DEVELOPMENT AND EVALUATION OF AN ASSISTIVE PROMPTING SYSTEM FOR PEOPLE WITH TRAUMATIC BRAIN INJURY

by

Jing Wang

B.S., Xi'an Jiaotong University, 2009

M.S., Xi'an Jiaotong University, 2011

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This dissertation was presented

by

Jing Wang

It was defended on

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and approved by

Dan Ding, PhD, Associate Professor, Department of Rehabilitation Science and Technology

Rory Cooper, PhD, FISA/PVA Chair, Distinguished Professor, Department of Rehabilitation Science and Technology

Michael McCue, PhD, Professor and Vice Chair, Department of Rehabilitation Science and Technology

Pamela Toto, PhD, OTR/L, Assistant Professor, Department of Occupational Therapy

Jodi Forlizzi, PhD, Professor, Human-Computer Interaction Institute, Carnegie Mellon University

Dissertation Advisor: Dan Ding, Ph.D., Associate Professor, Department of Rehabilitation Science and Technology

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Cognitive deficits in executive functioning are among the most frequent sequelae after traumatic brain injury (TBI) at all levels of severity. Due to these functional deficits in cognition, individuals with TBI often experience difficulties in performing instrumental activities of daily living (IADL), especially those IADLs that involve a sequence of goal-directed actions. We obtained updated information on the use of assistive technology for cognition (ATC) through a survey study among twenty-nine participants with TBI. Results highlighted the needs to support the development and evaluation of ATC in assisting multi-step tasks. Cooking tasks were selected as a representative for they are cognitively demanding and have been identified essential for living independently. With the recent advance in sensing and smart home technologies, it's possible to provide context-aware prompts with minimal user inputs. However, limited information is known regarding what types of context-aware prompts are really needed by people with TBI in completing cooking tasks. We compared the effectiveness and usability of current available prompting methods (e.g. paper-based prompting method and user-controlled method) among ten individuals with TBI in their home kitchens. We categorized the nature of problems faced by end-users with both prompting methods in cooking tasks and proposed relevant context-aware solutions. A test-bed Cueing Kitchen with sensing and prompting elements was developed to address these identified needs and to evaluate the feasibility of context-aware ATC interventions in assisting people with TBI with kitchen activities. Sixteen

individuals with TBI participated in the study. Results showed that comparing to the conventional user-controlled method, the automatic method decreased the amount of external assistance required by participants, received higher ratings in perceived ease-of-use, and was helpful for decreasing user stress levels. However, the user-controlled method showed strengths in offering participants more flexibility and control on the timing of prompts. The contributions from this dissertation not only developed a context-aware prompting testbed and evaluated the feasibility of an automatic system, but also advanced the guidelines and potential solutions for future development of assistive prompting technology for people with cognitive impairments in sequential tasks.

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PREFACE

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1.0 INTRODUCTION

1.1 BACKGROUND AND RELATED WORK

1.1.1 People with traumatic brain injury

Approximately 1.7 million people in the United States sustain a traumatic brain injury (TBI) each year [1]. Mild TBI is also a high-frequency injury among combat veterans [2]. Functional limitations associated with cognition (e.g., attention, memory, and executive functioning) are among the most frequent sequelae after TBI of all levels of severity [3, 4]. One of the most significant cognitive deficits after TBI is in the complex area of executive functioning. The key components of executive function include anticipation, goal selection, planning, initiation, sequencing, monitoring (error detection), and self-correction (initiation of novel responses) [5] . These are all necessary for carrying out goal-directed activities successfully in unstructured real-world settings. Impairments in executive functioning include lost or diminished cognitive regulation, decreased ability in initiating self-directed behaviors, impaired sequencing, poor error detection, and cognitive inflexibility with failure to self-correct [5-7]. Some individuals, for example, have great difficulty initiating self-directed behaviors but are able to carry out most behaviors successfully once cued to initiate them. Others may initiate easily but guide and regulate themselves poorly during the execution of behaviors [5]. Individuals with TBI may also have impaired self-monitoring or self-control when completing tasks and may display under-confidence or over-confidence with their ability to complete certain activities [8-10] These individuals may experience difficulties due to many of the consequences of lack of insight or practical goals, especially in an unstructured world [5]. For example, when trying to follow a written and carefully sequenced "to do" list, individuals with TBI may not have the insight to recognize the fact if novel and unstructured situations arise to adapt their actions if the list does not apply.

Due to these functional deficits, individuals with TBI often experience difficulties in performing instrumental activities of daily living (IADL), especially those IADLs that involve a sequence of goal-directed actions such as cooking and vocational tasks [11, 12]. In addition, severe cognitive deficits often necessitate a high degree of personal care and support [13, 14], and have been associated with a diminished quality of life, poor self-esteem, and social isolation in people with TBI [15, 16].

1.1.2 General ATC use in people with cognitive impairments

Compensatory strategies are often recommended to help people with TBI cope with their cognitive deficits. These strategies include internal strategies (such as visual-association techniques for remembering names), external aids (such as calendars, notebooks, and electronic organizers), and environmental adaptations (such as labeling cabinets) [17]. External aids often termed as Assistive Technology for Cognition (ATC) or “cognitive orthosis”, are tools or devices that either limit the cognitive demands of a task or transform the task or environment to match the users’ abilities [18, 19]. Over the past two decades, the use of ATC has evolved into an effective and widely used intervention for cognitive impairments after TBI [19-23]. Some evidence suggests that the use of ATC could improve performance and community participation of people who have cognitive impairments [24-26].

A variety of types of ATC have been documented in the literature as potentially helpful for people with cognitive impairments. For example, some low-tech ATC like paper-pencil materials and daily planners are often recommended interventions [27-29]. However, most low-tech ATC are effective only when users remember to look in the planner to review their reminders and are used more in scheduling. In contrast, with the development of technology, some high-tech ATC uses an external device such as a computer or portable device (e.g., smart phone) to provide scheduling services that remind users to perform a task or sequencing services that guide users in the performance of a task.

The majority of existing ATC are scheduling devices [12]. The main use of these cognitive aids is to support prospective memory functioning. Most studies have investigated whether the device improved specific target behaviors, such as remembering to take medication on time and keeping track of appointments. Less focus has been given to sequencing devices [12]. A number of commercial products and research prototypes have been developed to provide reminders of scheduled events, and only a handful of available devices and systems address sequencing issues [18].

1.1.3 ATC for sequencing multi-step tasks

ATC that support memory and executive functioning can either remind a person to perform a task at an appropriate time or guide a person to carry out a sequence of steps for a complex task.

Most sequencing devices operate in an open-loop fashion by requiring users to monitor their own progress and provide feedback to the device such as pushing a button on the device after a step has been completed or when they need more detailed instructions [30]. Memory Aiding Prompting System (MAPS) [31] enables users to create a sequence of primarily visual prompts on a desktop computer. The prompts are then loaded onto a portable digital device and, once being activated, the system prompts the user step-by-step through the given task. Users respond by pressing buttons on the device. Other commercial products (e.g., Visual Assistant [32] and iPrompts [33]) and most research prototypes for sequencing assistance also work in a similar fashion. Davies et al. conducted a study on the effectiveness of Visual Assistant in assisting ten individuals with mental retardation to complete two vocational tasks [34]. Participants received training on the two tasks prior being tested with and without Visual Assistant. The results showed that the average error per task dropped from 2.25±2.05 without Visual Assistant to 0.75±0.83 with Visual Assistance. Though the results were overall positive, the authors commented that ease-of-use of the device should be improved. Kirsch et al. evaluated an interactive computer-assisted compensatory cueing system against written instructions in assisting four individuals with TBI to perform a simulated multi-step janitorial task [35]. Two of the four participants improved their performance with 17% to 20% increase in steps completed correctly. The other two participants did not show improvement. The authors recommended that careful considerations must be given to the range and severity of cognitive deficits that a patient experiences and future work is needed to determine whether any specific patterns of deficits are more or less likely to respond to these types of cueing techniques [35].

With the recent advance in sensing and smart home technologies, it is possible to infer context (i.e., information that can be used to categorize the current situation of a user) based on sensors embedded in the environment, which can enable a sequencing device to provide context-based prompts automatically with minimal user input. One of them is the Cognitive Orthosis for Assisting Activities in the Home also known as COACH that employed computer vision and artificial intelligence (AI) techniques to autonomously provide users with dementia verbal and/or visual prompts during a hand-washing task. It uses artificial intelligence algorithms and a video camera to monitor user progress, determine context, and provide pre-recorded verbal prompts when necessary. It also has the ability to adjust the details provided in the verbal cues based on user responses. They have evaluated the system among six participants with moderate-level dementia and found that when with the COACH system, subjects were able to complete an average of 11% more hand-washing steps independently and required 60% fewer interactions with a human caregiver. Four of the participants achieved complete or very close to complete independence [36, 37].

Chang et al developed a context-aware prompting system Kinempt for sequential vocational tasks based on the gesture recognition using Kinect [38, 39]. The Kinempt system was deployed in a way that mimicked a local pizza chain store that provided short order food preparation training to adults with cognitive impairments. A PC running the task prompting software was set up to work with a Kinect. The sequence of user gestures was compared step-by-step to the routine sequence of vocational task analysis. If steps in the task analysis were not followed, the Kinempt system would deliver an alert in text, sound, picture or a combination of the above. If a gesture was recognized as a correct task step, the cue for the next task step would be prompted. Two participants with cognitive impairments participated in the study to complete a 6-step task, i.e., preparing a vegan pizza. The study was carried out according to an ABAB sequence in which A represented the baseline and B represented the intervention phases. Data showed that the two participants significantly increased their success rate (56% and 70% success rate for the two A phases increased to 100% for both B phases). Thus, their vocational job skills were improved during the intervention phases [39].

Peters et al developed a context-aware prompting system named the TEeth BRushing Assistance (TEBRA), which provides assistance in the execution of brushing teeth by offering audio-visual prompts to users with moderate cognitive impairments [40]. The TEBRA system infers a user's behaviors based on the states of objects manipulated during the behaviors and deals with the temporal variance by using a dynamic timing model that is automatically adjusted during a trial. The evaluation study was conducted with seven individuals with cognitive disabilities. The study data comprised 20 trials with a caregiver's assistance and 35 trials with the TEBRA system's assistance. The results showed that all participants were able to perform significantly more independent steps of the tooth brushing task with the TEBRA system compared to only with a human caregiver.

Another system is the General User Interface for Disorders of Execution also known as GUIDE that simulates normal conversational prompting to provide task guidance [41]. It prompts users, asks users questions, and accepts verbal responses instead of requiring users to provide feedback to the device by pressing buttons. O'Neill et al. evaluated the GUIDE in assisting eight amputees with cognitive impairment of vascular origin to put on their prosthetic limbs. The overall safety critical errors dropped from 2.22 ± 1.71 to 0.94 ± 1.48 with six of the eight participants showing statistically significant benefits.

1.1.4 Smart kitchen work

Kitchens are places where humans perform important everyday multi-step activities like cooking, cleaning, and dining that contribute to their health and well-being. Cooking tasks are cognitively demanding and have been identified essential for living independently and important for an individual's health, accomplishment in social roles, self-esteem, and sense of control [42-44]. Kitchens are also critical places for peoples' safety, especially for people with cognitive impairments. Most domestic injuries are related to working in the kitchen: kitchen tools, cutlery and household appliances are potentially dangerous utensils [45]. With the current sensor technology and smart home development, more and more research has been moved to kitchens. Different sensors and algorithms are being used in kitchen environments on activity recognition and context-based prompting. Blasco et al. developed a smart kitchen for ambient assisted living of the elder population [45]. Their kitchen implemented standard sensors (gas, fire, smoke, flooding), magnetic sensors, light sensors, and presence sensor, to provide information and warnings about the use of household appliances and to detect routine changes in the kitchen. Lei et al. used a RGB-D camera (modern depth cameras that provide synchronized color and depth information at high frame rates) to identify activity and tools used in the kitchen (between a selected group of 35 objects and 25 actions) [46]. The system is capable of identifying objects with an accuracy of 60% and activities with an accuracy of 82%. Coronato and Paragliola presented an approach for the modeling and detecting dangerous situations in kitchens using RGB-D cameras and wearable accelerometers [47]. The anomalous classification algorithm was based on events frequency, location, timing, and duration information collected by sensors in the kitchen. Wu and Tsai analyzed user motions and actions involved in the process of cooking (e.g.

Cut, fry, and relevant sub-actions) for a smart kitchen system [48]. They used a RFID system, green stickers on cooking utensils, and video cameras to record cooking sections and tried to discover multiple action identification characteristics through video analysis. Space and time differences were also used as clues to help identify a list of action items.

Some other smart kitchen studies focused primarily on developing smart tools in the kitchen, which enable users to cook easier and healthier. Ficocelli and Nejat developed an assistive kitchen with speech communication and an automated cabinet system to help with storing and retrieving items and obtaining recipes for meal preparation [49]. Qureshi et al used RFID tags and weight sensors to develop smart containers, smart surface, and actuators. Applications were designed to assist with recipe recommendation, expiry control, and nutrition planning using smart objects [50]. There are also several smart kitchen services like Nutrition-Aware Cooking that senses cooking activities and presents nutritional information in real-time to persuad family cooks to make informed decisions [51, 52]; Diet-Aware Dining Table that tracks the nutritional intake of persons dining on it and presents such information for encouraging healthy eating habits [53].

1.2 PROBLEM STATEMENT

From the literature, we find that few studies looked into the opportunity to integrate inferred context, which is based on embedded sensors in the environment, to enable automatic prompts for multi-step cooking tasks. The types of context-aware prompts that are really needed for people with TBI in completing cooking tasks are still unknown. There may be several reasons.

First, there are still technical challenges in developing a reliable and accurate context-aware system [36, 54-56]. Second, research in context-awareness is mostly done in the field of computer science focusing on computer vision and algorithm development without concerns on applying them to applications that serve user needs. Thus there is limited information available regarding how to achieve a balance between practicality of implementation/deployment and effectiveness in assisting users.

People have argued that ATC has the potential to reduce the load of care-givers and the cost of care while also increasing independent activity and self-confidence of end-users [18, 57]. However, ATC have yet to achieve this promise. Problems include not only the novelty or complexity of ATC for people with cognitive impairment, but also mismatch between the user's cognitive profile and the prescribed ATC [18, 30, 57]. Researchers in ATC call for "matching user demands and suitable technology to optimize the therapeutic effect." [58]. It is also not clear yet to what extent a context-aware sequencing device would enhance user performance in carrying out a sequence of goal-directed actions and how individuals with TBI at different levels of severity would respond to such a device [59].

1.3 AIMS AND DISSERTATION STRUCTURE

This dissertation has three primary aims. First of all, we want to identify end-users difficulties in multi-step kitchen tasks and specific needs for sequencing prompting devices among people with TBI. The second aim is to develop a context-aware prompting testbed using smart home technology, which can provide a platform to evaluate different types of prompting methods among people with cognitive impairments. The third aim is to evaluate the advantages and feasibility of an ideal automated sequencing device as compared to commercially available user-controlled method in assisting people with TBI in cooking tasks. We examine the adequacy of using low-cost sensors for improving prompting effectiveness of conventional ATC, extract justifications for context-aware ATC, and propose guidelines for the future ATC development for people with different neuropsychological characteristics.

This dissertation includes six chapters:

Chapter 1 provides background information and introduction to this dissertation.

Chapter 2 discusses the updated information we obtained on the use of assistive technology for cognition (ATC) through a survey study among twenty-nine participants with TBI. Results highlighted the needs to support the development and evaluation of ATC in assisting multi-step tasks. This chapter addresses the first aim.

Chapter 3 compares the effectiveness and usability of the traditional paper-based prompting method and commercially available user-controlled methods among individuals with TBI in their home kitchens. We also categorized the nature of the problems faced by end-users when performing multi-step activities with current available prompting methods and proposed relevant context-aware prompting solutions. Results inspired the development of the Cueing Kitchen testbed and the automatic prompting system. This chapter addresses the first aim and builds design criteria for the second aim of this dissertation.

Chapter 4 introduces the design and development of the Cueing Kitchen testbed. With the recent advance in sensing and smart home technologies, Cueing Kitchen is developed to address the identified needs and to evaluate ATC interventions in assisting people with TBI with kitchen activities. The automatic prompting system is built on this testbed, which can provide context-based prompts automatically with minimal user input. This chapter addresses the second aim.

Chapter 5 evaluates the feasibility of a context-aware automatic prompting system built in the Cueing Kitchen test-bed with a user-controlled method among sixteen participants with TBI. Participants' performance and subjective feedback were compared with both methods. The relationship between participants' neuropsychological characteristics and their responses to different levels of assistive interventions were also discussed in this chapter. This chapter addresses the third aim of this dissertation.

Chapter 6 summarizes the contributions of this dissertation and discusses the implications regarding future research on assistive prompting systems for people with cognitive impairments.

2.0 USE OF ASSITIVE TECHNOLOGY FOR COGNITION AMONG PEOPLE WITH TBI: A SURVEY STUDY

2.1 BACKGROUND

Each year approximately 1.7 million people in the United States sustain traumatic brain injuries (TBI) [1]. Mild TBI is a high-frequency injury among combat veterans and non-deployed military service members are also at an increased risk of TBI due to intense, and often hazardous, training exercises [2]. Functional limitations associated with cognition (e.g. attention, memory, and executive functioning) pose practical hurdles for individuals with TBI with respect to performing activities of daily living (ADLs) [11, 60]. Compensatory strategies, especially external aids, Assistive Technology for Cognition (ATC) are often recommended to help people with cognitive impairments [61]. In clinical practice, the use of ATC has been widely considered most useful interventions for people with cognitive impairments after TBI [19-23].

According to a survey conducted in 2003 by Evans et al. on individuals with TBI, paper-based calendars, wall charts, and notebooks were the most commonly used ATC, while electronic aids (in particular, portable electronic ATC) were rarely used [61]. The authors speculated that the main reason for the infrequent use of electronic aids could be that they were too complicated to use and were infrequently recommended by rehabilitation professionals. Another survey conducted among individuals with TBI in 2004 agreed with the findings of the

2003 survey [62]. Studies also showed that in clinical practice, traditional ATC such as paper-pencil materials and daily planners were the most commonly recommended interventions for people with TBI [27-29]. These results may have been due to the availability and limited function of electronic devices at that time. However, most of the traditional ATC only provides passive engagement and is very limited in its capability. Moreover, most of such ATC is mainly applicable for tasks such as scheduling. In the last decade, the increasingly popular portable electronic devices (e.g. smartphones and smart pads) along with applications (apps) have transformed how people now engage in daily life activities, and the Prosthetic Clinical Management Program of the Department of Veterans Affairs has established clinical practice recommendations for electronic cognitive devices [63]. However, to our best knowledge, there are no published studies that provide an update on the use of portable electronic ATC among people with TBI in the last decade. The usability, service delivery process, and user satisfaction with these portable electronic ATC still remain unknown [24-26, 29].

Hart et al (2003) conducted a survey study among 81 TBI clinicians to examine experiences and expectations of clinicians as to uses of portable electronic devices as cognitive-behavioral orthosis in TBI rehabilitation. Respondents expressed low confidence overall in their ability to guide clients in use of such devices. Both low level of exposure to clients using portable technology and lack of personal use of portable computer technology were strongly related to their low confidence level. Results of this study indicated that clinicians perceived significant potential for portable electronic ATC, but clinical applications may be limited by costs of the technology and low clinician confidence with respect to using it [64]. Given the challenges of incorporating emerging technologies into TBI rehabilitation for clinicians, end users, and family members, up-to-date information about how people with TBI are using ATC, especially portable electronic ATC, is essential. The process of assessing end users' needs, preferences, and self-perceptions has also been emphasized as being important for selecting and supporting the long-term use of assistive technology and preventing device abandonment [57].

In this study, we designed and administered a survey to assess ATC use among veterans with TBI, especially the use of portable electronic devices together with apps. The aim of the survey was to obtain information on current ATC devices and applications used by veterans with TBI. The survey also collected information on users' experience with different features of ATC and their experience with training and support for their ATC. We expected to discover ADL areas where currently available ATC is not meeting user needs and inform future directions in ATC development.

2.2 METHODS

The study was approved by the Department of Veterans Affairs Institutional Review Board. It was conducted at the 26th annual National Disabled Veterans Winter Sports Clinic (NDVWSC), convened in April of 2012 at Snowmass Village, Colorado. Approximately 400 veterans participated in this event. The NDVWSC is an adaptive winter sports event for U.S. military veterans and active duty service members with disabilities, including traumatic brain injuries, spinal cord injuries, orthopedic amputations, visual impairments, certain neurological conditions and other disabilities. Participants in NDVWSC learn to develop sports skills and take part in a variety of adaptive sports workshops.

2.2.1 Participants

Research participants were recruited from participants of the 26th annual NDVWSC. Individuals were included in the study if they were over the age of 18, English speaking, and self-reported a diagnosis of TBI. Twenty-nine individuals enrolled in this study.

