as Echo, Google Home and Apple HomePod. Voice technology has been used for various purposes including self-care. For instance, the voice technology has been proven effective in improving a range of health outcomes, including diabetes (Kulnawan et al., 2011), medication compliance (Reidel et al., 2008), smoking cessation (McNaughton et al., 2013), substance abuse (Possemato et al., 2012), alcohol (Gail L. Rose et al., 2012), and health literacy (Bosworth et al., 2009; Long & Gambling, 2012; Walker et al., 2010). The voice technology is also beneficial to older adults who have visual impairments (i.e., residual vision and blind) as it can deliver information via voice user interfaces instead of graphical user interfaces (Kim, 2018, 2019). The voice technology typically assists users through a series of pre-programmed prompts by recognizing human voice and responding accordingly.

1.2. User interactions with voice user interfaces

Users can experience the voice technology via various types of user interactions and interfaces. The voice technology can call a user (i.e., outbound calls) or a user can call the technology (i.e., inbound calls). By using voice recognition and commands, users can manage personal information (e.g., keeping a record of his/her own daily food intake, physical activities, and medication adherence) and accordingly receive a customized intervention (e.g., a personalized self-care advice). As summarized in Table 1, the in- and out-bound call systems incorporate various voice user interfaces to interact with users.

1.3. Lack of consideration of individual differences on auditory information processing

There is lack of understanding on user interface and interaction designs of the voice technology suitable for older adults with visual impairments. Poor user experiences of the voice technology can be caused by less user-friendly information architecture – e.g., long menus, unclear instructions, difficulty in recovering from mistakes, and confusing shortcuts in the systems (Miller et al., 2011). It is critical to ensure that information architecture is well designed to accommodate an individual's capability of processing auditory information. Human Information Processing (HIP) is a theoretical framework used to explain how people receive, store, integrate, retrieve, and use information (Wickens, 1999). It is well documented that each individual has different capabilities for information processing, which is influenced by memory span (Baddeley, 2007; Johnson-Laird, 1983; Mayer et al., 2001). Memory span is a term in psychology and neuroscience to describe the longest list of items that an individual can

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Table 1. Voice user interactions and interfaces.

User interactions and interfaces		Descriptions
Inbound calls	User participation in a simple survey (e.g., Yes/No)	Users initiate a conversation with the voice-enabled technology (i.e., inbound call) and participate in a simple survey (e.g., Have you taken a medication?) via a simple response (e.g., yes or no) (Lindsay et al., 2014).
	User's voice messages	After connecting with the technology via the inbound call, users leave a message to update personal information (e.g., drinking episode) (Helzer et al., 2008).
	User's voice messages and system's feedback	Given users' self-reports, the voice technology provides preprogrammed feedback, e.g., advice on alcohol consumption or drug use (Gail L Rose et al., 2015) and also provides users with advanced features, such as *Weekly Caregiver's Conversation* to leave messages; *Personal Mailbox* to communicate with a clinical nurse specialist or share confidential messages; and *Bulletin Board* (i.e., a computer chat group) to interact with other users anonymously (Mahoney et al., 2003).
Outbound calls	System's messages (i.e., listen only mode)	The system initiates a conversation by contacting users (i.e., outbound call) to deliver a simple message (e.g., encouraging prompts) without any further user interaction (Derose et al., 2013), to deliver a reminder of refilling the prescriptions (Reidel et al., 2008), and to increase medication adherence (Stacy et al., 2009).
	System's invitation to a simple survey (e.g., Yes/No)	The system contacts users to conduct a simple survey, for example, by asking whether users had fallen in the past (Albert et al., 2015) and whether users had taken a drug (Shet et al., 2014). Given user responses to the simple survey, the system provides users with a health behavior message (e.g., physical activity and dietary messages) once a week (Estabrooks & Smith-Ray, 2008).
Combination of inbound and outbound calls		The system can also be programmed to call a user (i.e., outbound calls) to deliver health information (e.g., patient education of the benefits and risks of a certain therapy) and, if no one answered, a voicemail message with a toll-free number can be left to encourage the user to call back (i.e., inbound calls) and retrieve the health information (Cizmic et al., 2015).

repeat back in correct order immediately after presentation (Blankenship, 1938).