2.2.2 Survey instrument

The survey instrument was developed by the author and reviewed by three experts in occupational therapy and rehabilitation sciences. The survey had three parts (appendix A). Part one contained a series of demographic questions. Questions assessing personal traits and readiness to use technical support were included in from Section C of the Assistive Technology Device Predisposition Assessment [65]. Part two contained questions designed to identify the areas that the participants had difficulty with and the types of ATC participants used in these areas. Participants rated their difficulties in eight areas using a 4-point scale (1=no challenges, 2=minor challenges, 3=moderate challenges, and 4= serious challenges). The eight areas included: keeping track of appointments and events, performing multi-step tasks, keeping track of medications, staying focused on a task, remembering names and faces, locating items, managing emotion, and navigating paths. Participants also rated the impact of these difficulties on their quality of life using a 4-point scale (1=not at all, 2=a little, 3=a moderate amount, and 4= a great deal). Part 3 asked the participants to review the ATC they were using. The first set of questions centered on participants' opinions with respect to perceived usability of the reported ATC. Nine statements regarding perceived usability were adapted from the Assistive Technology

Device Predisposition Assessment [65], where the participants rated these statements using a 5-point Likert scale (1=never and 5=all the time). The higher score (with the maximum score of 45) indicated greater usability and user satisfaction. Next, participants' feedback and insights on ATC features were obtained through six semi-structured interview questions. Participants then were required to respond to questions about where they had acquired their ATC. Finally, they responded to multiple-choice questions about the training experience with their ATC, including the availability of relevant training, the length of training, and the perceived helpfulness of training. Participants rated the helpfulness of the training received using a 5-point Likert scale (1=not at all helpful and 5=extremely helpful). Participants were allowed to report on more than one ATC if they were using more than one.

2.2.3 Procedures

Before administering the survey, the investigator explained to each participant the purpose and overall procedures of the study. After signing the informed consent, participants were surveyed individually in a face-to-face meeting with one of the investigators, all of whom had been trained to communicate with people with disabilities. For participants who had reading or writing difficulties, the questionnaire was read aloud by the investigator and the answers were checked according to the participants' choices.

2.2.4 Data analysis

Descriptive statistics were performed on all variables, including mean and standard deviations for continuous data and frequencies for categorical data. Participants were considered to have difficulties in an ADL area if they reported minor, moderate, or severe challenges with that specific ADL area. Participants' quality of life was considered to be "significantly" affected by their difficulties in an ADL area if they reported that the effect was a moderate amount or more. The overall score of perceived usability of an ATC was obtained by first adding user responses for each statement and then converting the total responses to a scaled score ranging from 0 (the most negative experience) to 1 (the most positive experience). Content analysis of participants' answers to the interview questions related to user preferred features and barriers of ATC were performed by two investigators independently and final agreement was reached on the extracted themes.

2.3 RESULTS

2.3.1 Demographic and psychosocial characteristics of the sample

Twenty-nine veterans participated in this study. Their demographics characteristics are shown in Table 1. The participants had a mean age of 43±11.4 years and were primarily male, Caucasian, and living with family members or significant others. More than half of them were from the Army branch of service and their average duration of military service was 7 years. Eighteen out of the twenty-nine participants (62.1%) did not have undergraduate degrees. Only 4 participants were full-time or part-time employed. Seventeen participants had caregivers. Regarding the psychosocial characteristics, most participants reported a positive mood state and higher than average levels of autonomy, self-determination and self-esteem.

Table 1. Characteristics of the sample (n=29)

Variables		n (%) mean ±SD
Age		42.7±11.4
Gender	Male	20(69)
	Female	9(31)
Racial	Caucasian	22(75.9)
	African American	2(6.9)
	Hispanic	2(6.9)
	Two or more races	3(10.3)
Education	<12	18 (62.1)
(years)	12	4 (13.8)
	>12	7(24.1)

2.3.2 ATC use in eight ADL areas

Table 2 summarizes the ATC use in eight ADL areas. For each ADL area, more than half of the participants reported having experienced difficulties in that area. The three most challenging ADL areas were remembering names and faces, staying focused on a task, and locating items. The impact of the difficulties in each ADL area on quality of life varied. Having difficulties in performing multi-step tasks was reported to have the most significant impact on participants' quality of life (78.9%, 15 out of 19), followed by the difficulties experienced in keeping track of appointments and events (77.3%, 17 out of 22). As Table 2 illustrates, the largest number of ATC was used to compensate for difficulties in keeping track of appointments and events, and the majority of these cases involved use of a smartphone. Smartphones were used in seven out of the eight ADL areas.

Table 2. Difficulties and ATC use in ADL areas

ADL areas	No. of participants who had difficulties (N=29)	No. of participants who were significantly affected[1*]	Total number of ATC used	Types of ATC devices used in each area[2*]	Proportion of portable electronic ATC[3*]
Perform multi-step tasks	19	15 (78.9%)	5	Smart phone (3) Computer (1) Alarm/Timer (1)	60%
Keep track of appointments & events	22	17 (77.3%)	29	Smart phone (16) Computer (4) Smart pad (2) Paper tools (5) Alarm/Timer (2)	62.6%
Stay focused on a task	27	18 (66.7%)	4	Smart phone (1) Computer (1) Paper tools (1) Alarm/Timer (1)	25%
Keep track of taking medications	17	11 (64.7%)	5	Smart phone (2) Alarm/Timer (1) Pillbox(2)	40%
Remember names and faces	28	17 (60.7%)	5	Smart phone (1) Computer (2) Paper tools (2)	20%
Manage emotion	22	13 (59.1%)	1	Smart phone (1)	100%
Navigate ways	17	9 (52.9%)	3	Smart phone (1) GPS (2)	100%
Locate items	26	9 (34.6%)	0	N/A	N/A

1*: The percentage is based on the number of participants who reported difficulties in each ADL area.
2*: device (n), n represents the frequency of the reported using of ATC device
3*: Smart phone, computer, smart pad, and GPS are grouped into high-tech ATC category.

2.3.3 User experience with ATC

GPS and pillbox received the highest usability ratings; 1 for GPS and 0.94 for pillbox. Portable electronic devices such as smartphones also received high usability ratings (0.84±0.14). Paper-based tools received lowest ratings (0.65±0.30).

The interview results for preferred functions and features of the participants' ATC are summarized in Table 3. Ease-of-use of apps and the reminder function were the most favored features of electronic ATC. Portability and versatility were also preferred features for some participants. In addition, participants mentioned their preference for features like alerts to draw a user's attention, a check-list for achieving goals, zooming in/out, and calendar synchronization with family members and/or friends. Some apps used on portable electronic ATC were able to provide emotional support for users. For example, two participants stated that using the ATC made them feel positive about their behaviors and thus enhanced their feeling of security; one participant reported that using the mood tracker app on his smartphone enhanced his self-awareness of his day-to-day emotional status.

Table 3. Participants preferred functions and features of ATC

	Functions and Features	Frequency*
For portable electronic ATC	Ease-of-use of Apps	6
	Reminder function for time management	5
	Portability	4
	Versatility of devices	4
	Effectiveness	2
	Enhance feeling of secure	2
	Social networking & contacts management	2
	Zoom in/out	2
	Check-list of goals	1
	Alerts to get user attention	1
	Calendar synchronization	1
	Cost effective	1
	Enhance self-awareness	1
	Fun-of-use	1
For traditional ATC	Ease-of-use	2
	Effectiveness	1
	Alerts to get user attention	1
	Aesthetics design	1
	Check-list of goals	1

*Frequency means the number of participants reported the preferred functions and features of ATC in interviews.

The interview results regarding the difficulties and barriers related to the use of ATC are summarized in Table 4. The most frequently reported difficulty for electronic ATC was that the devices were difficult to use. One participant stated that the procedure of setting up the reminder app on his smartphone was very difficult; however, he was able to follow the reminders once they were set up correctly. Another participant reported that learning to use the electronic ATC was time consuming. In addition, short battery life and high cost of the portable electronic ATC devices were also reported as barriers. The maintenance of portable electronic ATC was also reported as a barrier by two participants, which involves keeping up with the updates of the device operating system and the apps, and preventing the device from dropping on the floor or in the water. Other barriers such as limited processing speed, unreliable signal, limited memory storage, and the lack of build-in reminders for the daily use of the ATC itself were also mentioned. One participant stated that using some apps on his smartphone as ATC was very effective; however, he usually forgot to use any of these apps unless his wife reminded him to use them. For traditional ATC tools such as paper-based tools (e.g., paper calendars, notebooks, and pop-up notes) and alarms/timers, the lack of built-in reminders and feedback to users were of most concern. The inability to remember to check the paper calendar on their own was a big barrier, and locating the correct page for "Today" was also a difficult task for some participants.

Table 4. Difficulties and barriers related to the use of ATC

	Difficulties and barriers	Frequency*
For portable electronic ATC	Difficult to use the devices	4
	Short battery life	3
	High cost of devices	3
	Time consuming to learn how to use	2
	Prone to physical and water damage	2
	No build-in reminders for using the Apps	1
	Difficult to set up smartphones and Apps	1
	Need for frequent updates	1
	Slow response speed	1
	Unreliable signal	1
	Limited memory storage	1
For traditional ATC	Need for frequent replacement of paper	1
	Limited feedback information	1
	No build-in reminders for events	1
	Time consuming to set it up	1
	Need for locating correct calendar page	1

*Frequency means the number of participants reported the difficulties and barriers in interviews.

2.3.4 ATC acquisition and training

More than 75% (18 out of 23) of the reported portable electronic ATC devices were purchased by the participants themselves or their family members and friends without going through a prescription process. Four of the electronic ATC devices were provided by the Department of Veterans Affairs and one device were provided by the Defense and Veterans Brain Injury Clinic. Most of the apps used in smartphones and smart pads either came with the devices or were purchased by the participants themselves, family members, and/or friends.

Among 23 reported cases of portable electronic ATC use, participants received training for the device in 7 cases, and for the apps in 6 cases. The training was mainly provided by speech therapists or occupational therapists. The duration of the training sessions ranged from half an hour to over 3 hours. Three out of the seven training experiences on the devices and five out of the six training experiences on the apps were rated as "very helpful" or "extremely helpful." Among these training cases, individuals who acquired ATC from the Department of Veterans Affairs took up 4 cases of training for the device, and 4 cases of training for the apps.

2.4 DISCUSSION

This study investigated the use of ATC, especially portable electronic ATC devices, among people with TBI in eight ADL areas. User feedback on different features of the existing ATC was also obtained and examined in this study.

The results show that portable electronic ATC, especially smartphones and a variety of apps, were widely used by the participants to compensate for cognitive limitations. Some features of smartphones like ease-of-use of apps, reminder function, portability, and versatility of devices were highly endorsed by participants. Hart et al (2004) conducted a consumer survey study on portable electronic devices for memory aids in people with TBI. Most participants in the study did not have experience with using these devices, but they reported that the simplicity of use and ability to perform multiple functions would be most desired features of these devices. The ability of smartphones along with apps to provide these most desired features may lead to its wide use as portable electronic ATC. Even though the small screen and buttons were identified as limitations which may prevent smartphones from being suitable ATC devices [57], one preferred feature reported in this study - the ability to zoom in/out - seems to serve as a good compensation for this weakness. Moreover, some novel features also seem to increase the potential of smartphones and apps to become a more ideal platform for ATC. For example, the internet-based app synchronization among multiple devices may create new ways for caregivers to help individuals with cognitive impairments, and the physical/emotional status logger could enhance the self-awareness of users and provide more reliable information for clinicians. In this study, we also found that most apps used by participants (e.g. Calendar and Reminders) were designed for the general population. The growing use of smartphones, smart pads, and various apps in the general population encourages app development, which may also increase the amount of potential applications that can be used as ATC. On the other hand, it also reveals that the amount, categories, and the spread of apps designed for people with cognitive impairments are still very limited.

Among the difficulties and barriers in using portable electronic ATC reported in this study, "difficult to use the devices" was the most common barrier for users, which was consistent with previous studies. Participants stated that it was difficult to set up the devices (e.g. smartphones and smart pads) and install apps on them. Though the versatility of these devices was favored by participants, they also pointed out that it was challenging to navigate all functions on devices, which added complexity in using devices along with apps as ATC. This indicated that the interface of operating systems on smart phones and smart pads may need to be simplified to better adapt the needs of portable electronic ATC. Meanwhile, many new barriers for using portable electronic ATC were also reported, such as the steep learning curve, the need to keep operating systems and apps updated, and the effort to keep devices from physical and water damage. Considering that most of participants acquired portable electronic ATC on their own without going through a prescription process and less than 1/3 of the reported cases received training on using the ATC, these barriers may also reveal the inadequate service delivery process for electronic ATC. A lack of assessment, inappropriate devices, and limited access to training resources can negatively affect end users' health and limit the benefits of using assistive technology [66-68].

Most of the reported barriers in this study may be removed by appropriate training programs. Svoboda and Richards (2009) investigated training a client with memory impairment in how to use a smartphone. The results showed that the client demonstrated consistent and novel generalization of smartphone skills across a broad range of real-life memory-demanding circumstances [69]. These results suggest that theory-driven, systematic, hierarchically organized training can allow users to exploit commercially available tools to successfully support memory. Phillips et al (1993) concluded that training provided in users' usual environment would decrease the likelihood of assistive technology abandonment [70]. Thus, adequate training may not only have the potential to significantly improve user experience of the particular ATC, but also can empower users to adapt to other types of portable electronic ATC and to get the most out of the available technology. The potential benefit of training may explain the result in this study that though only one third of participants ever received training on how to use these aids, most of these participants rated the training as very helpful or extremely helpful.

The present study also shows that most of the training was given by clinicians in a rehabilitation setting. Most of the participants did not go through a systematic service delivery process that involves assessment and training, which may have limited the benefits of using these devices. Considering participants themselves and family members were the main providers for their ATC devices, it is important to explore alternative methods of delivering training resources and materials and make them readily available to the end users and their family members. For example, online training like webinars and YouTube videos, embedded training portions in apps on smartphones, and so on. It may also be included in the development process and follow-up service of ATC. The developers may want to consider how to add an effective training portion to the ATC before releasing the products to end users or clinicians.

For the future development of ATC, the feature of built-in reminders for prompting users to use the ATC regularly should be considered. Effort should also be made to improve the battery life and physical endurance of ATC. Moreover, the development and evaluation of ATC in areas of supporting multi-step tasks and keeping user focused on tasks warrants attention from researchers and product developers. Both previous studies and our survey found that majority of ATC were used to support scheduling tasks [57, 71]. However, our results show that difficulties in performing multi-step tasks and staying focused on a task also affected participants' quality of life significantly, and only a very limited number of ATC were available to match users' needs in these ADL areas. A previous systematic interview on the efficacy of ATC also concluded that deficits in other cognitive domains, especially in executive function and attention, should be targeted by future multipurpose ATC devices, such as PDAs or smartphones [57].

There are several limitations of this study that could affect the generalizability of the results. First, the sample is relatively small and drawn from veterans and military personnel who participated in the NDVWSC. This may limit the generalizability of the study results. Second, the study procedure did not include a clinical assessment of cognitive dysfunctions of the participants and relied on their self-report on their difficulties in each ADL area and their compensation strategies using ATC. The cognitive impairments of participants may affect the reliability and validity of the results. However, during the interviews, most of the participants showed the investigators how they interacted with the reported ATC and provided detailed explanations on their experience, which helped increase the validity of the results. Third, because of the lack of neuropsychological assessment for participants in this survey study, we are not able to investigate the link between the participants' feedback for each ATC and their cognitive functions. Further research may examine the association between the neuropsychological characteristics of end users and specific features of ATC to obtain a thorough understanding of ATC use and help match the technology with end users in clinical practice.

Despite these limitations, this study provided a more updated picture of ATC use, especially portable electronic ATC use, among people with TBI. The information collected in the study could potentially inform the future development of ATC and support the need for training and an appropriate acquisition process of portable electronic ATC devices.

3.0 AN INVESTIGATION OF PAPER-BASED AND USER-CONTROLLED PROMPTING METHODS IN GUIDING PEOPLE WITH TBI IN COOKING TASKS

3.1 INTRODUCTION

Survivors of TBI usually suffer from various cognitive deficits and one of the common impairments is in the area of executive functioning [22]. Deficits in executive functioning can pose significant challenges in initiating, stopping, shifting, and adjusting tasks and due to these deficits, individuals with TBI often experience difficulties in performing a sequence of goal-directed actions such as cooking and many vocational tasks [5]. When doing multi-step cooking tasks, managing cooking time, making judgments, multitasking, interpreting recipe instructions with cognitive flexibility, and problem solving can be very challenging [44]. Individuals with TBI may also display under-confidence or over-confidence with their ability to complete certain activities [9, 10].

External aids, ATC, have been considered the most effective and widely used intervention for cognitive impairments after TBI. The low-tech ATC such as paper-based tools (e.g. paper calendars and paper recipes), are widely recommended for cooking tasks. However, these paper-based tools are limited in terms of the amount of information and the form of presentations they can provide. Paper-based tools also provide no cues to the user as to when he or she needs to perform a task.

With the prevalence of computers and portable devices such as smartphones and tablets, these devices along with custom software are used to remind users of performing a task and/or present sequencing steps that guide users through a task. Most sequencing devices today operate in a step-by-step user-controlled fashion by requiring users to monitor their own progress and provide feedback to the device such as pushing a button on the device after a step has been completed or when they need more detailed instructions. A number of commercial products and research prototypes enable users to create a sequence of primarily visual prompts on portable digital devices which can prompt users step-by-step through a multi-step task [31, 32]. These new features may have potential to better compensate cognitive deficits of users. However, most ATC evaluation studies focus on scheduling services, and evidence on prompting methods in guiding multistep tasks is relatively scarce [12]. In addition, current evaluation studies usually compared user-controlled method with the baseline condition where no ATC assistance was given to the participants. It was still not clear to what extent such step-by-step user-controlled systems would be beneficial when compared with simple paper-based tools.

The objective of this study was to examine the performance of individuals with TBI in cooking tasks when following a paper-based recipe versus a step-by-step user-controlled recipe on an iPad mini in their home kitchens. In addition to user performance, we will also examine the perceived ease-of-use, usefulness, and stress level with the two prompting methods. We are also interested in communicating the nature of problems faced by people with TBI when performing activities in the kitchen with current available prompting methods, and gathering design recommendations to inform the design of future advanced assistive devices for cognition.

Part of the work described in this chapter has been published in Smart Homes and Health Telematics, pp. 83-92. Springer International Publishing, 2015.

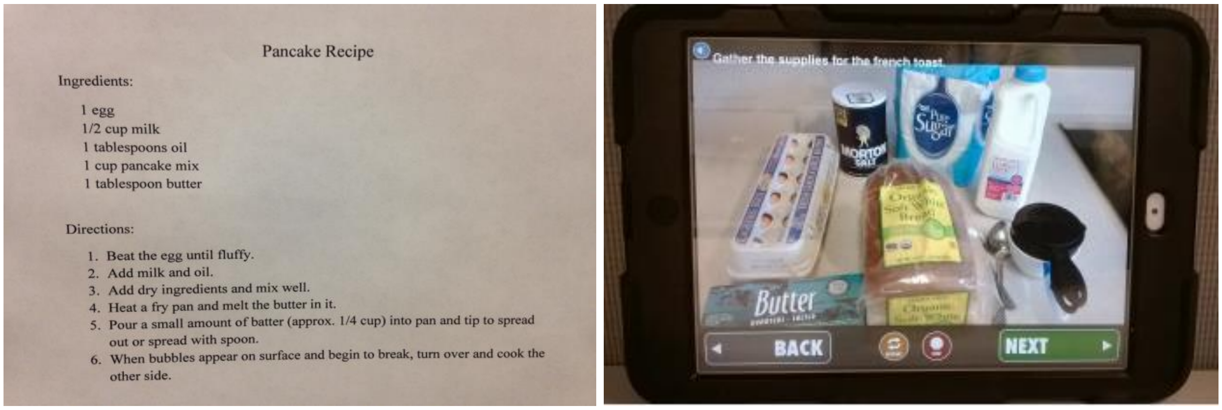
3.2 METHODS

3.2.1 Participants

The study was approved by the University of Pittsburgh Institutional Review Board and was conducted in each participant's residence. Participants were recruited from the local TBI support groups and rehabilitation institutes. Inclusion criteria consisted of 1) being 18 years or older; 2) having a self-reported diagnosis of TBI; 3) be able to understand the objectives, risks, voluntary nature, and procedures of this study. Ten individuals with TBI participated in this study.

3.2.2 Settings

A randomized cross-over design was used in this study. The two types of prompting methods were a paper-based method and a step-by-step user-controlled app on an iPad Mini. To minimize the learning effect, two different recipes (i.e., pancakes and French toast) with the same number of steps and similar complexity were made available for each method. Two online recipes (i.e., one for pancakes and one for French toast) were converted to paper-based and iPad-based recipes, respectively. The iPad-based recipes were programmed with a commercially available app (i.e., Visual Impact Pro [72]). The interface for each prompting method is shown in Figure 1. Participants can navigate the user-controlled recipe by pressing "Back" and "Next" buttons on the screen.



(a) Paper-based method (b) user-controlled method

Figure 1. The interfaces of the two prompting methods

3.2.3 Measures

A basic information questionnaire was administered prior to the testing. It includes questions on participants' demographics, injury related information, and previous experience with assistive technology (AT).

The Trail Making Test (Condition 4: Number-Letter Switching) from the Delis–Kaplan Executive Function System (D-KEFS) [73] was used as a neuropsychological measure for participants. This test was selected as it represents a measure of executive function [74].

The Performance Assessment of Self-Care Skills (PASS) was used to evaluate participants' performance in completing cooking tasks. PASS is a performance-based, criterion-referenced, observational tool designed to assist practitioners in documenting functional status and change in daily activities in many populations including TBI. PASS has been shown to be valid and have excellent test-retest reliability, and inter-observer reliability [75]. Individuals are evaluated on their ability to carry out a task, and whether their performance meets pre-defined criteria while completing the task. The PASS consists of 26 core tasks in mobility, personal self-care, Instrumental Activities of Daily Living (IADLs) with a cognitive emphasis, and IADLs with a physical emphasis. It also provides a template for others to develop new PASS tasks. The two cooking tasks used in this study were adapted from PASS core tasks using the template (appendix B). PASS tasks are decomposed into atomic steps that can be rated based on three separate constructs: independence, safety, and adequacy.

- Independence refers to how much assistance the individual needs to complete each step. PASS scoring includes a structured grid of hierarchical assistance for each step, including nine levels of graduated prompts: (1) verbal supportive, (2) verbal non-directive, (3) verbal directive, (4) gestures, (5) task or environment rearrangement, (6) demonstration, (7) physical guidance, (8) physical support, and (9) total assist. When a step of the task cannot be performed independently, the investigator provides the least powerful/intrusive type of prompt to facilitate task performance, noting the level of assistance by using a checkmark on the scoring grid each time a prompt is given for the participant to accomplish the step. The total amount of assistance given by the investigator and the highest level of assistance were used to evaluate the independence of participants in each cooking task.
- Safety refers to whether the individual is taking risks to their personal safety while completing the task. Under safety, the investigator places a checkmark for each step if any safety-threatening activities are observed or if the investigator is required to intervene because of a risk to safety. Each step is assigned a safety score on a four-point ordinal scale from 0 (step stopped by investigator to prevent personal injury) to

3 (completely safe practices). The safety score for each cooking task is computed as the minimum of the safety scores for each step.

- Adequacy refers to how well the task is performed, including the quality of the outcome of the task and the process of reaching that outcome. The adequacy score for each cooking task is quantified by the investigator who considers the frequency and severity of the process and outcome issues encountered by the participant while performing the task. The score is rated on a four-point ordinal scale from 0 (outcome standards not met, process so poor that it prevents the completion of the task) to 3 (task performed relatively efficiently and with outcome standards met). The adequacy score for each cooking task is computed as the minimum of the adequacy scores for each step.

A custom post-test questionnaire (appendix C) was used to assess user perceived ease-of-use and usefulness of the two prompting methods, user stress levels, and overall satisfaction level and this questionnaire were reviewed by three experts in occupational therapy and rehabilitation science. The questions on perceived ease-of-use and usefulness were adapted from the Technology Acceptance Model (TAM) and use a 7-point Likert scale (1=strongly disagree and 7 = strongly agree) [76]. There were 10 statements for perceived usefulness and 7 statements for ease-of-use. The total score for perceived usefulness was calculated by adding the user response for each statement and ranged from 10 to 70, while the total score for perceived ease-of-use was ranged from 7 to 49. Both scores were then scaled between 0 and 1 (0=most negative, 1=most positive). Participants' stress level was evaluated using a 5-point Likert scale (1=not at all stressful and 5=extremely stressful). The overall satisfaction was evaluated using a 7-point Likert scale (1=completely dissatisfied and 7=completely satisfied). In addition, guiding questions for a semi-structured interview were used to assess user feedback on specific features and preferences to the two prompting methods.

3.2.4 Protocol

Researchers paid one visit to each participant's residence. After providing signed informed consent, participants completed the basic information questionnaire. Participants were then administered the Trail Making Test (Condition 4: Number-Letter Switching) from the D-KEFS. A short interview was followed to obtain more information about the participant and his/her recovery process. Prior to testing, one of the investigators demonstrated how to use the paper recipe and the user-controlled recipe on an iPad Mini, and made sure participants were able to use both recipes according to a usability checklist. The checklist mainly included whether participants were able to see the text/images clearly, to understand the sentences/phases, and to press the buttons to navigate the recipe on the iPad Mini. Participants were then asked to complete two cooking tasks using two different prompting methods. The sequence of prompting methods/cooking tasks was counterbalanced. Participants used their own ingredients and utensils. Investigators also brought all ingredients and utensils needed for these two tasks in case a household did not have them. During the cooking tasks, participants were evaluated by a trained investigator using the PASS. After each task, the custom questionnaire was administered to gather user feedback.

3.2.5 Data analysis

Descriptive statistics was used to analyze the data obtained from the basic information questionnaire. Results of the Trail Making Test were converted to T-scores. Participants with scores more than one standard deviation below the mean value of general population (T-score<40) were categorized as the group with relatively substantial cognitive impairment ("Impaired"), and participants with scores within one standard deviation or above the mean of general population (T-score>=40) were categorized as the group with relatively minimal cognitive impairment ("Intact"). PASS scores for user performance (total amount of assistance, highest level of assistance, safety, and adequacy), user perceived ease-of-use, usefulness, stress level, and satisfaction level with both methods were compared using the Wilcoxon Signed-Rank Test in SPSS [77]. The level of significance was set to 0.1 given the exploratory nature of the study. Content analysis was conducted by two investigators independently to extract common themes from the observations and interviews. In case of different themes extracted, the two investigators reviewed the content together and reached agreement.

3.3 RESULTS

3.3.1 Participants

Ten individuals with TBI participated in this study (Table 5). Their average age was 41.3±10.4 years old and 17.1±12.3 years post brain injury. Nine participants lived in community settings and one participant (P8) lived in the group home of a local rehabilitation institute. All participants were able to walk without using any mobility assistive technology. Six participants were using calendar apps on their smart phones or iPads for scheduling assistance. The results for the Trail Making Test were also included in Table 5. Based on the test results, P2, P5, P6, P7, and P8 were grouped to the impaired group and the other participants were grouped to the intact group with reference to their sequencing and cognitive flexibility.

Table 5. Basic information of participants

Participants	Age	Gender	TBI duration (years)	Trail making test*	ATC in use
P1	36	F	20	47	None
P2	34	M	6	33	None
P3	38	F	8	40	None
P4	40	F	4	50	Smart phone/iPad with calendar app
P5	54	F	18	33	iPad with calendar app, Timex watch
P6	35	M	31	20	Smart phone with calendar app, paper calendar, pillbox
P7	54	M	12	37	None
P8	34	M	31	37	Smart phone/iPad with calendar app
P9	59	M	37	43	Laptop with calendar app, note pad
P10	29	F	4	40	Smart phone with calendar app, paper calendar, timer

**T*-score of the D-KEFS Trail-making test (condition 4: number-letter switching)

3.3.2 Performance evaluation

As shown in Table 6, no significant difference was found in the total amount of assistance, highest level of assistance, and safety score between the paper-based and the user-controlled method. Participants received significantly higher adequacy scores with the user-controlled method as compared to the paper-based method (2.20±0.63 vs 1.70±0.67, p=0.096). It may indicate that participants were able to complete the task with better quality or efficiency with the user-controlled method. Eight out of ten participants required at least one assist from investigators in completing tasks with each method. The highest level of required assistance for most participants was verbal directive or gestures.

Table 6. Results for quantitative outcomes among all participants (n=10)

Outcomes	Paper-based Method	User-controlled Method	Wilcoxon test (two tails)	
	Mean (SD)	Mean (SD)	Z	*P*
Objective outcomes				
PASS- Total amount of assistance	6.50 (7.01)	5.50 (7.49)	0.409	0.683
PASS- Highest level of assistance	2.60 (1.51)	2.60 (1.43)	0.000	1.000
PASS- Safety score	2.50 (0.53)	2.60 (0.52)	-0.264	0.792
PASS- Adequacy score	1.70 (0.67)	2.20 (0.63)	-1.667	0.096*
Subjective outcomes				
Usefulness	0.58 (0.27)	0.82 (0.31)	-1.887	0.059*
Ease-of-use	0.63 (0.23)	0.83 (0.20)	-1.719	0.086*
Stress	2.70 (1.06)	1.80 (0.92)	1.897	0.058*
Satisfaction	5.30 (1.16)	6.20 (1.32)	-1.487	0.137

* $P<0.1$

3.3.3 User feedback

Table 6 shows the results on user feedback. Compared to the paper-based method, the user-controlled method received significantly higher ratings in user perceived usefulness (0.58±0.27 vs 0.82±0.31, *p*= 0.059) and ease-of-use (0.63±0.23 vs 0.83±0.20, *p*= 0.086). Participants also reported lower stress levels with the user-controlled method (2.70±1.06 vs 1.80±0.92, *p*= 0.058). No significant difference was found in user satisfaction level between the two methods.

Qualitative feedback during the semi-structured interview was summarized as follows. All participants had experience of using paper recipes prior to the study. Recipe books and online recipes were the main sources. One participant (P1) emphasized that she was so used to paper recipes that it was much easier for her to follow. Three participants indicated that the separate list of ingredients in the paper recipe were very helpful. Regarding the disadvantages of the paper-based method, four participants commented that keeping track of steps and self-checking on completion of steps consumed significant mental effort and created stress. P7 commented "I have to constantly go back to look at it (the paper recipe). I lost my direction when I look back on it". P5 and P6 commented that text instructions on the paper were very difficult to use for individuals' with injured reading abilities as sequela of TBI. P5 shared that it took her many years to regain the ability to read more than one word at a time after the injury.

None of the participants had previous experience with the user-controlled prompting method on an iPad or any other platform such as computers or other tablets. However, seven out of 10 participants expressed greater satisfaction with this method and especially favored the picture prompt and the step-by-step instructions. Five participants also liked the way that they could navigate the steps at their own pace. However, participants also identified some limitations of the user-controlled method. First, users may forget to press the button to get further prompts after distracted by other factors in the environment. P5 commented "There is nothing to say 'come back to me (the user-controlled recipe on the iPad)' for the next step". Second, two participants expressed that pressing the "Next" button for each step was distracting and not convenient, especially when their hands were busy with cooking. P1 commented that she didn't like to keep touching the iPad during cooking. P8 would prefer to control the pace by voice. Third, some participants felt the sequence of steps were not organized to support efficiency and multi-tasking. P1 commented that she would like to see multiple steps at once to offer her more freedom. P4 and P5 thought cleaning-up tasks could also be added to the steps.

3.3.4 Problems encountered during the cooking tasks

Errors and difficulties of participants during cooking tasks with the two methods were identified and categorized in Table 7.

Problems related to cooking experience. The lack of cooking knowledge and techniques led to problems related to food quality and cooking efficiency with both methods. Most participants had problems in determining the timing to flip the food and whether the food was fully cooked. The use of the wrong utensils led to excessive amount of time spent on tasks. For example, P6 used a fork to mix the pancake batter and failed.

Table 7. Problems observed during cooking tasks (n=10)

Category of problems	Paper-based prompting method	User-controlled prompting method
	Problems related to cooking experiences	
Inadequate knowledge on cooking	Did not know to adjust the heat level to improve efficiency (2, 2)* Had difficulties in identifying appropriate utensils (1,2) Had difficulties in identify the right timing to flip food in the pan (1, 1)	Did not know to adjust the heat level to improve efficiency (3, 3) Had difficulties in identifying status of food (e.g. whether burned) (2, 2)
Inadequate techniques for kitchen tasks	Had difficulties in understanding the markings of measuring tools (3, 3) Used inappropriate utensils in tasks (1, 3) Used utensils in wrong ways (1, 1)	Used inappropriate utensils in tasks (2, 2) Did not know to use a utensil to improve efficiency (2, 2)
	Difficulties with following the instructions of recipes	
Difficulties in follow steps of recipes	Lost track of steps (1, 1) Lost track of kitchen storage/utensils (2, 2) Had difficulties in locating ingredients (1, 2) Misunderstood the instruction (3, 3) Failed to follow the instruction after coming back from distractions (1, 1) Kept asking for confirmations during tasks (2, 9)	Ignored the text instruction (1, 1) Misunderstood the pictures (2, 2) Kept asking for confirmations during tasks (2, 10)
Safety threats activities	Left pan on hot burner after cooking (3, 3) Put paper recipe and ingredients on stove (1, 1)	Left pan on hot burner after cooking (3, 3) Turned on a wrong burner (1, 1)
Inefficiency	Spent excessive amounts of time on specific parts of tasks (e.g. measuring ingredients and mixing) (1, 3)	Spent excessive amounts of time on specific parts of task (e.g. measuring ingredients and mixing) (1, 2)
	Cognitive/Emotion difficulties	
Distraction	Distracted by the environment (4, 11)	Distracted by the environment (2, 5)
Impulsiveness	Flipped/removed food before the right timing (6, 16)	Flipped food before the right timing (4, 4) Acted before seeing instructions for next steps (3, 4)
Resistance	Refused to accept prompts given by the investigator (2, 2)	Refused to accept prompts given by the investigators (1, 3)

For each bullet of categorized incidents (N1, N2), N1 indicates the number of participants encountered the difficulties, and N2 indicates the number of total incidents among participants.

Difficulties with following the instructions. Participants encountered similar types of difficulties on adequacy and safety with both methods. Problems occurred more frequently with the paper-based method including difficulties in keeping track of steps, kitchen storage, and utensils, and failure to follow instructions after distraction. Two participants constantly asked for confirmations from the investigator about their actions.

Cognitive/emotion difficulties. Participants had fewer incidents due to distraction and impulsive actions with the user-controlled method. However, three participants acted before pressing the "Next" button to receive instructions for the following steps, and required assistance from the investigator to prevent irreversible mistakes.

3.4 DISCUSSION

This study evaluated the usability and effectiveness of the paper-based and user-controlled methods in assisting people with TBI in cooking tasks.

Results showed that no difference was found in the independence or safety level of participants' performance with both methods. Most participants required more than one external assistance to complete the task, indicating that participants would not be able to complete the tasks independently with either prompting method (Appendix A). The reason was that assistance from the PASS was only given to prevent task failure or safety threats. In other words, if the PASS administrator did not intervene, most participants would fail the task or encounter dangerous situations when using a traditional paper-based method or a conventional user-controlled method. Thus, better prompting methods are in need to reduce the amount of required assistance and improve independence and safety of people with TBI.

When examining the observed problems with both methods (Table 7), we found that fewer incidents occurred with the user-controlled method. However, participants still faced similar types of problems with both methods. One of the reasons could be that the open-loop approach of both prompting methods depended on users' self-monitoring and self-prompting. No additional prompts can be provided before and/or after users made mistakes or were distracted. For participants with TBI, especially those with more impaired cognitive functions, self-awareness and self-monitoring problems may interfering their abilities to accurately track their own progress and recognize errors during tasks, thus limiting the potential benefits of the user-controlled methods in improving user independence, safety, and using experience. Future development of prompting devices may consider adding some sensing components to monitor user actions. The authors proposed specific incidents that may need to be detected or inferred by sensing components, and potential prompts that could help prevent or recover from user problems. These recommendations are summarized in Table 8.

We also found some possible trends which may indicate the relationship between participants' responses to both prompting methods and their status in sequencing and cognitive flexibility. The user-controlled method seemed to be more beneficial for participants in the intact group in improving efficiency and completion quality, but these participants showed comparable satisfaction levels for both methods. However, participants in the impaired group tended to be more satisfied with the user-controlled method, even this method seemed to be limited in improving their adequacy. The qualitative feedback may explain these trends to some extent. For participants in the impaired group, they may experience more difficulties with reading, keeping track of steps, and memorizing instructions with the traditional paper-based method. Therefore, they may be more sensitive to the benefits provided by the user-controlled method such as step-by-step prompts and intuitive visual information. Thus, they experienced significantly decreased stress level and cognitive load. For participants in the intact group, it may not be that challenging to follow paper-based recipes, while discrete steps and the requirement of pressing a button at each step in the user-controlled method may add extra work instead. They may not recognize the improved efficiency and quality in completing tasks with the user-controlled method.

Table 8. Proposed sensing and prompting solutions for problems observed

Category of problems*	Sensor Inference	Future Prompts
Inadequate knowledge and techniques on cooking tasks	Power/gas consumptions of the appliances Cooking temperature of the appliances Cooking time Object recognition for utensils	Provide prompts for appropriate utensils, how to use, and recommended food status through images or short video clips.
Difficulties in following the steps of the recipes	Infer what kind of task is being carried on Infer the correct completion of a sub-task	Make sure text instructions in big font with high contrast background Provide verbal instructions Allow users/family members to adapt pictures in prompting devices Provide check boxes for users Provide confirmations by sensor inference
Safety threats activities	Locations of pans/pots and active burners Consumption of power, gas, and water On/off status and on duration of appliances The location of the user	Include explicit prompts to prevent possible safety threats Inform caregivers or family members when possible safety threats detected Direct control by the system (e.g. cut off power of the stove)
Inefficiency	The amount of time spent on a specific task	Inform the time spent on the task Remind the goal of the task
Distraction& Impulsive	Infer what kind of task is being carried on The location of the user The action of the user The amount of time spent on a specific task	Prompt to draw attention to the task Inform the time spent on the task Remind the criteria for the action (e.g. flip the toast when the underside is brown)

This study has several limitations. First, the sample size is small, which may limit the generalizability of the results. Second, although the contents of recipes for both prompting methods were the same, there were no picture prompts in the paper-based method while the user-controlled method had step-by-step picture prompts. This factor can affect user experience with the two methods. However, as the text-only paper-based recipes are the most widely used method, it may be reasonable to use it as a comparison method. Third, we used multiple self-reported quantitative outcomes to assess the usability of both prompting methods. The cognitive impairments of the participants may affect the validity and the reliability of the results. However, the information we got from semi-structured interviews were consistent with participants' self-reported quantitative outcomes, and these information also provided insight to the self-reported variables, which helped to increase the validity and reliability of the results. The main strength of this study was that the testing was conducted in each participant's home kitchen. The familiar environment and kitchen set-up minimized the influence of other factors on their performance and allowed investigators to observe participants' natural behaviors when interacting with prompting methods. Another strength of this study was to use the in-depth qualitative analysis to examine problems with both methods and proposed potential solutions. The information may contribute to the future development of advanced prompting technology for people with TBI or other cognitive impairments in completing sequential tasks.

4.0 DEVELOPMENT OF A SMART KITCHEN FOR PEOPLE WITH TRAUMATIC BRAIN INJURY

4.1 INTRODUCTION

People with TBI have issues performing many instrumental activities of daily living (IADLs) independently, often due to problems with attention, memory, and executive functioning. Kitchen activities are among the most important IADLs that are identified by individuals with TBI as problematic or hard to complete independently. The inability to independently complete these activities is associated with poor self-esteem, diminished quality of life, and social isolation [18]. Hence, increasing independence and autonomy in kitchen activities is a common long-term rehabilitation goal for persons with TBI.

According to the results in Chapter 2 the survey study and Chapter 3 the comparison between paper-based and user-controlled prompting methods, we found that people with TBI have a significant unmet need in ATC for sequencing multi-step tasks, and they were not able to complete cooking tasks independently and safely with current available prompting methods. Advanced prompting systems need to enhance end-users safety and performance-monitoring by implementing context-aware technology.

There has been some research among people with cognitive impairments where researchers used multiple sensors and learning algorithms to recognize user activities, especially certain unsafe user behaviors in the kitchen environments. Blasco et al. developed a smart kitchen for ambient assisted living of the elder population [45]. Their kitchen implemented standard sensors (gas, fire, smoke, flooding), magnetic sensors, light sensors, and presence sensor, to provide information and warnings about the use of household appliances and to detect routine changes to kitchen tasks. Lei et al. used a RGB-D camera (modern depth cameras that provide synchronized color and depth information at high frame rates) to identify activity and tools used in the kitchen (between a selected group of 35 objects and 25 actions) [46]. Coronato and Paragliola presented an approach for modeling and detecting of dangerous situations in the kitchen using RGB-D cameras and wearable accelerometers [47]. The anomalous classification algorithm was based on events frequency, location, timing, and duration information collected by sensors in the kitchen. However, most of these research studies focused on computer vision and algorithm development; very few studies looked into the opportunity to integrate inferred context based on embedded sensors in the environment to enable automatic prompts for multi-step cooking tasks. Thus there is limited information available regarding how to achieve a balance between practicality of implementation/deployment and effectiveness in assisting users.

The primary aim of this chapter is to present the development of a smart kitchen testbed which can be used as a platform to develop and evaluate different types of prompting applications for people with TBI. Specific features of this system were designed based on identified user needs. A preliminary assessment on prompting modalities was also performed on this testbed.

Part of the work described in this chapter has been published in the proceedings of the 36th Annual Conference of the Rehabilitation Engineering and Assistive Technology Society of North America (RESNA), 2013.