Individual differences in memory span are found among people with various visual acuity levels. For example, people with congenital blindness tend to have greater semantic and episodic memory as compared to sighted people (Pasqualotto et al., 2013). Individuals with blindness showed a better performance on a short-term memory test as compared to their sighted peers (Pigeon & Marin-Lamellet, 2015; Rokem & Ahissar, 2009; Withagen et al., 2013). Such individual differences are also observed within the group of individuals with visual impairments; in that, early-onset blind individuals are more likely to have greater arithmetic and working memory capabilities compared to late-onset blind individuals (Dormal et al., 2016). Yet, when more complex tasks are involved for memory span testing, a contradictory result is found – i.e., there is no significant difference on memory span between sighted and visually impaired people (Cornoldi & Vecchi, 2000; Rokem & Ahissar, 2009; Swanson & Luxenberg, 2009). For instance, the empirical study by Wan et al. (2010) uncovered that when participants were asked to differ between the first and last tones of sound among a series of tones, the performances between visually impaired and sighted participants were not significantly different. Pigeon and Marin-Lamellet (2015) also found no significant difference between early- and late-onset blind participants on working memory capability testing.

Individual difference in information processing can also be influenced by aging (Bopp & Verhaeghen, 2005). Younger adults can recall significantly more chunks of information than older adults (Naveh-Benjamin et al., 2007). Older adults tend to have poorer immediate recall for language and have a difficulty binding words together to form multi-unit chunks because a deficit in memory for spoken language is likely to be associated with an age-related decline in the working memory capacity measured in chunks (Gilchrist et al., 2008).

Furthermore, there is lack of understanding of the combined effects of memory span, aging, and visual impairments. While memory span is likely to be decreased due to aging in general populations (i.e., sighted individuals), it is not clear yet as to the degree to which memory span is likely to be decreased in older adults with visual impairments. As the underlying mechanisms are unclear about the combined effects of visual impairments and aging on memory span of auditory information, researchers and professionals are likely to encounter a challenge with developing a user-centered design of voice technology suitable for older adults with visual impairments.

This study aims to investigate the memory span of older adults with visual impairments (e.g., residual vision and blindness) and to explore user-friendly voice technology designs for them.

2. Methods

2.1. Participants

A convenient sampling method recruited 20 older adults with visual impairments (see Table 2) who have visual acuity worse than 20/70 (World Health Organization, 2008). To ensure the visual acuity, each participant's visual acuity was measured with a Snellen eye chart (Falkenstein et al., 2007).

2.2. Procedure

2.2.1. Word memory span

Word memory span testing was conducted based on the validated protocol of Daneman and Carpenter (1980) to examine the degree to which older participants with visual impairments correctly recall words. We prepared a series of two, three, four, five, and six words, which consisted of one- or two-syllable

Table 2. Characteristics of the participants

Participants	n = 20
Visual acuity	
Between 20/70 and 20/200	2
Between 20/200 and 20/400	11
Between 20/400 and 20/1200	1
Less than 20/1200, but has light perception	1
No light perception at all	5
Duration of visual impairments (years)	28.35 ± 23.04
Age (years)	72.85 ± 7.96
Gender	
Male	4
Female	16
Race/Ethnicity	
Black or African American	12
White	8
Marital status	
Married	6
Not Married	4
Widow/Widower	4
Divorced	6
Education	
High school or equivalent	7
Bachelors	7
Masters	5
Doctorate	1
Occupation	
Full time	1
Unemployed	6
Retired	13
Household income	
< 25,999 USD	8
26,000 USD – 51,999 USD	7
52,000 USD – 74,999 USD	2
≥ 75,000 USD	2
Declined to say	1

common nouns that were as semantically and phonetically unrelated as possible (La Pointe & Engle, 1990). Each participant was given three sets for each word memory span unit, i.e., two, three, four, five, and six words. We presented the word sets to a participant at a rate of one word per second. A participant was instructed to recall all of the words in the order of presentation. We informed a participant that the number of words (per each word memory span unit) would increase during the test session. When a participant recalled only two out of three sets, it was considered as his/her word memory span (Daneman & Carpenter, 1980).