4.2 NEED ASSESSMENT

To examine a range of possible difficulties faced by end-users in kitchen-related activities, five individuals with TBI were interviewed in their residences. Participants were included if they met the following inclusion criteria: being 18 years or older; having a self-reported diagnosis of TBI; be able to understand the objectives, risks, voluntary nature, and procedures of this study. Previous research has shown that about five users are sufficient to explain 80-85% of the problems associated with usability studies [78, 79]. After the informed consent, an investigator started a dialogue with the participant to learn about their background, rehabilitation process, and the importance of kitchen activities in their daily schedule. The investigators then observed the participant performing a kitchen task of his/her choice, such as preparing a meal and making a cup of coffee. The participant was further interviewed on his/her experiences in the kitchen, food and cooking-related anecdotes, and any unaddressed needs and issues especially since their brain injury. The interview session was audio recorded and the observation session was video recorded.

Ethnographic techniques of saturation and synthesis were used to analyze the interviews [80]. During the saturation phase, three investigators individually reviewed the recorded interviews and used post-it notes to list most impressive activities/comments of each participant, their problems with kitchen activities, and salient features from the participant's kitchen environment. This was followed by the synthesis phase where the investigators grouped related observations based on commonly occurring unmet user needs and insights.

Five needs statements were generated based on the results of synthesis phase.

Needs Statement #1: People with TBI need to maintain their focus on the task at hand, because they get easily distracted by other stimuli.

It was observed that most participants created an impromptu staging area in their kitchens to gather all required materials for cooking tasks and only worked around that area. We observed that participant P5 went looking for a mixing spoon in his kitchen drawer away from the work area during meal preparation. After picking the correct spoon, the participant felt lost. He asked to himself “What am I doing now?” and took several minutes to catch up with the task. One of the common strategies in teaching cooking skills to people with TBI during the rehabilitation process is to gather all recipe essentials in one work area prior to beginning a task to minimize possibilities of getting distracted. To facilitate this, we considered one working area in the design of the Cueing Kitchen and a feature in the Cueing Kitchen prompting software that can prompt users to gather all essential ingredients and utensils to the work area prior to the meal preparation activities.

Needs Statement #2: People with TBI need to feel like the kitchen is a stress reducer, not stress producer, since they seek to limit the complexity and control pace of their daily activities.

Through interviews, participants expressed a strong dislike for having too many items around the working/storage area because a cluttered space can be overwhelming and distracting. Participants also reported that any change in the order/location of items in the kitchen could be a source of stress and frustration. The user feedback prompted the need for a kitchen inventory manager software where the user or caregiver can add, delete, or edit any kitchen items at ease. Also a feature to prompt users to return items to cabinets or refrigerator after meal preparation is warranted.

Needs Statement #3: People with TBI need to receive specific yet detailed instructions without impeding the current task, because too much information is a source of distraction and stress.

Participants did not prefer more information presented at one time, as it would distract them from the cooking task, and make it harder to get back to where they left off. P3: “See when I’m cooking my recipe, I cover up the rest items of the recipe so I don’t get too far ahead [showed how she uses two pieces of paper to cover other steps of the recipe]...After each step is complete, I can pull it [the covering paper] down so I don’t lose track”. The user feedback prompted the need to include a feature of breaking a recipe into a number of manageable steps in the Cueing Kitchen software, as well as the need to include a number of embedded sensors to monitor user actions and prompt users with different levels of details based on their actions.

Needs Statement #4: People with TBI need to be sure that their home appliances are used correctly and safely because fear of causing an accident is a source of anxiety that affects their focus on other important day to day activities.

Needs Statement #5: People with TBI need to be reminded in a way that doesn't limit them to the kitchen while waiting for timed processes, because existing timers are unreliable and difficult to hear.

All participants reported being extremely cautious and at times even paranoid when ensuring their kitchen appliances were turned off appropriately after use. Four participants reported having serious incidents because they forgot to turn off their oven, stove, or other appliances. P2: "I almost burned the house down …. Toaster oven was right there, and I forgot to turn it off and I left the house". Several participants also reported they would leave for work but often had to return home to verify that all appliances were turned off. P4: “it’s just keeping my sanity with things when I come back when I don’t know if I turned the oven off or anything”. The user feedback prompted the need for monitoring the safety of appliance use for the Cueing Kitchen.

4.3 CUEING KITCHEN DEVELOPMENT

Based on the needs statements and previous work in the ATC survey and the comparison of paper-based method and user-controlled method, we designed and developed the Cueing Kitchen, a testbed for developing and evaluating assistive technologies for cognition with kitchen activities.

This fully furnished kitchen has the typically used appliances like microwave oven, stove, oven, dish washer, refrigerator, and coffee maker (Figure 2a). The hardware system of the Cueing Kitchen includes sensing components (Figure 2b) and prompting components (Figure 2c). An integrated network of sensing components has been implemented in this kitchen environment. All sensors selected are wireless to reduce clusters and improve portability of future field applications. Insteon wireless switches are used to detect the opening and closing of furniture cabinets and appliance doors. The Kinect is used to detect the locations and movements of users. A Brultech ECM 1240 Energy Monitor is mounted in the electric panel board to monitor the power consumption information from various kitchen appliances. Prompting components have also been implemented for the environment (Figure 2c). The cabinet doors are fitted with suspended particle display glasses doors. These glass doors can switch between translucent and transparent by switching electric current through them. The cabinet doors when translucent can also be used to project pictures of items. The kitchen cabinet handles are custom made and the LED lights inside can be wirelessly controlled through the software system. The display interface of the computer on the countertop can be used to show picture, video and text instructions for specific tasks. An array of speakers has been mounted in the kitchen and the Anna voice in Windows 7 is used to generate audio instructions.

(a) Layout of the kitchen

(b) Sensing components

(c) Prompting components

Figure 2. Cueing Kitchen testbed with sensing and prompting components

Software applications have been developed to integrate the information gathered from the sensor network and give context-aware prompts (Figure 3). The software system includes three main modules and two interfaces. The three main modules include sensor inference engine, prompting manager, and databases. The two interfaces are designed for end-users and caregivers/family members. Through the Caregiver Interface, a recipe can be broken down into a number of manageable steps and specific sensor monitor events can be added to relevant steps. Caregivers can also customize the prompting modalities needed for each step. The information can be stored in the Task Database. Caregivers or users can also manage kitchen inventory through this interface. They can add or discard any kitchen item by scanning its barcode. The Inventory Database maintains the most up-to-date information about kitchen items, which can help users monitor the expiration dates of food, recommend weekly shopping list, and enable users to search the location of an item in the database. The prompting Manager is able to read recipe information and deliver prompts through the User Interface on a computer. End-users can also select a recipe through the User Interface. The Sensor Inference Engine uses real time information gathered from the sensor network to make inferences about user activities. The automatic prompts generated by the Prompting Manager are based on the context (user activities of environment situations) inferred by the Sensor Inference Engine.

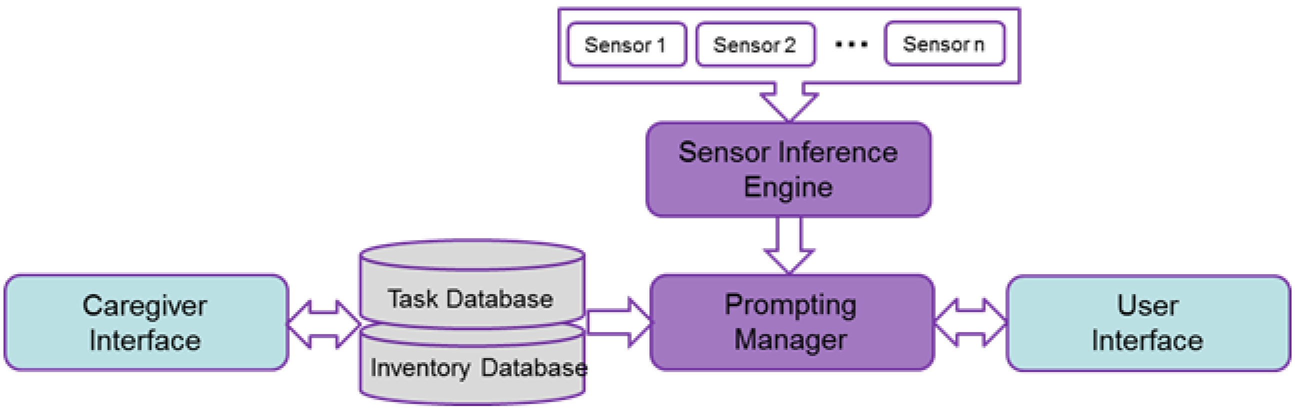


Figure 3. Structure of the software applications of Cueing Kitchen

4.4 PRELIMINARY ASSESSMENT OF PROMPTING MODALITIES

To evaluate the usability of the prompting components in the Cueing Kitchen, we selected the tasks of retrieving items for a recipe. Four types of Retrieving recipe items from kitchen cabinets were selected for the usability assessment. Four types of prompting modalities, including audio, light, picture, and transparent glass, were assessed (Figure 2c). Audio prompts were played through computer speakers, where both the name of the item and the location of that item were provided verbally. For example, “take out peanut butter from the cabinet above the microwave”.

Light prompts were in the form of illuminated cabinet handles. Picture prompts were projected onto the cabinets or the refrigerator that contain the item. Transparent glass prompts were in the form of smart glass doors of cabinets which can be controlled to switch between transparent and opaque. For the last three types of prompts, audio prompts were also provided. For example, “take out pasta from the lighted cabinet” was given along with the light-up handle of the cabinet. Four recipes, each with four non-repeating items, were randomly assigned to four different types of prompting modalities. The sequence of the four recipes with the four different prompting modalities was counterbalanced for each participant. When returning the items to their locations, participants were required to scan the barcode of the item using a commercial barcode scanner to receive location instructions. For example, “put back the coffee in the transparent cabinet”. All user activities were logged with the sensors deployed in the Cueing Kitchen.

This testing was approved by the University of Pittsburgh’s Institutional Review Board. Study fliers were advertised in TBI rehabilitation clinics. Two groups of participants were recruited, participants with TBI and participants who were clinicians working with people with TBI. Five individuals with TBI (T1-T5) and three clinicians (C1-C3) participated in this assessment. The inclusion criteria for participants with TBI were: self-reported diagnosis of TBI, over the age of 18, and self-reported difficulties in independently completing kitchen tasks. Inclusion criterion for participants who were clinicians was at least two years of experience working with people with TBI.

Participants with TBI were asked to complete retrieving ingredients and utensils for four recipes with the four types of prompting modalities. If the sensors in the Cueing Kitchen detected that the participant accessed the correct location for an item and placed the item to the designated location, the system automatically proceeded to prompt users for the next item. Otherwise, the system repeated the same prompts twice before prompting the participants to ask for assistance. Participants then completed a questionnaire about their individual preferences of the prompting modalities. At the end, participants with TBI went through a series of neuropsychological assessment (BDEA Complex Ideation subtest, Greek Cross Drawing, Go No-Go Test, Logical Memory Subtest from Wechsler Memory Scale IV, COWAT – Controlled Fluency Digit Span, Cancellation subtests of the Wechsler Adult Intelligence Scale – IV, Trail Making Test A & B, Stroop Color-Word test, and Grooved Pegboard Test) to evaluate their cognitive level respect to memory, executive function, and attention.

For participants who are clinicians, we walked them through different features of the Cueing Kitchen. They were asked to complete questionnaires about their impressions about the usability and feasibility of the prompting modalities and Cueing Kitchen components for assisting their patients with TBI.

Two outcome measures were derived from sensor logging data including the task completion time and response time. The task completion time was defined as the total time taken by a participant to successfully complete getting out each item. Response time was defined as the time between the time when an instruction was given and the time when the participant acted on it (by opening the correct cabinet). Both time measures from all steps of each task were averaged for each prompting modality. Descriptive comparisons were performed with the task completion time, response time, user preferences, number of errors committed by each participant, and number of required investigator assistance.

Neuropsychological status of T1 to T5 is shown in Table 9. Scores below one standard deviation of the mean can be viewed as having significant impairments in the relevant cognitive components. The participants range in age from 31-63 (Mean=47.2, SD=14.4), and four were male. Their duration post brain injury was 15.6 years. Two of the participants (CI01 and CI04) had their highest education in vocation/technical school and the other three had a GED or high school diploma. All participants were able to walk without using any mobility assistive technology. Three clinicians (C1 to C3) participated in this study. They were 34.3±11.9 years old with 7.3±5.9 years of clinical experience working with people with TBI.

Table 9. Neuropsychological tests of participants with TBI

Domains	Tests	T1	T2	T3	T4	T5
Memory	Log Mem I	-2.0	-1.0	-2.9	-0.7	-0.7
	Log Mem	-2.0	-1.0	-2.9	-1.1	-1.0
Executive function	Trails A	-1.3	-2.4	-2.1	0.1	-0.5
	Trails B	-1.1	-2.4	-2.3	-1.3	-0.3
	Stroop W	-1.3	-3.0	-2.1	-1.7	-0.6
	Stroop C	-2.3	-3.0	-2.1	-0.9	0.3
	Stroop CW	-1.2	-2.3	-1.1	-0.3	-0.3
Language	COWAT	-1.6	-2.2	-1.4	0.8	0.7
	BDAE	1.0	1.0	-2.5	-0.4	-1.5
Sensory Motor	GPeg DH	-2.4	-3.4	-2.6	-1.2	-0.6
	GPeg NDH	-2.5	-4.5	-	-1.3	-1.6
Spatial	Crosses 1	-1.0	-0.6	0.7	0.8	0.4
	Crosses 2	0	-0.6	0.7	0.8	0.4
Attention	DigSpan	-0.7	-1.3	-1.6	0.0	0.3
	Cancellatio	-2.7	-2.0	-2.0	-0.6	-0.6

The results are shown in the standard deviation from the mean of the general population. The unit for the data is one standard deviation. Scores below one standard deviation of the mean represent impaired function.

Figure 4 showed the time measures for participants using the four prompting modalities. Participants used the least amount of time to complete the task with the picture prompts, and longest time with the audio prompts. They responded with the least amount of time to picture prompts and the most amount of time to transparent glass prompts.

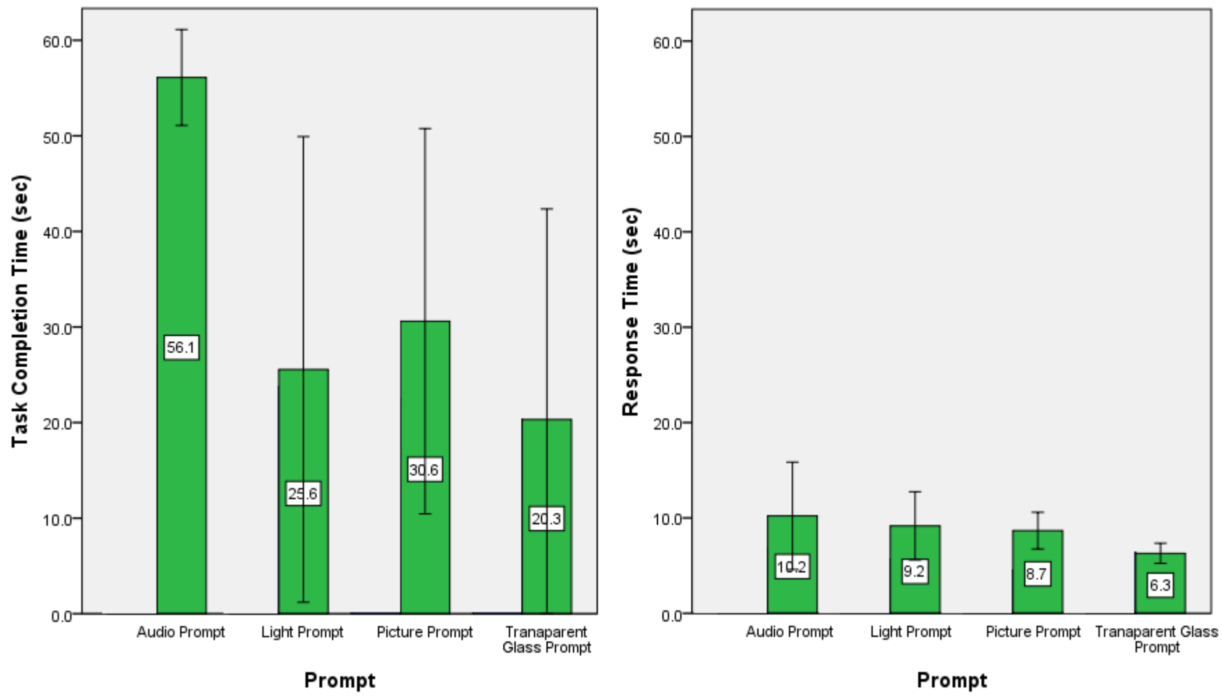


Figure 4. Average time measures with the four types of prompts for participants with TBI

Table 10 summarized the total frequency of assistance and mistakes during the item retrieval tasks. The assistance meant that the participant required additional human assistance from investigators to complete a step besides the prompts given by the Cueing Kitchen system; the mistakes included opening a wrong cabinet, retrieving a wrong item from the cabinet, and leaving a step incomplete. They did not require any assistance or commit any errors with audio prompts and picture prompts.

Table 10. Total frequency of assistance and mistakes of participants with the four prompting modalities

Participants	Audio	Light	Picture	Transparent Glass
T1	0	Assistance:1	0	0
T2	0	Wrong Cabinet:1	0	0
T3	0	Assistance:1	0	Assistance:3 Wrong Cabinet:2 Wrong items:3
T4	0	0	0	Assistance:1
T5	0	0	0	0

Table 11 showed the rankings of user preferences for the four prompting modalities. Most of the participants preferred picture prompts and transparent glass prompt to other modalities. When examining Table 10 and Table 11, we found that T1, T2, T4, and T5 committed no errors when guided by their favorite prompting modality. T2 committed one error when guided by a less favored prompting modality.

Table 11. Preference rankings for automated prompts by participants in TBI group and clinicians group

	Participants	Audio	Light	Picture	Transparent Glass
TBI group	T1	1	4	2	3
	T2	2	3	1	4
	T3	4	3	2	1
	T4	4	2	3	1
	T5	4	3	1	2
Clinicians	C1	4	1	3	2
	C2	4	1	2	3
	C3	4	3	2	1

1- most preferred, 4 – least preferred.

For the clinician group, all participants believed that audio only prompts would be least useful for people with TBI. They suggested that audio instructions need to be very succinct, direct, and short to limit distractions. Clinicians had mixed feedback on other prompts. One clinician pointed out that the transparent glass prompt may be too subtle, and it may be omitted if the user had visual impairments. They all thought that the picture or light prompts may work best in such environments to better attract and retain user attention. Another clinician commented on the picture prompts, “some individuals with TBI have issues with generalizability, so the images should exactly match what is inside (the cabinet)”.

When asked about the overall impressions of the Cueing Kitchen, clinicians liked the idea of giving automated context-specific instructions. Clinicians suggested that there should be a way for users to inform the system that they understand the instruction but need more time. It may avoid the system from giving repeated instructions which can confuse or frustrate users.

4.5 DISCUSSION

This chapter presented the development of a smart kitchen testbed based on identified needs and a pilot assessment on the different prompting modalities.

When multimodal audio-visual prompts were used by people with TBI, overall faster task completion times and in most cases faster response times were seen as compared to audio only prompts. This indicated that the visual cues may have made the audio instructions more intuitive and can potentially help participants to complete tasks with lower cognitive demand. More research is needed to understand the contribution of specific neuropsychological characteristics associated with the task performance and the resulting cognitive load experienced.

Among the four types of prompts, picture and transparent glass were highly preferred by participants. In contrast, audio prompts were least preferred by users. No clear correlations or patterns were found between participant preferences and their neuropsychological status. The reason may be that preferences are more related to user habits and aesthetic factors. For example, even though T3 and T4 performed poorly with the transparent glasses (more errors high response time and completion time), they favored this prompting modality and stated that they were impressed by the neat design.

The preliminary assessment of prompting modalities had several limitations. First of all, the sample size was small, which may limit the generalizability of the results. Secondly, only item retrieval tasks were used in the assessment. Future studies may use more comprehensive kitchen tasks among end-users to assess the effectiveness and usability of different prompting modalities.

Recent advances in wearable sensor technologies and portability of tablet computers show great promise for integration in the Cueing Kitchen. In future versions of advanced prompting systems, algorithms may need to be improved to intelligently identify the user's intent, level of confusion, and other critical factors that may affect task performance.

5.0 THE FEASIBILITY OF AN AUTOMATIC PROMPTING SYSTEM IN ASSISTING PEOPLE WITH TRAUMATIC BRAIN INJURY IN COOKING TASKS

5.1 INTRODUCTION

Compensatory strategies, especially ATC, are often recommended to help people with TBI cope with their cognitive deficits. A number of commercial products and research prototypes have been developed to provide reminders of scheduled events, and only a handful of available devices and systems address sequencing issues [18]. Most sequencing devices today operate in a user-controlled fashion by requiring users to monitor their own progress and provide feedback to the device such as pushing a button on the device after a step is completed or when they need more detailed instructions [30, 81]. For example, Memory Aiding Prompting System (MAPS) [82] and the commercial product Pocket Coach provided by Able Link enable users to create a sequence of primarily visual prompts on a desktop computer. The prompts are then loaded onto a portable digital device which can prompt the user step-by-step through the given task. Users respond by pressing buttons on the device. Other commercial software products (e.g., Visual Assistant [32] and iPrompts [33]) [30, 81] and most research prototypes for sequencing assistance also work in a similar fashion. Davies et al. conducted a study on the effectiveness of Visual Assistant in assisting ten individuals with mental retardation to complete two vocational tasks [34]. Participants received training on the two tasks prior being tested with and without

Visual Assistant. The results showed that the average error per task dropped from 2.25±2.05 without Visual Assistant to 0.75±0.83 with Visual Assistance. Though the results were overall positive, the authors commented that ease-of-use of the device (for example, the user-friendliness of the operating system and the switch placement) should be improved.

Studies have shown that many individuals with TBI have self-awareness and self-monitoring problems interfering with their abilities to self-cue [83, 84]. Thus these individuals may not accurately track their own progress and recognize errors during tasks [85]. In Chapter 3, we found that although the user-controlled method showed the advantages of facilitating users to track steps and received higher user satisfaction when compared with the traditional paper-based method, most participants still required external assistance from an investigator when completing simple cooking tasks, and experienced similar safety-related difficulties, distractions, and impulsiveness as shown in using the paper-based method. Several review articles also pointed out that the open-loop operation of the existing devices may increase cognitive burden by necessitating user interaction with the devices while performing the task and the cognitive ability of some individuals may prevent them from self-checking the completion status of each step successfully [12, 86].

With the recent advance in sensing and smart home technologies, it is possible to infer context (i.e., any information that can be used to categorize the current situation of a user) based on sensors embedded in the environment, which can enable a sequencing device to provide context-based prompts automatically with minimal user input. One of the context-aware prompting systems is the Cognitive Orthosis for Assisting Activities in the Home also known as COACH. COACH employed various computer vision and artificial intelligence (AI) techniques to autonomously provide users with dementia verbal and/or visual prompts during a hand-washing task. It uses artificial intelligence algorithms and a video camera to monitor user progress, determine context, and provide pre-recorded verbal prompts when necessary. The system was evaluated among six participants with moderate-level dementia. Results showed that subjects were able to complete an average of 11% more hand-washing steps independently and required 60% fewer interactions with a human caregiver [36, 37]. Another system is the General User Interface for Disorders of Execution also known as GUIDE that simulates normal conversational prompting to provide task guidance [41]. The system is able to understand simple verbal responses such as “yes”, “no”, or “done” and provides assistance according to the user’s responses. O’Neill et al. evaluated the GUIDE in assisting eight amputees with cognitive impairment of vascular origin to put on their prosthetic limbs. The overall safety critical errors dropped from 2.22±1.71 to 0.94±1.48 with six of the eight participants showing statistically significant benefits. Peters et al developed a context-aware prompting system named the TEeth BRushing Assistance (TEBRA), which provides assistance in the execution of brushing teeth by offering audio-visual prompts to users with moderate cognitive impairments [40]. The TEBRA system infers a user’s behaviors based on the states of objects manipulated during the behaviors and deals with the temporal variance by using a dynamic timing model that are automatically adjusted during a trial. The evaluation study was conducted with seven individuals with cognitive disabilities. The study data comprised 20 trials with a caregiver’s assistance and 35 trials with the TEBRA system’s assistance. The results showed that all participants were able to perform significantly more independent steps of the tooth brushing task with the TEBRA system compared to only with a human caregiver.

All of these context-aware prompting systems were compared with the baseline condition where no ATC assistance was given to the participants. It was still not clear to what extent such advanced automatic systems would be beneficial when compared to commercially available devices. In this project, we will assess the feasibility of an automatic prompting method for guiding users with TBI to complete kitchen related sequencing tasks. We will examine how much performance improvement users would have when with the automatic method comparing to a user-controlled prompting method, to what extent users would accept the automatic method, and the technology capacity. The user-controlled method is based on the same commercially app we used in Chapter 3, Visual Impact Pro [87], where users need to confirm each step before proceeding to the next. The automatic method delivers prompts automatically based on context inferences through a network of sensors embedded in the kitchen environment and confirmations provided by a human observer. Proposed sensor inferences and future prompts in Chapter 3 have been implemented in this automatic prompting method. Using a human observer to confirm or override sensor decisions allows us to not only evaluate the adequacy of context inferences made by the system, but also evaluate the full potential of an automatic method. We would also like to explore the possible relationship between participants' neuropsychological characteristics and their performance and feedback when with the automatic method.

5.2 METHODS

The study was approved by both the University of Pittsburgh Institutional Review Board and the VA Pittsburgh Healthcare System Institutional Review Board.

5.2.1 Settings

The study was conducted in the research kitchen of the Human Engineering Research Labs (HERL), which is the research collaboration between the University of Pittsburgh, VA Pittsburgh Healthcare System, and the UPMC. Tests were performed in the Cueing Kitchen testbed (introduced in chapter 4) in the Activities of Daily Living Lab at HERL. A randomized cross-over design was used in this study to compare the effect of the automatic method to a user-controlled method.

The research kitchen is a fully functional kitchen with integrated sensor network and prompting elements monitored/controlled by a central computer [88]. Insteon wireless contact switches [89] were used to detect the open/close of furniture cabinets and appliance doors, Kinect [90] were used to detect room occupancy and user actions, and Brultech ECM 1240 Energy Monitor [91] was used to monitor the usage of various kitchen appliances. The central computer can show user interface through a 17’’ computer monitor and deliver audio prompts using speakers installed in the kitchen area. All handles of cabinets and drawers were installed with LED lights which were controlled wirelessly by the software running on the central computer. Cabinets and drawers in the kitchen were labeled to show the categories of items inside.

To reduce carry-over/learning effect in this crossover design for the two prompting methods, we developed two cognitively equivalent kitchen tasks for this evaluation protocol. These two tasks represented a level of cognitive demands sufficient to challenge individuals with impairments secondary to TBI. They required multiple cognitive skills (attention, memory, planning, sequencing, prospective memory, self-monitoring, self-regulation, sensation, judgment) and had sufficient face validity to reflect a task of functional importance and relevance to individuals with TBI. These two tasks also reflected a series cognitive task demands that may be generalized to other daily living and vocational challenges experienced by persons with cognitive impairments.

Each task was broken down into discrete steps, and a task analysis was directed at the cognitive processes underlying performance (Table 12). The two tasks were reviewed by three experts in occupational therapy and neuropsychology. Experts' comments were incorporated during the task development procedure.

Two prompting methods were used in this study including the user-controlled method and the automatic method. Identical pictures and text instructions were used in both methods for the same task. All pictures were photographed in the research kitchen. The verbal instructions for both methods were generated using the Anna voice of Microsoft text-to-speech function in a Windows 7 operating system.

The two cooking tasks using the user-controlled method were programmed with a commercial available app, Visual Impact Pro [87] on an iPad Mini, where participants can navigate the prompts by pressing “Back” and “Next” buttons on the screen (Figure 5). The verbal prompt is delivered immediately when a new step starts.

Table 12. Procedures and Cognitive Task Demands of the Two Tasks

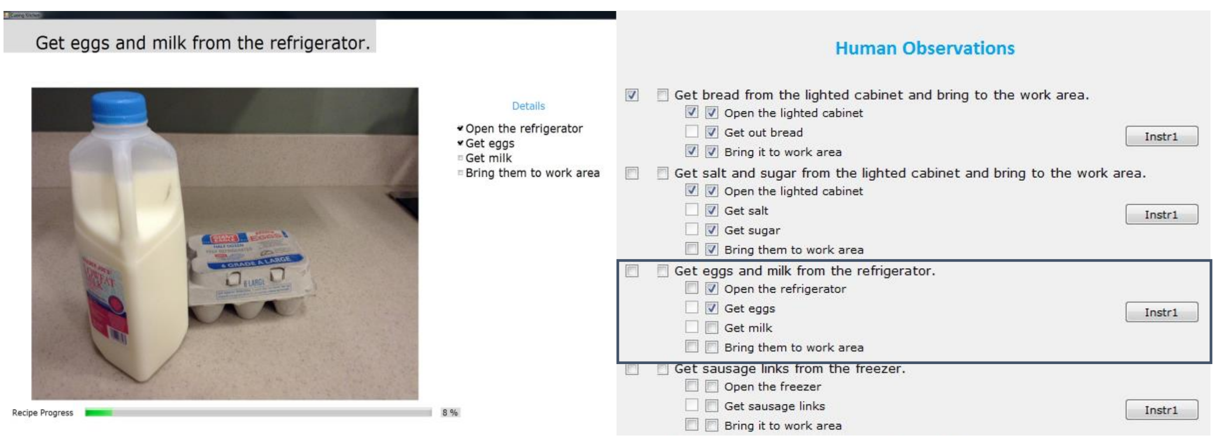
<table>
<tr><th>Task 1-French Toast & Sausage</th><th>Task 2-Pancake & Sausage</th><th>Cognitive Task Demands</th></tr>
<tr><td colspan="2">Locate ingredients and utensils</td><td rowspan="2">Initiation, planning, perceptual motor skills, monitoring</td></tr>
<tr><td>bread, salt, sugar, eggs, milk, sausage links, butter
measuring set, fork, bowl, plate, frying pan, butter knife, spatula</td><td>pancake mix, oil, eggs, milk, sausage patties, butter
measuring set, whisk, bowl, plate, frying pan, butter knife, spatula</td></tr>
<tr><td colspan="2">Measure ingredients</td><td rowspan="2">Judgment, measure, evaluate, perceptual motor skills</td></tr>
<tr><td>1 egg
1/2 TSP of salt
2 TBSP of sugar
1/3 cup of milk</td><td>1 egg
1 cup pancake mix
1 TBSP of oil
1/2 cup of milk</td></tr>
<tr><td colspan="2">Mix ingredients</td><td>Sensory-perceptual skills, judgment, Perceptual motor skills</td></tr>
<tr><td colspan="2">Turn on stove</td><td>Sensory-perceptual skills, Perceptual motor skills</td></tr>
<tr><td colspan="2">Cut butter</td><td>Sensory-perceptual skills, judgment, Perceptual motor skills</td></tr>
<tr><td colspan="2">Specific preparation for the food</td><td rowspan="2">Sensory-perceptual skills, judgment, Perceptual motor skills</td></tr>
<tr><td>-Melt the butter
-Coat the bread both sides in the mixture
-Transfer the coated bread into the pan</td><td>-Melt the butter
-Whisk the butter until well blended
-Pour a small amount of butter into the pan</td></tr>
<tr><td colspan="2">Fry the food on the pan and flip when necessary</td><td>Perceptual motor skills, monitor, evaluate, judgment, prospective memory</td></tr>
<tr><td colspan="2">Multi-tasking module - Turn on the microwave to reheat the sausage while waiting for the food on the pan</td><td rowspan="2">Prospective memory, planning, monitoring, initiation, self-regulation, judgment</td></tr>
<tr><td>Reheat 2 sausage links</td><td>Reheat 2 sausage patties</td></tr>
<tr><td colspan="2">Remove the food to the plate when fully cooked</td><td>Perceptual motor skills, monitor, evaluate</td></tr>
<tr><td colspan="2">Turn off stove</td><td>Sensory-perceptual skills,</td></tr>
<tr><td colspan="2">Return ingredients and utensils</td><td>Planning, perceptual motor skills, monitoring</td></tr>
</table>

Figure 5. Interface of the user-controlled method on an iPad mini

The two cooking tasks using the automatic prompting method were developed by the investigators of this study. The user interface of this method provided the same picture prompt, verbal prompt, and text prompt for each step as the user-controlled method (Figure 6a). In addition, a checklist of details on the screen for each step and light-up handles of target cabinets/drawers for steps involving retrieving items were also included in the automatic method. Step-by-step prompts were delivered automatically based on sensor inferences and confirmed completion of a current step by a human observer on another interface (Figure 6b). Participants did not need to press any button during the process. The human observer only confirmed the occurrence of the expected activities within a fixed amount of time.

Each cooking task was divided into 38 major steps and each major step was divided into 2-4 steps, including a series of details for users' reference and can be monitored by separate sensor events. Each cooking task had 103 steps in total, among which 57 steps had sensor detectable events. The other 46 steps were very visual which cannot be detected by current low-cost sensor settings, for example, cracking the egg in the bowl, mixing the batter until completely smooth, and flipping the bread on the pan. These undetectable steps were only confirmed by the human observer. These 57 sensor detectable steps included 16 events monitored by contact switches, 9 events by power consumption sensors, and 32 events by Kinect. Contact switch events were used to infer whether users opened/closed correct doors of cabinets/drawers/appliances to retrieve cooking ingredients or utensils. Power consumption events were used to infer whether the process of turning on/off an appliance has been completed and whether the food has been cooked for a required amount of time. Kinect sensor events were used to infer whether users completed location-related steps, for example, placing a pan on the stove, bringing a bowl to the sink, and cooking near the stove.

A major step was considered as finished when all included steps had been confirmed as completed successfully by the human observer. Additional secondary prompts would be given automatically if the completion had not been confirmed within a predefined amount of time. Sensor Inference Engine sent machine inferences to the Human Observer Interface (Figure 6b) which can tick check boxes in the first column, and the human observer can confirm/overwrite the user's completion of a step by ticking check boxes in the second column.



(a) User Interface (b) Human Observer Interface

Figure 6. User interface and human observer interface for the automated prompting method

5.2.2 Measures

The Montreal Cognitive Assessment (MoCA), which was designed as a rapid screening instrument for mild cognitive dysfunction, was used to screen out individuals without cognitive impairments [92]. MoCA assesses various cognitive functions which are frequently impaired as sequelae after TBI such as attention, executive functions, memory, language, and visuoconstructional skills. Time to administer the MoCA is approximately 10 minutes. The score range is 0-30 points. The MoCA has been shown to be valid and sensitive to subtle cognitive deficits in a variety of populations including TBI [93-95]. Studies revealed an balance of sensitivity and specificity at cut off score 25 to differentiate individuals with TBI or mild cognitive impairments from healthy controls [94, 95]. Guise et al. contucted a study to examine MoCA in 214 patients with TBI and results showed that the range of patients' MoCA scores was [11.56, 24.60] [93]. Hence, the high cut off score was set to 25 and low cut off score was set to 11.

A battery of neuropsychological/behavioral assessment tests was used to assess cognitive levels of participants. The assessment includes six standard tests on different cognitive domains: Digit Span and Digit Symbol subtests from the Wechsler Adult Intelligence Scale-Third edition (WAIS-III) [96], Visual Reproduction from the Wechsler Memory Scale–Third Edition (WMS-III) [97], the California Verbal Learning Test–Second Edition (CVLT–II) [98], the Trail Making Test (condition 4: number-letter switching) from the Delis–Kaplan Executive Function System (D-KEFS) [99], and Modified Six Elements Test from Behavioral Assessment of the Dysexecutive Syndrome (BADS) [100]. Eight scores of this battery were used. Score of Digit Span were used to evaluate participants' attention. Scores of Digit Symbol were used to assess participants' processing speed. Visual Reproduction recognition score was used to assess participants' capabilities to recognize actual kitchen items after seeing a pictorial prompt. Scores of CVLT–II immediate free recall, short-delay free recall, and long-delay free recall were used to evaluate participants' verbal learning and memory. Score of Trail Making Test, Condition 4 number-letter switching, was used to test cognitive flexibility and multi-tasking. Modified Six Elements profile score was used to assess functions in planning, task scheduling, and self-monitoring.

The Performance Assessment of Self-Care Skills (PASS) is a performance-based, criterion-referenced, observational tool designed to assist practitioners in documenting functional status and change in many populations including TBI, and has been shown to be valid and have excellent test-retest reliability, and inter-observer reliability [75]. Individuals are assessed on their ability to carry out a task and whether their performance meets pre-defined criteria while completing the task. The PASS consists of 26 core tasks in mobility, personal self-care, IADLs with a cognitive emphasis, and IADLs with a physical emphasis. It also provides a template for others to develop new PASS tasks. The two cooking tasks used in this study were adapted from PASS core tasks (appendix E). PASS tasks are decomposed into atomic steps that can be rated on independence, safety, and adequacy. Independence refers to how much assistance the individual needs to complete the step. PASS structured a grid of the hierarchical assistance for each step includes nine levels of graduated prompts, starting with (1) verbal supportive, (2) verbal non-directive, (3) verbal directive, (4) gestures, (5) task or environment rearrangement, (6) demonstration, (7) physical guidance, (8) physical support, and (9) total assist. When a task cannot be performed independently, the investigator provides the least powerful/intrusive type of assistance to facilitate task performance and place a checkmark each time a prompt is given for the participant to accomplish the step. The total amount of assistance needed by the participant (total number of prompts given by the investigator) through completing a whole task and the highest level of the assistance were used to evaluate the independence of participants in this study. Safety refers to whether the individual is taking risks to their personal safety or the environment while completing the task. Under Safety, the investigator places a checkmark for each step if any safety-threatening activities are observed or if the investigator is required to intervene because of a risk to safety. Each step is assigned a safety score on four-point ordinal scale from 0 (step stopped by investigator to prevent personal injury) to 3 (completely safe practices). The safety summary score for the whole task is computed as the minimum of the safety scores for each step. Adequacy refers to how well the task is performed, including the quality of the outcome of the task and the quality of the process of reaching that outcome. The adequacy summary score is quantified by the investigator who considers the frequency and severity of the process and outcome issues encountered by the participant while performing the task. The score is rated on a four-point ordinal scale from 0 (outcome standards not met, process so poor that it prevents the completion of the task) to 3 (task performed relatively efficiently and with outcome standards met). The adequacy summary score for the whole task is computed as the minimum of the adequacy scores for each step.

NASA Task Load Index (TLX) were used to assess subjective workload of subjects with the two prompting methods [101, 102]. It consists of six dimensions: mental demands, physical demands, temporal demands, performance, efforts, and frustration. Twenty-step bipolar scales are used to obtain ratings on these dimensions, resulting in a score between 0-100. A score of 0 indicates the minimal level and a score of 100 indicates the maximal level of each dimension.

The custom questionnaire was developed by the investigators of this study to assess the user-perceived ease-of-use and usefulness of the two prompting methods, user stress levels, as well as to obtain qualitative feedback from the participants (appendix F) and the questionnaire were reviewed by three experts in occupational therapy and rehabilitation science. The user-perceived ease-of-use and usefulness were assessed using 7-point Likert scales (1=strongly disagree and 7 = strongly agree) on statements adapted from the Technology Acceptance Model (TAM) [76]. There were 10 statements for perceived usefulness and 7 statements for ease-of-use. The total score for perceived usefulness was calculated by adding the user response for each statement and ranged from 10 to 70, while the total score for perceived ease-of-use was ranged from 7 to 49. Both scores were then scaled between 0 and 1(0=most negative, 1=most positive). The stress/anxiety level was assessed with eight questions from the Emotional Distress- Anxiety-Short Form 8a of the Patient-Reported Outcome Measurement Information System (PROMIS) [103]. Each question has 5-point response options ranging in value from 1 to 5 (1=Never and 5=Always). The values of the response to each question were summed as a raw score for the stress level and the score ranged from 8 to 40 (8= Not stressful and 40=extremely stressful). Open-ended semi-structure interview questions were also used to obtain user feedback on specific features of each prompting method and preferences to the two prompting methods.

5.2.3 Participants

Participants were recruited through the TBI Research Registry at the University of Pittsburgh Medical Center's Rehabilitation Institute, which contains 431 patients with a TBI diagnosis, and through advertisements and outreach at local brain injury support groups and agencies serving individuals with TBI. Inclusion criteria consisted of 1) over the age of 18; 2) have mild to severe TBI based on self-report; 3) at least 6 months post injury; 4) live in a private or group residential setting; 5) participants are able to understand the purpose, risks, benefits, and voluntary nature of this study; 6) participants score between 11 and 25 in the MoCA screening test. Participants were excluded from the study 1) if they have severe physical impairments that prevent them from independently completing kitchen tasks; 2) if they have vision or hearing impairments that cannot be corrected by the use of assistive technology. Sixteen individuals with TBI participated in this study.

5.2.4 Procedures

Participants paid one visit to HERL. After the consent process, eligible participants filled a demographic questionnaire. A brief orientation session was then followed where an investigator demonstrated the organization of the kitchen and how to use the appliances such as the stove and the microwave oven. Each prompting method was demonstrated to the participants before the start of the cooking tasks. A usability checklist was used to make sure participants were able to retrieve ingredients/utensils, operate the stove and the microwave oven, and use each prompting method in the kitchen before the testing started.

Participants were asked to complete two cooking tasks using different prompting methods. The sequence of the two prompting methods and two cooking tasks was counterbalanced. All ingredients and utensils needed for these two tasks were placed in the kitchen. During the cooking tasks, participants were evaluated by an investigator using the

PASS. After each task, a NASA TLX questionnaire and a custom questionnaire were administered.