2.2.2. User preferences

We investigated user preferences for voice user interfaces and interactions. This study relied on the qualitative analysis to obtain a more in-depth understanding of the user group's needs (Gerdes & Conn, 2001; Schirr, 2013), e.g., a participant was informed of different designs (e.g., auditory menu designs) and asked to choose his/her favorite design(s) and to state reasons for their choice(s). Team discussions (this paper's authors) ensured credibility; we met regularly as a group to reconcile individual ideas and resolve any emerging differences through negotiated consensus. Preference testing was administered via the Wizard-of-Oz method (Hanington & Martin, 2012). The Wizard-of-Oz method is to evaluate a prototype with fake user interactions; for example, user interactions are accomplished via a human control rather than a computer (e.g., algorithms or software codes). This study focused on a voice (non-graphical) technology such that a tangible user interface prototype was not necessary. This study did not aim to design the user interfaces of the hardware (e.g., a smart voice speaker's plastic case design); thus, this study did not involve a smart speaker hardware prototype. Voice user interfaces in this study were simulated by the research team's voice. Research participants experienced the voice user interfaces by listening to the menus, choosing one of them, and so on. As there were no high-fidelity, fully working prototypes, participants might have somewhat relied on his/her imagination.

Firstly, a participant was informed of a scenario of use, i.e., there is a personal health record (PHR) system in which users can maintain and manage their health information in a private, secure, and confidential environment; the PHR system is accessible to users via voice technology (e.g., smartphone); voice user interactions include (a) an inbound call (e.g., The inbound call allows a user to initiate a call to communicate with the system), (b) an outbound call (e.g., A user receives a call from the system and is not allowed to initiate a call), (c) a combination of inbound and outbound calls, (d) an interactive multi-level menu mode (e.g., Menus are hierarchically organized, allowing navigation through different levels of the menu structure. A user is empowered to control and select one of "parent" menu items, followed by expanding it to present its child menus (i.e., a second level, a third level, and so on) with options or other commands related to the selected item), (e) a yes/no simple menu mode, and (f) a "listen-all-menu" mode. A participant was instructed to work through the different designs of user interactions in a random order and choose his/her favorite design(s).

Secondly, as the Wizard-of-Oz experiment continued, a participant was also instructed to assume that he/she was successfully able to connect with the PHR system via voice-enabled technology and just about to retrieve personal health data. A participant was then given the following three user interface designs in a random order and asked to choose his/her favorite design(s) – i.e., a user is informed of the personal health data categorized by (i) activities of daily living; (ii) timeframe in which the data were collected; and (iii) simply listening to all data available at once.

3. Results

3.1. Word memory span

The word memory span was, on average, 3.00 (SD = 0.34). As shown in Table 3, the majority of the participants were able to recall up to 3 words. Yet, a few participants could recall up to 4 words, i.e., two participants recalled a single set of 4 words while one participant recalled two sets of 4 words.

Table 3. Word memory span.

The number of words successfully recalled (at least two of three sets)	n	%
Up to 2 words	20	100%
Up to 3 words	19	95%
Up to 4 words	3	15%

Table 4. User preferences for user interaction.

User interactions		n	%
Connection method	Inbound call	5	25%
	Outbound call	0	0%
	Combination of inbound and outbound calls	15	75%
Voice menu	Interactive multi-level menu	12	60%
	Listen-all-menu	6	30%
	Yes/No simple menu	2	10%

Table 5. User preference for data access.

	Participants who prefer the structured information architecture		Participants who prefer the unstructured information architecture
Categorized	By the activities of daily living	By timeframe	Just listening to all data without any category
n	9	4	7
%	45%	20%	35%
Duration of visual impairments (yrs.)	36.60 ± 24.50		13.00 ± 8.22

3.2. User preferences

3.2.1. User interaction with the system

As shown in Table 4, the majority of the participants preferred the combined interaction of *inbound and outbound calls*, followed by the interaction of *inbound call only*. However, none of the participants appreciated the interaction of *outbound call only* – i.e., a user receives a call from the system that does not allow a user to initiate a call. When the participants were instructed to assume that they were connected to the system, many of them would then like to interact with the system via the "interactive multi-level menu" mode, followed by the "listen-all-menu" mode and the "yes/no simple menu" mode.