Participants were administered half of the neuropsychological/behavioral assessment battery after the first cooking task and the other half after the second cooking task. The reasons for separating the assessments to two parts were to add some washout time between two cooking tasks and to prevent mental fatigue of participants. The first half of the assessment included Visual Reproduction, Modified Six Elements Test, Trail Making Test (condition 4: number-letter switching), and Digit Span. The second half of the assessments included CVLT-II and Digit Symbol.

5.2.5 Data analysis

Descriptive statistics were used to analyze the data obtained from the demographic and the custom questionnaire. Content analysis was conducted to extract common themes from the observations and interviews. Means and standard deviations were calculated for all quantitative variables. Paired t-test was used to compare the scores from the PASS, NASA TLX, usability ratings, and stress levels between the two prompting methods. All tests were two-tailed and the level of significance was set to 0.05.

To examine the relationship between participants' neuropsychological characteristics and the relationship with user performance and subjective ratings between the two methods, we first obtained the difference between the two prompting methods in user performance (safety summary score, adequacy summary score, total amount of required assistance, highest level of required assistance), cognitive load (NASA-TLX score), and usability ratings (usefulness, ease-of-use, stress level). Then raw scores of the neuropsychological/behavioral assessment battery were converted to T scores. Spearman's rho correlation was used to examine the relationship between participants' T scores of the neuropsychological/behavioral tests and the differences in user performance, cognitive load, and usability ratings with the two prompting methods.

Machine inferences and the human observer decisions for all steps during cooking tasks were logged with timestamps through the system software. The system received binary on/off or enter/exit signals together with timestamps from the contact switch sensors and the Kinect sensor, and power consumption logging data of specific outlets from the power monitor sensor. The number of steps where the machine inferences were made, and the timing difference between the machine inferences and human observer's confirmation were obtained. We calculated the percentage of total sensor-detectable steps where the machine inferences were made adequately for each participant. The criteria to define "adequately" included that machine inferences were in agreement with human observer decisions, the timing difference was within 5 seconds before human observer decisions, and the supervising investigator did not intervene to correct the participants after machine inferences were made. The results were also categorized by the type of sensors.

Content analysis was conducted by two investigators independently to extract common themes from the observations and interviews.

5.3 RESULTS

5.3.1 Participants

Sixteen adults with TBI participated in this study (Table 13). The average age was 46.8±13.7 years old and the duration post brain injury was 12.8±10.9 years. Fifteen participants lived in community settings and one participant lived in the group home of a local rehabilitation institute. All participants were able to walk without using any mobility assistive technology.

Table 13. Demographic information of participants

Demographic variables		Mean ± SD
Age		46.8 ± 13.7
Post TBI (yrs.)		12.8 ± 10.9
Sex	Female	6
	Male	10
Ethnicity	African-American	1
	Caucasian	15

5.3.2 User performance

As shown in Table 14, no significant difference was found in the PASS safety scores, adequacy scores, and highest level of required assistance between the automatic prompting and the user-controlled method. However, participants required significantly less amount of assistance from the investigator when using the automatic method compared to the user-controlled method (1.19±1.60 vs 2.94±3.23, p=0.034).

5.3.3 Quantitative feedback

Table 14 also showed the results for user ratings in the custom questionnaire. No significant difference was found in user-perceived usefulness and NASA-TLX scores bwteen the two prompting methods. The automatic method received significantly better ratings in user-percieved ease-of-use than the user-controlled method (0.92±0.08 vs 0.85±0.14, *p*=0.016). Participants also reported less stress when using the automatic method compared to the user-controlled method (10.44±3.16 vs 12.50±4.51, *p*=0.047).

Table 14. Results from Paired-T test for outcomes from participants (n=16)

Outcomes	Automatic Method	User-controlled Method	Paired-T test (two tail)	
	Mean (SD)	Mean (SD)	t	P
Objective outcomes				
PASS- Safety summary score	2.88 (0.34)	2.75(0.48)	1.00	0.333
PASS- Adequacy summary score	2.75 (0.45)	2.38 (0.50)	2.09	0.054
PASS- Total amount of required assistance	1.19 (1.60)	2.94 (3.23)	-2.33	0.034*
PASS- Highest level of required assistance	1.75 (2.05)	2.50 (1.15)	-1.11	0.283
Subjective outcomes				
NASA-TLX[1]	23.83 (13.62)	29.78 (14.51)	-2.04	0.060
Usefulness	0.89 (0.01)	0.87 (0.14)	1.39	0.186
Ease-of-use	0.92 (0.08)	0.85 (0.14)	2.71	0.016*
Stress	10.44 (3.16)	12.50 (4.51)	-2.17	0.047*

1: One participant failed to complete the NASA-TLX questionnaire. There were only 15 data points for NASA-TLX results.

5.3.4 Possible relationship between neuropsychological characteristics and user performance and feedback

Participants' T scores of the CVLT Long-delay free recall was significantly correlated with the difference of the amount of assistance between two methods (rho=0.552, p=0.027), indicating that comparing to using the user-controlled method, for participants with lower scores in this test, their required assistance tended to decrease more when using the automatic prompting system. Participants' T scores of the Modified Six Elements test was significantly correlated with the difference of the safety scores between two methods (rho=-0.591, p=0.016), indicating that participants with lower scores in this test tended to have greater improvement in safety scores with the automatic method versus the user-controlled method. All the other differences in user performance and usability ratings were not significantly correlated the results of the neuropsychological/behavioral tests.

When examining the relationship between neuropsychological/behavioral tests and usability ratings of both methods using spearman's rho correlation test, we found the T scores of Digit symbol, CVLT immediate recall, and Trail Making test were significantly correlated with the user-perceived usefulness of the automatic method (rho=-.561, p=.024; rho=-.532, p=0.034; rho=-.512, p=0.042, respectively), indicating that participants with lower scores in these three tests tended to give better ratings to the usefulness of the automatic method. All the other test results were not significantly correlated with the usability ratings of each prompting method.

5.3.5 Machine inferences

Table 15 showed the results of machine inferences compared to human observer decisions. Approximately 90% of machine inferences made based on contact switch sensors agreed with human observer decisions in detecting both the occurrence of these events and the appropriate timing for users to complete these events. Around 60% of machine inferences made based on power consumption sensors and Kinect sensor agreed with the occurrence of relevant events, but less than 20% of these inferences were made at appropriate timing when users actually completed relevant tasks. Most of these power sensor and Kinect inferences were made ahead of the actually time when users were ready to go to the next step.

Table 15. Machine inferences made by different types of sensors (N=15*)

	Machine inferences agree with human observer decisions		Machine inferences' timing agree with human observer timing (±5 seconds)
	Percentage (mean ± SD)	Timing Differences** (seconds)	Percentage (mean ± SD)
All sensors	67.5% ± 7.9%	-------------	34.1% ± 6.2%
Contact switch sensors	96.0% ± 4.75%	-0.8±1.4	92.9% ± 6.4%
Power consumption sensors	62.4% ± 17.3%	-28.0±31.1	15.4% ±12.5%
Kinect sensor	59.4% ± 13.3%	-17.4±18.9	12.8% ± 8.0%

* The data of 15 trials of 15 participants (P2-P16) were used for analysis. Each trial included 57 sensor detectable steps with machine inferences.
** Timing difference was calculated by machine inference time minus human observer time for each sensor event. Minus value in timing difference meant that the machine inferences were made ahead of human observer decisions. Results showed for the timing differences are the median value of the average timing differences of all sensor events for each participant plus minus the median value of the standard deviation of timing differences of all sensor events for each participant.

5.3.6 Qualitative feedback

Qualitative feedback during the semi-structured interview was summarized as follows:

User-perceived Usefulness

Regarding the perceived usefulness, nine participants thought the automatic method was more useful than the user-controlled method. The two main advantages of the automatic method mentioned by the participants were the hands-free feature, and the capability of providing system confirmations for safety concerns (for example, the user interface showed that the stove has been turned off). These participants thought the hands-free feature made the procedure more fluent, and the confirmations provided by the automatic method for each step made them feel safe and secure during the cooking tasks.

P4 "The automated one (was more useful). It watches you through it, physically and mentally, rather than having to bring something back and hit a button, then it goes on to the next thing. It's already done that for you, walking you through it, and after you are done, it says hey you're done, lets' going on to this.”

P6 “The automatic system was more useful. The other (the user-controlled method) was more like you are pressing "next", "next", "next"... The automatic one, even though just don't pressing that "Next", make it more fluent.”

P12 “AU is more useful. It walks me through step by step. There is a flow to it. And the safety issue are really more useful, it will keep reminding me come back to the stove.”

P13 “The automatic method, especially for newly injured people. The details (confirmations) told you whether you did it. The detail feature and it moves automatically are great in the whole process.”

Six participants felt the user-controlled method was more helpful because they had greater control on the pace/timing of completing the tasks. They liked the fact that users were allowed to stop at any time or skip some steps with this prompting method. One participant (P11) also mentioned that if users can control their pace by voice, that’ll be ideal.

P1 “I prefer the user-controlled one. I like the ability to skip forward, and also to return.”

P7 “The user-controlled one was more useful, because it's my rate of speed.”

P8 “The user-controlled one (more useful). Because I could go at my own pace.”

P11 “For the user-controlled method, if I can just say NEXT and it can move on, that'll be ideal. Because my hands were dirty, I didn't want to push the NEXT.”

Several participants also stated that the inventory-based light-up handles feature of the automatic system was very helpful and they would like to have user-controlled method to include this feature. One participant (P1) also suggested that more assistance may be needed with the grocery shopping based on the inventory system.

P1 “There is one thing I can definitely recommend for both systems. Is it possible to have a grocery checklist or something on the computer itself, so whenever they (users) in supermarket, they can see what they need to get?”

P8 “The only thing I would think most beneficial of the automated method, was the door handles light up. You don't need to run and looking for where things were. If you can interface that into the user-controlled app, that'll work too. That'll be great.”

P16 “I have a strange suggestion for you, maybe why don't you link your system with Giant Eagle. When I go and use my Giant Eagle card, and I bought the ingredients, when it goes and identifies your system, (the system) tells you for the recipe, you haven't bought this, the ingredients you are going to do with the recipe. You will not only be my cooking instructor, but also my supply instructor.”

Stress and workload

Regarding the sources of stress and work load using each prompting method, five participants stated that working with the user-controlled method was more stressful because there was no confirmation from this prompting method, and they needed to monitor/check the progress on their own.

P11 “I was more stressful with the user-controlled one because I was not sure about the cooking time.”

P15 “The user-controlled method was more stressful, because I’m trying to remember that the stove is on, which burner I'm using, and walking away from it. I need to monitor myself for many things.”

Three participants felt the automatic method was more stressful because they did not have control on the timing of prompts.

P3"(when using the automatic method) you were driven by the system and lost freedom and flexibility."

P12 "I think the automatic method was more stressful, because I have to be more alert cause I don't know when the next prompt would be given, and if I miss something, I could not go back."

The other eight participants thought these two prompting methods were similarly stressful or not stressful at all.

User Acceptance

Participants also gave feedback on whether they would like to install the automatic prompting system in their own kitchen. Nine out of the sixteen participants were willing to use this automatic prompting system at home. The main reasons they mentioned were the sensor monitoring capabilities of the system. These participants favored the features that the system was able to monitor the use of appliances, to display context-aware visual confirmations on user activities, and to provide sensor-based reminders. Participants thought that these features enhanced their self-awareness, helped with concentrations, and made them feel more confident and secure with cooking tasks. Several participants' quotes were listed below.

P1 "I like the portion that the (automatic) system knows how long the microwave has cooked. I like the system knowing the stove, and the microwave, and being able to jog between. You can actually see 'yes, I'm cooking two things', rather than somebody like my case, would burn things and forgetting I'm cooking it".

P5 "I guess the reminder thing is the best aspect… I guess I would be more secure with that just because my experience with distractions."

P6 “Yes, it (the automatic prompting system) makes you aware of it, just be more aware what I'm doing, won't get distracted.”

P11 “I feel like more confident with the automated system, cause it would know whether I finished the step so it would move on, so I know I did it right.”

P12 “Yes. I think the bigger reason is safety, it (the automatic prompting system) can be really helpful that way.”

However, the other seven participants were not willing to use this automatic prompting system at home. Participants didn’t like the fact that they cannot work on their own pace with the automatic system. They would rather use the user-controlled method instead. Two participants (P4 and P15) liked the required more mental thinking of this method.

P4 “(I prefer) the user-controlled one, I would rather feel I'm capable of doing something. I'd rather push myself to improve more.”

P15 “The user-controlled method makes me think more, which is great, which means your brain is working and may be better for my rehabilitation.”

In addition, the advantages of the user-controlled method like portability, practicality, easy-to-maintain, and family-friendly features were also favored.

P3 “I'm afraid that I would break the automatic system. My kids know how to use their own iPad, so they can help me with the user-controlled app on the iPad.”

P8 “You don't need to have a smart kitchen. You can bring it (user-controlled app on the iPad) to a friend's house and cook at friend's house, use the app. That's what I like most.”

P10 “The user-controlled one is a lot more practical. It's portable. You can take it to any kitchen and you can stick it (the app) on any commercial device.”

Some participants also expressed concerns about the cost of the automatic system. When asked about how much money would be reasonable and affordable for the automatic prompting system, five participants listed prices under $500, six participants proposed prices between $500 to $1,200, and the other participants listed prices between $1200 to $20,000.

5.4 DISCUSSION

This study assessed the feasibility of an automatic prompting system in assisting people with TBI in cooking tasks. Compared to the user-controlled prompting method, the automatic method showed advantages in improving user performance. Results also showed that the automatic method received better ratings in user perceived ease-of-use and was helpful for decreasing stress levels. However, participants showed concerns about the limited flexibility and control on their own timing of this automatic prompting system.

Regarding user performance, the automatic system showed significant effect in improving independence levels of participants with TBI. The system not only decreased the average amount of external assistance required by participants, but also enabled several participants to complete the cooking tasks independently. By looking at the PASS results of each participant individually (appendix G), we found that 12 out of 16 participants required less assistance with the automatic method; six participants (P1, P5, P8, P11, P12, and P16) complete tasks independently with the automatic method while they all required necessary assistance when using the user-controlled method. How effectively an ATC can enable users with cognitive impairments to cook safely is a critical question. Chapter 3 showed that the user-controlled method failed to prevent safety-threatening activities compared to the paper-based method. In this study, the automatic system controlled the process of tasks and the timing of prompts instead of relying on the self-monitoring by users. This feature had the potential to avoid/decrease safety-threatening activities of participants. According to the qualitative feedback, most participants did think that the automatic method make them feel more secure and comfortable with cooking tasks, but the average safety score based on the PASS evaluation did not show significant differences between the automatic method and the user-controlled method. There may be several reasons. First, most participants stated that leaving the stove or oven on after they were distracted during cooking was a major type of safety-threatening activity in cooking. Our study was conducted in a laboratory environment with two investigators being present in the kitchen area during the testing. Participants were relatively alert during the cooking tasks and less likely to get distracted, so there was less chance of them to perform safety-threatening activities. Secondly, the study only asked the participants to perform one cooking trial with each prompting method. Long-term use of the automatic prompting system in participants' own kitchens could be valuable to evaluate.

Regarding user experience and acceptance, most participants rated the automatic system as easier to use and less stressful due to sensor-based confirmations and reminders, but the loss of control on the timing of prompts turned out the be a major concern. The actual timing of prompts in this automatic prompting system were controlled by human observer decisions, which can be viewed as the optimal timing that an automatic system can provide with most advanced monitoring technology and artificial intelligence. However, according to participant feedback, the automatic timing for step-by-step prompts was not what they would need or prefer, instead, most participants were against this feature and thought it harmed their feeling of control, increased stress, and decreased their motivations. Even more advanced sensors and algorithms can be implemented to better predict the timing, users won’t like the timing controlled by the machine. We learned an important lesson that the aim of future sensor-based automatic prompting system should not be set to minimize or totally replace users’ mental thinking. Instead, the required mental workload should be adjusted to an appropriate level to balance safety, function, and flexibility. Several participants mentioned that a certain amount of thinking and challenges during the tasks could be beneficial for their cognitive rehabilitation and keep them motivated. The prompting system should be designed to involve users’ thinking, decisions, and self-checking at a level that matches their capability. Users need to feel that the prompting system is designed to help them at some critical challenging points instead of replacing their mental thinking.

Future development of advanced prompting devices may consider adding some portable reliable sensing components to the current user-controlled method to make a semi-automatic system. Instead of using sensor inferences to control the timing of prompts, future prompting systems may return the pace control to user themselves, and use sensing information as back-up assistance for users in critical situations. This system should be able to help users monitor their actions and offer confirmations, especially at steps with safety concerns, thus enhancing the sense of security and reducing the stress levels from self-prompting and self-monitoring. In addition, secondary reminders could be added based on sensor information or time duration in a current step to hold users’ attention. The semi-automatic system could also involve user feedback through voice recognition or voice control to free their hands. Detailed content of tasks and prompts should be customizable to maximize users’ flexibility. In this way, the prompting system can still be kept at an affordable price and relatively simple structure to avoid complex setting up and maintenance process, and it would be more practical and feasible for individuals with TBI to accept and use these assistance in their home kitchens.

We also explored the technical feasibility and capacity of this automatic prompting system. Machine inferences in this system were using a rule-based approach, where spatial-temporal information from three types of sensor events were used to infer the occurrence/completion of specific cooking steps. Results showed that it was pretty accurate and timing-wise adequate for the machine inferences made based on contact switch sensor signals for participants to open/close cabinets, drawers, and the refrigerator to retrieval/return items. However, the machine inferences based on power consumption and Kinect signals were not adequate enough. Only around 60% of these machine inferences agreed with human observations and most of these machine inferences were made 20-30 seconds ahead of human observer decisions, which was used as the gold-standard completion timing of participants' actual activities. There are several reasons for the results. Frist, the system was designed in a way that relevant machine inferences would only be made within the process of a major step. After this major step was completed by the participants (according to human observer decisions), the system delivers prompts for the next major step automatically and also starts to make inferences for the next major step. Events where machine inferences were not made before the completion of the major step, the system would no longer monitor and infer these events. Thus, machine inferences that did not agreed with human observer decisions may mainly due to the limited system speed of making inferences. It usually took several seconds for the power consumption sensors and the Kinect sensor to update signals. Secondly, the timing of the completion for each particular step required precise inferences during cooking tasks. Without the training period for the machine to learn each participant's activity patterns, it was challenging for our rule-based assumptions to infer the timing of an event. Third, the time threshold set in the system seemed to be shorter than the actual time participants took to complete tasks, especially for steps monitored by power sensors and Kinect sensors. For example, the system would infer that participants completed the returning the dishes task after being monitored that the participant had moved to the sink area after received the prompt “Bring the used dishes to the sink” and stayed there for 5 seconds. However, most participants took longer to place and organize the dishes in the sink. These situations also happened to inferences made based on power consumption sensors. Participants usually took longer when cooking to complete using appliances than our assumptions. Thus, with the current design and structure of our system, the capability to infer adequate timing for each prompt and predict user activities is limited.

We explored possible relationship between participants’ neuropsychological/behavioral characteristics and their performance and responses to the automatic prompting system. Results indicated some possible trend that people with more impaired cognition may benefit more from using the automatic prompting system, but strong associations between global cognition levels and participants’ responses to ATC were not found. The reasons may be related to the sample of this study or to the measures we selected. Given the small sample size, the range of cognitive impairments of participants was limited and most of the participants were well post injury. The neuropsychological tests used in this study were more to test individuals’ levels in a structured way, which may have limited generalizability to predict participants’ functioning abilities in the real world. Future study may examine the relationship using larger sample that can present a full range of cognitive impairments and recovery levels of people with TBI through more comprehensive behavioral tests.

This study has several limitations. First, although the content of prompts (text, audio, and image) of these two prompting methods were the same, the two prompting methods used different screen sizes with one using the iPad Mini and the other using a 17” computer monitor. The automatic method also used light-up handles to help with retrieving items. These factors can affect user experience. Secondly, this study used a randomized crossover design, where the learning effect may affect user performance and experience. Thirdly, the testing was conducted in a laboratory setting instead of participants’ own kitchens and each participant was only completed the tasks once. The unfamiliar environment may affect their performance and the results only presented the one-time effect of the system. Fourth, the sample size was relatively small and the range of participants’ cognitive impairments were limited. The feasibility of this automatic prompting system among acute TBI survivors were still left unknown. The cognitive impairments of participants may have possible effects on the self-reported outcomes in this study. However, the information we got from semi-structured interviews were consistent with participants’ self-reported quantitative outcomes on usability of both methods, their stressful levels, and their workload, and these information also provided insight to the results, which helped to some extent to increase the validity and reliability of the self-reported outcomes.

Nonetheless, to the best of our knowledge, this is the first study to assess the feasibility of a context-aware automatic prompting system, comparing to a readily available user-controlled prompting method. The results provided insight into the potential benefits of the context-aware prompting system and user acceptance. The information would also contribute to the future development of advanced prompting technology for people with TBI or other cognitive impairments in completing sequential tasks.

6.0 CONCLUSIONS AND FUTURE RESEARCH

6.1 CONTRIBUTIONS

This dissertation discussed the development and evaluation of an assistive prompting system for people with TBI in completing sequential cooking tasks. This dissertation contributes in the following ways.

First of all, different methodologies including survey, ethnographic observations, interviews, and randomized cross-over design were used in this dissertation to identify specific user needs for advanced sequencing devices to guide future development of more intuitive cognitive assistive devices for people with TBI. Needs statements and insights were identified to direct future development of ATC. Results also proved that participants were not able to complete multi-step cooking tasks independently using a traditional paper-based method or conventional user-controlled method. Context-aware prompting and monitoring systems are in need. In addition, specific events needed to be monitored or reminded in particular scenarios and users' needs for pace control and flexibility were also identified.

Secondly, the sensor-network based Cueing Kitchen testbed was developed. This testbed not only works as a platform to evaluate and compare different prompting methods and prompting modalities among people with cognitive impairments, it can also facilitate future development of ATC applications for various kitchen tasks. The feasibility of using low-cost sensors to improve the effectiveness of conventional prompting methods was also studied. Even though results showed that it was difficult to make timing-wise adequate machine inferences to predict the pace of participants, a wireless sensor-network does have potential to provide sensor-based monitoring and reminders for critical safety-related events and distractions.

Thirdly, effectiveness and usability of different types of prompting methods were compared in this dissertation, including a traditional paper-based method, a commercial available user-controlled method, and an ideal automatic method. The findings contribute to the understanding of how context-aware prompting methods may help. Results showed that the automatic method decreased the amount of external assistance required by participants, improved the adequacy of task completion, and was helpful for decreasing user stress level compared to the user-controlled method, especially for participants with more impaired cognition. The user-controlled method showed strengths in offering participants more flexibility and control on the timing of prompts.

Fourthly, this dissertation explored the relationship between participants' neuropsychological characteristics and responses to different levels of ATC interventions. This research contributes to the understanding of user satisfaction, and the relationship between clinical characteristics of individuals with TBI and specific features of prompting methods. These findings may facilitate future prescription of cognitive assistive devices, improve the match of technology and person with different profiles, and reduce the abandonment rate of cognitive assistive devices.

This research will potentially increase the independence of individuals with TBI and reduce caregiver or family members' burden by supporting the completion of sequential activities. The findings of this research may extend beyond home-based IADLs to target other life areas such as vocational tasks. The information may also be helpful for research among people with cognitive impairments due to other diagnoses such as stroke, multiple sclerosis, and dementia.

6.2 FUTURE RESEARCH

Future research may continue to incorporate low-cost sensors for conventional user-controlled prompting. The semi-automatic hybrid system may provide context-based prompts to reduce the amount of inputs from users while still offer control and flexibility to people with TBI. Sensor-based monitoring and context-aware reminders should focus on critical safety-related events and distractions. Future advanced prompting systems may return the pace control to the user themselves, and use sensing information as back-up assistance for users in critical situations, make users more secure, comfortable, and less stressful.

Family members, caregivers, and clinical professionals may need to be more involved in the development and evaluation of future assistive prompting systems. To make future prompting systems effective, feasible, and practical in end-users homes, researchers may want to pay more attention to the family-friendly design of the system and how to simplify the process of set-up, customizability, and maintenance of the systems for these supporters of people with TBI. Some sensor-based home monitoring systems focused on the safety of end-users may also be able to make these tasks less stressful and more secure.

We also learned that a grocery shopping assistant and inventory management are needed for people with cognitive impairments. How to link these functions with context-aware prompting system may be very important to enhance the independence of end-users.

Future evaluation studies on prompting systems may expand to more types of sequential tasks, not only the IADLs, but also vocational tasks. The long-term effect of these advanced systems in the field also needs to be further studied.

Therefore, we designed a semi-automatic cognitive assistive system, "Portable Cueing Kitchen", as the next phase of the Cueing Kitchen system to provide context-based prompts while reducing the amount of inputs from users with cognitive impairments. The Portable Cueing Kitchen will integrate a series of sensors embedded in the environment, and two sets of software to provide safety monitoring, activity detection, and customizable task guidance for end-users and caregivers/family members. This system may also be used in rehabilitation clinics and group homes to provide treatment/training to clients with cognitive impairments in cooking related tasks or other sequential activities.

The Portable Cueing Kitchen will include a computer and a smartphone or pad. The computer will keep collecting information from embedded sensors and updating a sensor database on a web server. The smart phone or pad will run apps for end-users and caregivers/family members. Specific features of the Portable Cueing Kitchen system are proposed as follows:

1) The Portable Cueing Kitchen will be a portable, affordable, and easy-to-deploy context-aware system for sequencing tasks.

2) The Portable Cueing Kitchen will provide customizable pre-programmed cooking tasks, which can present adaptive and intelligent text, audio, picture, and video prompts based on

sensor inferred user activities, to assist users in completing cooking related tasks with minimal user input.

3) The Portable Cueing Kitchen will allow users to control/respond to the app by voice.

4) The Portable Cueing Kitchen will enhance end-users' safety in cooking tasks. End-users will receive alerts on their mobile devices (e.g. Smart phones or pads) if any potentially hazardous situations (e.g. the stove has been left on after cooking) detected by integrated sensor network embedded in the environment. They will also be able to check the safety status of appliances remotely through the app.

5) The Portable Cueing Kitchen will enable caregivers/family members to monitor the safety of end-users remotely. Caregivers/family members will receive alerts on their mobile devices if end-users leave appliances on longer than preset safe duration threshold and will be able to check the status of appliances in end-users home and the frequency and timing of end-users cooking/dinning activities remotely through the app.

6) The Portable Cueing Kitchen will help users to do food planning and preparation for cooking. For example, end-users can choose all recipes that they would like to cook for the next week, based on which the system can recommend a grocery shopping list for caregivers/family members. End-users will also be able to receive reminders to do some food preparation (e.g. food defrosts) sometime before a recipe is scheduled.

APPENDIX A

PART I FORM

Cognitive Assistive Technology Survey

SUBJECT ID_______

1. What is your age?

____

2. What is your gender?

- ☐ Male
- ☐ Female

3. Which one is your primary racial group?

- ☐ White or Caucasian
- ☐ Black or African American
- ☐ Hispanic or Latino
- ☐ Asian
- ☐ American Indian or Alaskan Native
- ☐ Two or more races
- ☐ Native Hawaiian or other Pacific Islander

4. What is/are your other diagnoses besides TBI? Please choose all that apply.

- ☐ Spinal Cord Injury
- ☐ Multiple Sclerosis
- ☐ Rheumatoid Arthritis
- ☐ Stroke
- ☐ Amputation
- ☐ PTSD/Anxiety Disorder
- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Other_______________

5. Are you a US Veteran?

- ☐ Yes, I am a veteran
- ☐ No, I am not a veteran
- ☐ No, I am active duty

6. What was your rank at time of discharge?

- ☐ Enlisted
- ☐ Warrant Officer
- ☐ Officer

7. In which branch of the military did you serve/are you serving?

- ☐ Army
- ☐ Marines
- ☐ United States Air Force
- ☐ Navy
- ☐ US Coast Guard

8. Were you in the National Guard or Reserves?

- ☐ Yes
- ☐ No

9. How long were you in the service or did you serve in total?

____________ years

10. What is the highest level of formal education you have completed?

- ☐ 8th grade or less
- ☐ 9th through 11th grade
- ☐ High School Diploma or GED
- ☐ Technical Certification
- ☐ Associate Degree
- ☐ Bachelor's Degree
- ☐ Master's Degree
- ☐ Doctorate (PhD, MD, JD, etc)
- ☐ Other ___________________

11. What is your marital status?

- ☐ Single, never married
- ☐ Single, but living with a partner as if married
- ☐ Divorced
- ☐ Married
- ☐ Separated
- ☐ Widowed
- ☐ Other: ________________________________

12. Which statement best describes your current employment status?

- ☐ Employed full-time
- ☐ Employed part-time
- ☐ Student
- ☐ Volunteer-based work
- ☐ Seeking employment
- ☐ Retired
- ☐ Not seeking employment
- ☐ Homemaker
- ☐ Not employed due to disability
- ☐ Other: ____________________________

PART I
FORM

Cognitive Assistive Technology Survey

SUBJECT ID________

13. Do you live by yourself?

☐ Yes ☐ No, I live with my family members ☐ No, I live with others

14. Do you have a caregiver?

☐ Yes, my family member(s) ☐ Yes, professional caregiver(s)
☐ No, but I am in the process of getting one ☐ No, I don't need a caregiver

15. Which statement best describes your status in buying new technology devices?

☐ I like to buy the latest technology that is right at the cutting edge as soon as it is available
☐ I may not be the first but I like to own the latest technology before most people
☐ I like to buy the latest technology but only after considering which is best
☐ I like to buy products that have a proven technology rather than simply the latest technology
☐ I only buy new technology when it has become standard and there is no alternative

16. Please mark all the statements below that describe you.
Mark only those that frequently or often apply to you and ignore those that very rarely or never apply to you.

☐ I have the support I want from family	☐ I am usually calm and patient	☐ I find technology interesting
☐ I have the support I want from friends	☐ My life has purpose, meaning	☐ I am cooperative
☐ I feel encouraged by therapists, caregivers	☐ I am self-disciplined	☐ I prefer a quiet lifestyle
☐ I feel the general public accepts me	☐ I am often angry	☐ I often feel isolated & alone
☐ I aspire to go to school or work	☐ I am often depressed	☐ I accomplish what I set out to do
☐ I have many things I want to accomplish	☐ I prefer to be left alone	☐ I am not sure who I am now
☐ I do what my therapists say without question	☐ I am often discouraged	☐ I want more independence
☐ I view my therapist(s) as friends, too	☐ I am quite resourceful	☐ I have a good self-image
☐ I am often frustrated or overwhelmed	☐ I like having a challenge	☐ I often feel insecure
☐ I am curious & excited about new things	☐ I am responsible & reliable	☐ I feel as if I have little privacy
☐ I am determined to meet my goals	☐ I am generally satisfied with my life	☐ My therapist(s) know better than I what I need

SUBJECT ID______

Cognitive Assistive Technology Survey

PART 2 FORM

Do you have challenges with the following daily activities? **Please check all that apply.**	1. No Challenges 2. Minor Challenges 3. Moderate Challenges 4 Serious Challenges			
A. Keep track of appointments (e.g., medical appointments) and other events (e.g., birthday, anniversary, and meetings)	☐ 1	☐ 2	☐ 3	☐ 4
B. Perform tasks that have multiple steps (e.g. meal preparation, laundry)	☐ 1	☐ 2	☐ 3	☐ 4
C. Keep track of what medications are being taken and when to take.	☐ 1	☐ 2	☐ 3	☐ 4
D. Stay focused on a task	☐ 1	☐ 2	☐ 3	☐ 4
E. Remember names and faces (e.g. friends)	☐ 1	☐ 2	☐ 3	☐ 4
F. Locate items (e.g., key, phone, household items)	☐ 1	☐ 2	☐ 3	☐ 4
G. Manage emotion (e.g. frustration, anxiety)	☐ 1	☐ 2	☐ 3	☐ 4
H. Way finding (e.g. indoor, outdoor, familiar or unfamiliar places)	☐ 1	☐ 2	☐ 3	☐ 4

How often do you have difficulties in the following daily activities? **Please check all that apply.**	1. Never 2. Rarely 3. Sometimes 4. Very Often 5. Always 6. Not applicable					
A. Keep track of appointments (e.g., medical appointments) and other events (e.g., birthday, anniversary, and meetings)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
B. Perform tasks that have multiple steps (e.g. meal preparation, laundry)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
C. Keep track of what medications are being taken and when to take.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
D. Stay focused on a task	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
E. Remember names and faces (e.g. friends)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
F. Locate items (e.g., key, phone, household items)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
G. Manage emotion (e.g. frustration, anxiety)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
H. Way finding (e.g. indoor, outdoor, familiar or unfamiliar places)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6

How much does the problem in the following daily activities affect your quality of life? **Please check all that apply.**	1. Not at all 2. A little 3. A moderate amount 4. A great deal 5. Not applicable				
A. Keep track of appointments (e.g., medical appointments) and other events (e.g., birthday, anniversary, and meetings)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
B. Perform tasks that have multiple steps (e.g. meal preparation, laundry)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
C. Keep track of what medications are being taken and when to take.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
D. Stay focused on a task	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
E. Remember names and faces (e.g. friends)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
F. Locate items (e.g., key, phone, household items)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
G. Manage emotion (e.g. frustration, anxiety)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
H. Way finding (e.g. indoor, outdoor, familiar or unfamiliar places)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

SUBJECT ID_______

Cognitive Assistive Technology Survey

SUPPLEMENTAL

Challenge B: Perform tasks that have multiple steps (e.g. meal preparation, laundry)

If you have any challenges in multi-step tasks (e.g. preparing a meal, laundry), please answer the following questions.	1. Never 2. Rarely 3. Sometimes 4. Very often 5. Always 6. Not applicable
A. How often do you prepare meals on your own (over the past 6 months)?	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
B. How often do you have challenges in using the following appliances?	
Stove	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
Microwave	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
Dishwasher	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
Oven	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
Toaster	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
Coffee Machine	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
TV	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
Washer and Dryer	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
C. How often do you encounter the following problems in your kitchen?	
Forget where things are located in the kitchen	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
Cannot recall familiar recipes	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
Have difficulty keep tracking of steps in a recipe	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
Leave food unattended while cooking or baking (e.g. forgot pot on stove)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
Have difficulty organizing kitchen items (e.g., fail to return items to the right places)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
Other problem, please specify___________________________	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6

SUBJECT ID______		SUPPLEM-ENTAL

Cognitive Assistive Technology Survey

Challenge C: Keep track of what medications are being taken and when to take.

If you have any challenges in taking medications on schedule, please answer the following questions.	1. Never 2. Rarely 3. Sometimes 4. Very often 5. Always 6. Not applicable
A. How often do you have the following difficulties in taking your medication?	
Forget what medication you should take	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
Forget the amount you should take	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
Forget the time to take your medication	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
Other problem, please specify___________________	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6

Challenge H: Way finding (e.g. indoor, outdoor, familiar or unfamiliar places)

If you have any challenges in way finding (e.g. indoor, outdoor), please answer the following questions.	1. Never 2. Rarely 3. Sometimes 4. Very often 5. Always 6. Not applicable
A. How often do you have the following difficulties in finding an indoor or outdoor way?	
Forget your destination	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
Have difficulties in navigating in unfamiliar place	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
Have difficulties in navigating in familiar places	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
Cannot read the map	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
Other problem, please specify___________________	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6

SUBJECT ID_______	Cognitive Assistive Technology Survey	PART 2 FORM

What types of devices/tools do you use to help you manage the difficulties you identified earlier? **Please check all that apply.**

- ☐ 1. Paper-based tools (e.g., post-it notes, note-pads, paper calendars)
- ☐ 2. Alarms/Timers
- ☐ 3. Audio/Video Recording Devices
- ☐ 4. Reading Pens
- ☐ 5. Paging Systems
- ☐ 6. Smart Phone
- ☐ 7. Personal Digital Assistant (PDA)
- ☐ 8. Smart Pad
- ☐ 9. Computer
- ☐ 10. Other, please specify: _______________

If you have checked the device among 6-9, please specify the brand of the device and the names of the applications you usually use to help you manage the difficulties you identified earlier.

	Brand/Model	Application 1	Application 2	Application3
6. Smart Phone				
7. Personal Digital Assistant (PDA)				
8. Smart Pad				
9. Computer				

SUBJECT ID______

Cognitive Assistive Technology Survey

PART 3 FORM

Device ______________________ Software ______________________

How often do you use this tool to help you with the difficulties in the following daily activities?	1. Never 2. Rarely 3. Sometimes 4. Very often 5. Always 6. Not applicable
A. Keep track of appointments (e.g., medical appointments) and other events (e.g., birthday, anniversary, and meetings)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
B. Perform tasks that have multiple steps (e.g. meal preparation, laundry)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
C. Keep track of what medications are being taken and when to take.	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
D. Stay focused on a task	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
E. Remember names and faces (e.g. friends)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
F. Locate items (e.g., key, phone, household items)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
G. Manage emotion (e.g. frustration, anxiety)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
H. Way finding (e.g. indoor, outdoor, familiar or unfamiliar places)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6

Please rate this tool according to the scale on the right.	1. Never (around 0%) 2. Sometimes (around 25%) 3. Half of the time (around 50%) 4. Often (around 75%) 5. All the time (around 100%) 6. Not applicable
A. This tool is helping me with the difficulties I identified above.	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
B. This tool is benefiting me and improving my quality of life.	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
C. I'm confident I'm getting the most out of this tool and its various features.	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
D. I feel more secure (safe, sure of myself) when using this device.	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
E. This tool fits well with my accustomed routine.	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
F. I have the capabilities and stamina to use this tool without discomfort, stress and fatigue.	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
G. I have the supports, assistance and accommodations to successfully use this tool.	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
H. This tool physically fits in all desired environments (car, living room, etc.).	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
I. This tool is intuitive and easy to use.	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6

SUBJECT ID______

Cognitive Assistive Technology Survey

PART 3 FORM

Interview Session

	Interview Questions	Device: ______	Application: ______
A	What kind of challenges you identified earlier does this tool compensate most?		
B	How do you use this tool (e.g. how and who set up the tool before use)?		
C	How does this tool provide you with information (e.g., sound, voice, visual effect etc.)?		
D	What do you like most about this tool?		
E	What do you like least about this tool?		
F	Who recommended this tool for you?		

SUBJECT ID______

Cognitive Assistive Technology Survey

PART 3 FORM

The following questions are for the physical device/tool.

Who provided you with this device/tool?

☐ Client Assistance Program ☐ Private clinician ☐ VA Medical Center

☐ Defense and Veterans Brain Injury Clinic ☐ Charity Organization ☐ Store

☐ Family member or friend ☐ Other:____________________

Were you involved in the selection process?

☐ Not involved ☐ Minimal involved

☐ Somewhat involved ☐ Fully involved

Did you receive any training prior to using this device/tool?

☐ Yes ☐ No

If this answer is "Yes", please answer the following Questions A, B, C

A. Who provided training for your device/tool?

☐ Occupational Therapist ☐ Rehabilitation Counselor ☐ Speech/Language Pathologist

☐ Store ☐ Family member or friend ☐ Other: _____________

B. How many hours' training did you receive on this device/tool?

☐ Less than half 30 minutes ☐ 30 minutes -60 minutes ☐ 1 hour-3 hours

☐ More than 3 hours

C. Was the training helpful to get you to start using the device/tool?

☐ Not at all helpful ☐ Slightly helpful ☐ Moderately helpful

☐ Very helpful ☐ Extremely helpful

The following questions are for the software application.

Who provided you with this application?

☐ Client Assistance Program ☐ Private clinician ☐ VA Medical Center

☐ Defense and Veterans Brain Injury Clinic ☐ Charity Organization ☐ Store

☐ Family member or friend ☐ Other:____________________

Were you involved in the selection process for this application?

☐ Not involved ☐ Minimal involved

☐ Somewhat involved ☐ Fully involved

Did you receive any training prior to using this application?

☐ Yes ☐ No

If this answer is "Yes", please answer the following Questions A, B, C

A. Who provided training for this application?

☐ Occupational Therapist ☐ Rehabilitation Counselor ☐ Speech/Language Pathologist

☐ Store ☐ Family member or friend ☐ Other: _________________

B. How many hours' training did you receive on how to use this application?

☐ Less than half 30 minutes ☐ 30 minutes -60 minutes ☐ 1 hour-3 hours

☐ More than 3 hours

C. Was the training helpful to get you to start using this application?

☐ Not at all helpful ☐ Slightly helpful ☐ Moderately helpful

☐ Very helpful ☐ Extremely helpful

APPENDIX B

Subject #: Date:

Task # XXX: IADL: Meal Preparation: Making French Toast

Assistive Technology Devices (ATDs) used during task:

1.

2.

3.