3.2.2. User interface for data access

As shown in Table 5, nearly half of the participants preferred to be informed of the data categorized by *activities of daily living*, 20% *by timeframe*, and 35% *by listening to everything without any category*. In other words, the majority significantly preferred the voice user interfaces that provide users with *structured* information architecture as compared to *unstructured* information architecture.

The Welch's t-test found a statistically significant difference in the duration of visual impairments between participants who preferred structured and unstructured information architecture, t (15.60) = 3.21, p <.01. The duration of visual impairments of participants who preferred structured information architecture tend to be longer than that of their peers who preferred unstructured one.

4. Discussion

This study was undertaken to advance knowledge of the memory span of older adults who are visually impaired and user preferences for voice technology, leading to insights into user-friendly voice user interface and interaction designs which are likely applicable to many other voice technology applications including those in healthcare.

4.1. Word memory span

The word memory span (Mean = 3.00, SD = 0.34) of the older participants with visual impairments in this study is lower than that (Mean = 5.73, SD = 0.80) of sighted participants in Catinas' study (Catinas, 2017); however, it should be noted that the age of the participants in Catinas' study was younger (ranged from 50 to 70 years) than that (ranged from 65 to 91 years) in this study. Another study by Kim et al. (2008) conducted the word memory span testing with sighted participants whose age range (Mean = 72.10 years) is similar to that (Mean = 72.85 years) of this study. The word memory span of the older participants with visual impairments in this study is lower than that (Mean = 4.41, SD = 0.86) of sighted older individuals in the study by Kim et al. (2008); however, in Kim's study, a word memory span was defined as one in which an individual recalls a *single* set of words while this study relied on the scoring method of Daneman and Carpenter (1980) in which an individual should recall at least *two* sets of words. As a secondary data analysis, we used the scoring method of Kim's study and found that the word memory span (Mean = 3.11, SD = 0.46) of our older participants with visual impairments is still lower than that of sighted older individuals in Kim's study. Thus, it could be argued that the word memory span of older adults with visual impairments is likely to be shorter than that of their sighted peers.

The research findings of word memory span lead to the recommendation that the number of voice navigation menus be limited to three layers (e.g., horizontal or vertical navigation menu structures) as the older participants with visual impairments are likely to have a word memory span less than 4. If the menu structure goes beyond the memory span of the target user group, users would encounter a challenge in using the voice technology system.

From a theoretical point of view, memory capability is associated with short-term memory (e.g., maintenance of information) and working memory (e.g., manipulation of information) (Aben et al., 2012). The short-term memory is measured using digit span forward, name learning, and word span tasks while the working memory is measured using different methods such as listening span and digit span backward tasks (Cowan, 2008). As this study conducted the word span testing, the short-term memory was evaluated in the older participants with visual impairments. A future research will measure the working memory using the other methods (e.g., digit span backward task) to advance a comprehensive knowledge of memory capability of older adults with visual impairments.

4.2. User preferences for interaction with voice technology – in/outbound calls

The participants appreciated the inbound call system (i.e., users initiate to connect with the system) because they would like to control the system instead of being controlled by the system. On the other hand, participants who appreciated a combination of inbound and outbound call systems stated that they would not be reluctant to receive a call from the system (i.e., outbound calls), yet they emphasized the inclusion of the inbound call system because they would like to control the system and are less likely to adopt any technology that significantly interferes with their daily living activities. They would like to play an active role instead of simply waiting until they receive a call from the system, and they also shared the concern about the situation in which they may be in urgent need for speedy data retrieval.

Yet, after being connected to the system via the combination of inbound and outbound calls, their preferences for voice menu designs were divided in the following three groups. The first group of the participants appreciated an interactive multi-level menu option as they pointed out that not everything could be addressed by a simple menu option. They also argued that the simple menu option might be quicker; however, they still preferred the logical and well-structured user interaction. The second group would like to be given the listen-all-menus option even if the list of menus are lengthy because they would like to know what menus the system can offer; thus, after listening to all menus, they would choose a specific menu to proceed. The third group would like to have a simple menu option (e.g., a yes/no type of query)

4.3. User preferences for data access – information architecture designs

With regard to retrieving data from the system, the participants expressed three different preferences; that is, they would like to have data categorized by activity type and time or just listen to everything without any categorization.

4.3.1. By activity type

The participants would appreciate the system that could categorize the data by daily living activities (e.g., dressing, walking, eating, and so on) and inform a user accordingly; for example, "how far he/she went for walking" and "whether he/she took the medication." They anticipated that the updates should be available in real time whenever a user wants, but also available as a weekly summary to enable a user to compare with the history of daily living activities in the past. They also emphasized the efficiency of the system as they pointed out that a good voice technology system should deliver information quickly and directly to a user. They would like to avoid wasting their time in listening to all contents; therefore, they preferred a two-way communication mode to control the system (e.g., the provision of navigation menus). They valued the "interaction" between human and technology.

4.3.2. By time

Another group of the participants appreciated the system that could categorize the data by time and inform users accordingly. For example, the system briefs a user on what activities occurred within certain time frames such that a user obtains an overall sense of his/her daily living activity patterns, changes, and variability. They also suggested a hybrid format; that is, the system asks the user to choose both a particular time frame and data type, which will contribute to narrowing down the list of data to listen to.

4.3.3. By listening to everything

The other group of the participants argued that the more information the system could provide to a user will ultimately deliver a broader scope and deeper understanding, leading to a better decision by the user. They stated that the option of listening to everything is consistent with their mental model and decision-making process; that is, they typically hear everything and then make a decision. They noted another advantage that as a user may be unfamiliar with using the voice technology system, the user would not miss any critical information if he/she heard everything as a default setting. They also pointed out the efficiency, i.e. they would not like to interact with the system by answering questions that they are not interested in or providing information that the system is not interested in, therefore, they would like to listen to everything in the first place and control the system by using a control module (e.g., stop, play, pause, and skip), which those participants referred to as "user empowerment."

4.4. Relationship between user preferences and duration of visual impairments

Another finding is that the participants with longer duration of visual impairments (mean = 36.60 years) preferred more complex, structured information architecture as compared to their peers with shorter duration of visual impairments (mean = 13.00 years). It may be argued that such a long period of time would be sufficient for people with visual impairments to augment the ability of information processing and performing such complex tasks (e.g., comprehension and interaction with multiple navigation menus). From a theoretical point of view, people who become visually impaired are likely to benefit from a brain plasticity (also known as neuroplasticity) that enables the brain to access new pathways to overcome the visual challenge (Silva et al., 2018). For example, the brain would have the neurological changes to enhance connections between specific parts of the brain, leading to enhancement of the remaining sensory modalities (e.g., memory, listening, and touch) (Maguire et al., 2006). An empirical study (Pardhan et al., 2011) found that persons with longer duration of visual impairments showed non-significantly different performance outcomes in a complex task as compared to their sighted peers; on the other hand, persons with shorter duration of visual impairments (< 10 years) showed significantly poorer performance outcomes as compared to their sighted peers. The longer duration of visual impairments might have contributed to the outperformance. Thus, the participants with longer duration of visual impairments in this study might also have gained the benefits of brain plasticity and become comfortable with the complex interaction with the voice technology system. Future research will investigate further the brain plasticity and its relationship with user preferences between individuals with shorter and longer duration of visual impairments.

4.5. Limitations

It is well documented that humans are likely to recall better if they are given a list of semantically related words (as compared to unrelated words) (Kendler & Ward, 1972; Tse et al., 2011). Therefore, this study focused on exploring the memory span of older adults with visual impairments when given a list of unrelated words; therefore, their memory span would be anticipated to be greater when given a list of semantically related words. The future research will be conducted to study their memory span when given a list of semantically related words. With regard to practical implications, user interface designers could still refer to the findings of this study when designing the voice menus. For example, designers may design the voice menus that contain semantically closely related words only; however, they may also result in using a list of (partially or fully) unrelated words to design the voice menus, which would probably be caused by various factors associated with the target users, information to be presented, and system specifications. Thus, our research findings will be useful in that context despite the study limitation using the unrelated words only. As the word span testing contributed to measuring the short-term memory only, our future research will measure the working memory using the other testing methods (e.g., digit span backward testing) to advance a deeper understanding of memory capability of older adults with visual impairments. Another limitation is related to the Wizard-of-Oz method. As participants did not experience a high-fidelity, fully working prototype, they might have somewhat relied on his/her imagination and affected the results. Our future research will include a high-fidelity prototype.

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