Total # of ATDs used:_____

		INDEPENDENCE DATA									SAFETY DATA	ADEQUACY DATA		SUMMARY SCORES		
		1 Verbal Supportive (Encouragement)	2 Verbal Non-Directive	3 Verbal Directive	4 Gestures	5 Task or Environment Rearrangement	6 Demonstration	7 Physical Guidance	8 Physical Support	9 Total Assist	Unsafe Observations	QUALITY: Standards not met/improvement needed	PROCESS: Imprecision, lack of economy, missing steps	INDEPENDENCE	SAFETY	ADEQUACY
Subtasks	MOBILITY/ADL/IADL SUBTASKS															
1	Gather the ingredients correctly (Selects correct items, locations)															
2	Retrieve bowls/plates correctly and efficiently (selects appropriate locations, appropriate items)															
3	Crack the egg correctly (selects correct utensils, correct techniques, correct fluffy status)															
4	Measure 1/3 cup milk correctly (selects correct utensils, correct ingredients, correct amount)															
5	Measure 2 tablespoon sugar correctly (selects correct utensils, correct ingredients, correct amount)															
6	Measure 1/2 teaspoons salt correctly (selects correct utensils, correct ingredients, correct amount)															
7	Add these measured ingredients to the egg bowl efficiently and adequately (use correct techniques, add correct ingredients)															
8	Mix the ingredients well (select correct utensils, correct techniques and mix them to correct status)															
9	Coat the bread in the mixture adequately (coat both sides of the bread adequately)															
10	Measure 1 tablespoon butter correctly and safely (selects correct utensils, correct ingredients, correct amount)															
11	Place a fry pan on the stove correctly															
12	Safely turn on the stove (correct burner, does not burn self, appropriate heat level)															
13	Melt the butter in the pan correctly (selects correct ingredient, appropriate amount, does not burn self)															

14	Adequately put coated bread into pan (selects good timing, appropriate amount, does not mess up the environment or hurt self)																	
15	Flip the bread adequately and safely (select good timing to turn it over, correct utensil, does not burn self)																	
16	Get out the French toast and places on plate when it is done safely (selects good timing, does not burn self, all items removed from pan)																	
17	Turn off the stove safely																	

For this task, I would like you to follow this cooking App on this mini iPad to make French toast. The stove should be on medium heat. Please gather the ingredients egg, milk, salt, sugar, bread, and butter to the counter first, and then prepare the French toast. You can retrieve plates, bowls, and all utensils from your kitchen. Do you know what you need to do?

Subject #: Date:

Task # XXX: IADL: Meal Preparation: Making pancakes

Assistive Technology Devices (ATDs) used during task:

1.

2.

3.

Total # of ATDs used:_____

		INDEPENDENCE DATA									SAFETY DATA	ADEQUACY DATA		SUMMARY SCORES		
		Verbal Supportive (Encouragement)	Verbal Non-Directive	Verbal Directive	Gestures	Task or Environment Rearrangement	Demonstration	Physical Guidance	Physical Support	Total Assist	Unsafe Observations	QUALITY: Standards not met/improvement needed	PROCESS: Imprecision, lack of economy, missing steps	**INDEPENDENCE**	**SAFETY**	**ADEQUACY**
Subtasks	MOBILITY/ADL/IADL SUBTASKS	1	2	3	4	5	6	7	8	9						
1	<u>Gather the ingredients correctly</u> (Selects correct items, locations)															
2	<u>Retrieve bowls/plates correctly and efficiently</u> (selects appropriate locations, appropriate items)															
3	<u>Crack and beat the egg until fluffy correctly</u> (selects correct utensils, correct techniques, correct fluffy status)															
4	<u>Measure 3/4 cup milk correctly</u> (selects correct utensils, correct ingredients, correct amount)															
5	<u>Measure 2 tablespoons melted margarine correctly</u> (selects correct utensils, correct ingredients, correct amount)															
6	<u>Measure 1 cup flour correctly</u> (selects correct utensils, correct ingredients, correct amount)															
7	<u>Measure 1 tablespoon sugar correctly</u> (selects correct utensils, correct ingredients, correct amount)															
8	<u>Measure 3 teaspoons baking powder correctly</u> (selects correct utensils, correct ingredients, correct amount)															
9	<u>Measure 1/2 teaspoons salt correctly</u> (selects correct utensils, correct ingredients, correct amount)															
10	<u>Add these measured ingredients to the egg bowl efficiently and adequately</u> (use correct techniques, add correct ingredients)															
11	<u>Mix the ingredients well</u> (select correct utensils, correct techniques and mix them to correct status)															
12	<u>Place a fry pan on the stove correctly</u>															
13	<u>Safely turn on the stove</u> (correct burner, does not burn self, appropriate heat level)															

14	Grease the pan with butter correctly (selects correct ingredient, appropriate amount, does not burn self)																	
15	Adequately pour a small amount of batter into pan (selects appropriate amount, does not mess up the environment)																	
16	Spread out the batter adequately (select correct utensil/techniques, does not threat safety)																	
17	Turn over the pancake adequately and safely (select good timing to turn it over, correct utensil, does not burn self)																	
18	Get out the pancake and places on plate when it is done safely (does not burn self)																	
19	Turn off the stove safely																	

For this task, I would like you to follow this paper recipe to make pancakes with a fry pan. The stove should be on medium heat. All the necessary ingredients: egg, milk, margarine, flour, sugar, baking powder and better, are located on the counter. You can retrieve plates, bowls, and all utensils from your kitchen. Do you know what you need to do?

APPENDIX C

INTRODUCTORY QUESTIONS

- How was your ____ (morning/afternoon/evening)? How does it compare to your average weekday/weekend?
- If you had a friend visiting, where would you treat them to lunch or dinner?
- Where did you grow up? How big is your family?
- What has changed since your diagnosis? What have you learned?
- What is your support network like?
- What media (book/movie/TV show/etc) would you recommend for learning more about your condition? How did you educate yourself about it?

QUESTIONS ABOUT THE IPAD COOKING APP SESSION

Please mark your level of agreement regarding your perceived usefulness of this user-controlled prompting method	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Statement	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Using this system would improve the quality of the work I do in the kitchen							
Using this system would give me greater control over kitchen tasks							
This system would enable me to accomplish kitchen tasks more quickly							
This system would improve my productivity in the kitchen							
This system would enable me to accomplish kitchen tasks with less mistakes							
This system would allow me to complete more kitchen tasks that I							

cannot complete independently							
Using this system would enhance my effectiveness with kitchen tasks							
Using this system would make it easier to accomplish kitchen tasks							
This system makes me feel more confident and secure with kitchen tasks							
I would like to use this system to help my daily routine in the kitchen if it is available to me							

Please mark your level of agreement regarding your perceived easy-of-use of this user-controlled prompting method	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Statement	1	2	3	4	5	6	7
The system is unnecessarily complex							
The system is easy to use							
I would still need the support from another person to be able to use the system							
Learning to use this system is easy for me							
Using the system requires a lot of mental effort							
The system helps me concentrate on the task							
I found the system is very cumbersome or burdensome to use							

1. Please rate your overall performance with the preparing the meal.
   ☐ Very bad ☐ Bad ☐ Neither good nor bad ☐ Good
   ☐ Very Good
   Comments:
2. Please rate the overall perceived usefulness of the iPad app in assisting you with kitchen tasks.
   ☐ Extremely useful ☐ Very useful ☐ Moderately useful ☐ Slightly useful
   ☐ Not at all useful

3. Please rate your stress level when using the system to complete the kitchen tasks.
   ☐ Extremely stressful ☐ Very stressful ☐ Moderately stressful ☐ Slightly stressful ☐ Not at all stressful
   Comments:

4. Please rate the overall ease-of-use of the iPad app in assisting you with the kitchen tasks.
   ☐ Extremely difficult ☐ Very Difficult ☐ Somewhat difficult ☐ Neutral
   ☐ Somewhat easy ☐ Very easy ☐ Extremely easy

5. Please rate your overall satisfaction with the iPad app.
   ☐ Completely dissatisfied ☐ Mostly dissatisfied ☐ Somewhat dissatisfied ☐ Neutral
   ☐ Somewhat satisfied ☐ Mostly satisfied ☐ Completely satisfied
   Comments:

6. What features do you like most about the system?

7. What features do you like least about the system?

8. What additional features would you like to see in the iPad app?

9. What do you think about your interaction with the system?
   a. Was it challenging to use the system (e.g., remembering to press the button to proceed and knowing the current step is completed appropriately)
   b. Was pressing the button at each step distracting to you? Did it interfere with your cooking?
   c. How do you like the Step-by-step instructions in the recipe app on iPad?
   d. Do you think some steps were redundant? Was this acceptable to you or did it bother you?
   e. How do you like the pictures/videos in the recipe app on iPad?

10. How different was cooking with the iPad app from following recipe in a cook book?

APPENDIX D

Performance evaluation using PASS with Paper-based Method and User-controlled Method

Participants	Number of Assistance		Independence Score		Safety Score		Adequacy Score	
	P*	U*	P*	U*	P*	U*	P*	U*
P1	7	5	2.76	2.88	3	2	1	2
P2	6	3	2.76	2.88	2	3	2	2
P3	15	26	2.65	2.24	2	2	1	2
P4	1	2	2.94	2.94	3	3	2	2
P5	2	0	2.88	3.00	1	3	3	3
P6	18	6	2.47	2.76	2	3	2	3
P7	0	4	3.00	2.76	3	2	2	2
P8	0	4	3.00	2.88	3	1	2	1
P9	15	5	2.41	2.82	2	3	1	3
P10	1	0	2.94	3.00	3	3	1	2

P*: paper-based prompting method, U*: step-by-step user-controlled prompting method.
Score ranges for independence, safety and adequacy are all 0-3.

APPENDIX E

Subject #: Date:

Task: Meal Preparation: Making Pancakes and Sausage

For this task, I would like you to follow this (user-controlled recipe /automatic cooking App) on this computer to make pancakes and sausage. Please follow the instructions for each step of this recipe. Do you know what you need to do?

		INDEPENDENCE DATA									SAFETY DATA	ADEQUACY DATA		SUMMARY SCORES		
Subtasks	MOBILITY/ADL/IADL SUBTASKS	1 Verbal Supportive (Encouragement)	2 Verbal Non-Directive	3 Verbal Directive	4 Gestures	5 Task or Environment Rearrangement	6 Demonstration	7 Physical Guidance	8 Physical Support	9 Total Assist	Unsafe Observations	QUALITY: Standards not met/improvement needed	PROCESS: Imprecision, lack of economy, missing steps	INDEPENDENCE	SAFETY	ADEQUACY
1	Gather the ingredients (egg, milk, oil, pancake mix, butter and sausage) and measuring utensils correctly (Selects correct items, locations)															
2	Retrieve bowls/plates correctly and efficiently (selects appropriate locations, appropriate items)															
3	Cracks the egg into a bowl correctly (selects correct utensils, correct techniques)															
4	Measures 1/2 cup milk correctly (selects correct utensils, correct ingredients, correct amount) and adds to the egg bowl efficiently and adequately.															
5	Measures 1 tablespoon of oil correctly (selects correct utensils, correct ingredients, correct amount) adds to the egg bowl efficiently and adequately.															
6	Measures 1 cup pancake mix correctly (selects correct utensils, correct ingredients, correct amount) adds to the egg bowl efficiently and adequately.															
7	Mixes the ingredients well (selects correct utensils, correct techniques and mix them to correct status)															
8	Retrieves a frying pan correctly (Selects correct items, correct locations)															
9	Places the frying pan on the stove correctly															

Subject #: Date:

Task: Meal Preparation: Making Pancakes and Sausage

Cont.

Subtasks	MOBILITY/ADL/IADL SUBTASKS	INDEPENDENCE DATA: 1 Verbal Supportive (Encouragement)	2 Verbal Non-Directive	3 Verbal Directive	4 Gestures	5 Task or Environment Rearrangement	6 Demonstration	7 Physical Guidance	8 Physical Support	9 Total Assist	SAFETY DATA: Unsafe Observations	ADEQUACY DATA: QUALITY: Standards not met/improvement needed	PROCESS: Imprecision, lack of economy, missing steps	**INDEPENDENCE**
10	Safely turns on the stove (correct burner, does not burn self, appropriate heat level)													
11	Measures 1 tablespoon butter correctly and safely (selects correct utensils, correct ingredients, correct amount)													
12	Melts the butter in the pan correctly (places in pan, does not burn self)													
13	Adequately pours a small amount of batter into pan (selects appropriate amount, does not dirty the working area)													
14	Spreads out the batter adequately (select correct utensil/techniques, does not threat safety)													
15	Opens the sausage package and puts 2 sausage on a plate adequately (does not struggle to open package)													
16	Places the plate with sausage into the microwave oven adequately (opens oven door with ease, no spillage)													
17	Turn on the microwave oven correctly (sets appropriate cooking time)													

Subject #: Date:

Task: Meal Preparation: Making Pancakes and Sausage

Cont.		INDEPENDENCE DATA									SAFETY DATA	ADEQUACY DATA		
		1 Verbal Supportive (Encouragement)	2 Verbal Non-Directive	3 Verbal Directive	4 Gestures	5 Task or Environment Rearrangement	6 Demonstration	7 Physical Guidance	8 Physical Support	9 Total Assist	Unsafe Observations	QUALITY: Standards not met/improvement needed	PROCESS: Imprecision, lack of economy, missing steps	INDEPENDENCE
Subtasks	MOBILITY/ADL/IADL SUBTASKS													
18	Turns over the pancake adequately and safely (select good timing to turn it over, correct utensil, does not burn self)													
19	Removes pancakes from the frying pan safely and places on plate when it is done (selects good timing, does not burn self, all items removed from pan)													
20	Immediately turns off the stove safely and removes the pan from heat source as needed (for electric stove)													
21	Retrieves the sausage plate from the microwave oven when it is done safely(does not burn self, all items removed from the microwave oven)													

Subject #: Date:

Task: Meal Preparation: Making French Toast and Sausage

For this task, I would like you to follow this (user-controlled recipe /automatic cooking App) on this computer to make French toast and sausage. Please follow the instructions for each step of this recipe. Do you know what you need to do?

Subtasks	MOBILITY/ADL/IADL SUBTASKS	INDEPENDENCE DATA: 1 Verbal Supportive (Encouragement)	2 Verbal Non-Directive	3 Verbal Directive	4 Gestures	5 Task or Environment Rearrangement	6 Demonstration	7 Physical Guidance	8 Physical Support	9 Total Assist	SAFETY DATA: Unsafe Observations	ADEQUACY DATA: QUALITY: Standards not met/improvement needed	PROCESS: Imprecision, lack of economy, missing steps	SUMMARY SCORES: INDEPENDENCE	SAFETY	ADEQUACY
1	Gather the ingredients (egg, milk, salt, sugar, bread, butter, and sausage) and measuring utensils correctly (Selects correct items, locations)															
2	Retrieve bowls/plates correctly and efficiently (selects appropriate locations, appropriate items)															
3	Cracks the egg into a bowl correctly (selects correct utensils, correct techniques)															
4	Measures 1/2 teaspoons salt correctly (selects correct utensils, correct ingredients, correct amount) and adds to the bowl efficiently and adequately.															
5	Measures 2 tablespoon sugar correctly (selects correct utensils, correct ingredients, correct amount) and adds to the bowl efficiently and adequately.															
6	Measures 1/3 cup milk correctly (selects correct utensils, correct ingredients, correct amount) and adds to the bowl efficiently and adequately.															
7	Mixes the ingredients well (selects correct utensils, correct techniques and mix them to correct status)															
8	Retrieves a frying pan correctly (Selects correct items, correct locations)															
9	Places the frying pan on the stove correctly															

Subject #: Date:

Task: Meal Preparation: Making French Toast and Sausage

Cont.

Subtasks	MOBILITY/ADL/IADL SUBTASKS	INDEPENDENCE DATA: 1 Verbal Supportive (Encouragement)	2 Verbal Non-Directive	3 Verbal Directive	4 Gestures	5 Task or Environment Rearrangement	6 Demonstration	7 Physical Guidance	8 Physical Support	9 Total Assist	SAFETY DATA: Unsafe Observations	ADEQUACY DATA: QUALITY: Standards not met/improvement needed	PROCESS: Imprecision, lack of economy, missing steps	INDEPENDENCE
10	Safely turns on the stove (correct burner, does not burn self, appropriate heat level)													
11	Measures 1 tablespoon butter correctly and safely (selects correct utensils, correct ingredients, correct amount)													
12	Melts the butter in the pan correctly (places in pan, does not burn self)													
13	Coats the bread in the mixture adequately (dips bread into liquid mixture, coating both sides of the bread adequately; no spillage of liquid mixture)													
14	Adequately puts coated bread into pan (selects good timing, appropriate amount, does not dirty working area)													
15	Opens the sausage package and puts 2 sausage on a plate adequately (does not struggle to open package)													
16	Places the plate with sausage into the microwave oven adequately (opens oven door with ease, no spillage)													
17	Turn on the microwave oven correctly (sets appropriate cooking time)													

Subject #: Date:

3

Task: Meal Preparation: Making French Toast and Sausage

		INDEPENDENCE DATA									SAFETY DATA	ADEQUACY DATA		
Cont.		1 Verbal Supportive (Encouragement)	2 Verbal Non-Directive	3 Verbal Directive	4 Gestures	5 Task or Environment Rearrangement	6 Demonstration	7 Physical Guidance	8 Physical Support	9 Total Assist	Unsafe Observations	QUALITY: Standards not met/improvement needed	PROCESS: Imprecision, lack of economy, missing steps	**INDEPENDENCE**
Subtasks	MOBILITY/ADL/IADL SUBTASKS													
18	Flips the bread adequately and safely (selects good timing to turn it over, correct utensil, does not burn self)													
19	Removes French toast from frying pan safely and places on plate when it is done (selects good timing, does not burn self, all items removed from pan)													
20	Immediately turns off the stove safely and removes the pan from heat source as needed (for electric stove)													
21	Retrieves the sausage plate from the microwave oven when it is done safely(does not burn self, all items removed from the microwave oven)													

APPENDIX F

Subject ID__________Date___________Investigator___________

Evaluation of Different Prompting Methods in Cognitive Assistive Technology

Automatic Prompting Method

Please mark your level of agreement regarding your perceived usefulness of this automatic prompting method	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Statement	1	2	3	4	5	6	7
Using this system would improve the quality of the work I do in the kitchen							
Using this system would give me greater control over kitchen tasks							
This system would enable me to accomplish kitchen tasks more quickly							
This system would improve my productivity in the kitchen							
This system would enable me to accomplish kitchen tasks with less mistakes							
This system would allow me to complete more kitchen tasks that I cannot complete independently							
Using this system would enhance my effectiveness with kitchen tasks							
Using this system would make it easier to accomplish kitchen tasks							
This system makes me feel more confident and secure with kitchen tasks							
I would like to use this system to help my daily routine in the kitchen if it is available to me							

Please mark your level of agreement regarding your perceived easy-of-use of this automatic prompting method	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Statement	1	2	3	4	5	6	7
The system is unnecessarily complex							
The system is easy to use							
I would still need the support from another person to be able to use the system							
Learning to use this system is easy for me							
Using the system requires a lot of mental effort							
The system helps me concentrate on the task							
I found the system is very cumbersome or burdensome to use							

Subject ID__________Date____________Investigator____________

Please respond to each question or statement by marking one box per row.

During cooking tasks with the guidance of the automated prompting method…

		Never	Rarely	Sometimes	Often	Always
EDANX01 1	I felt fearful……………………………………	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
EDANX40 2	I found it hard to focus on anything other than my anxiety ………………………………	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
EDANX41 3	My worries overwhelmed me…………………	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
EDANX53 4	I felt uneasy ……………………………………	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
EDANX46 5	I felt nervous……………………………………	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
EDANX07 6	I felt like I needed help for my anxiety ……	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
EDANX05 7	I felt anxious……………………………………	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
EDANX54 8	I felt tense …………………………………………	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

1. Please rate the overall usefulness of the system in assisting you with kitchen tasks.
   - ☐ Extremely useful
   - ☐ Very useful
   - ☐ Moderately useful
   - ☐ Slightly useful
   - ☐ Not at all useful

2. Please rate the overall ease-of-use of this system in assisting you with the kitchen tasks.
   - ☐ Extremely difficult
   - ☐ Very difficult
   - ☐ Somewhat difficult
   - ☐ Neutral
   - ☐ Somewhat easy
   - ☐ Very easy
   - ☐ Extremely easy

Subject ID__________Date____________Investigator____________

3. Please rate your stress level when using the system to complete the kitchen tasks.
   - ☐ Extremely stressful
   - ☐ Very stressful
   - ☐ Moderately stressful
   - ☐ Slightly stressful
   - ☐ Not at all stressful

4. Please rate your overall satisfaction with the system.
   - ☐ Completely dissatisfied
   - ☐ Mostly dissatisfied
   - ☐ Somewhat dissatisfied
   - ☐ Neutral
   - ☐ Somewhat satisfied
   - ☐ Mostly satisfied
   - ☐ Completely satisfied

5. How do you think about the detailed sequence of steps?
   5.1 Do you think it is redundant (as you may already know certain steps)?
   5.2 Is the redundancy acceptable to you?

6. How do you think about your interaction with the system?
   6.1 Were the automatic prompts given at the good timing (you feel neutral to follow the prompts)?
   6.2 Did the prompts help you to concentrate on the tasks? Did the prompts interfere with your task performance?
   6.3 Was it cognitively demanding to use the system (e.g., remembering the audio prompts or checking the image/video prompts)

7. How do you think about the prompts in the system?
   7.1 Which kind of prompts do you think is most useful for you (e.g. audio, text, image, or video)?
   7.2 Which kind of prompts do you think is easier to follow?

8. What features do you like most about the system?

9. What features do you like least about the system?

10. If this prompting system is available for you, do you desire to use it in your own kitchen? Why?

11. How much money do you think is reasonable for this prompting device?

Subject ID__________Date____________Investigator____________

Evaluation of Different Prompting Methods in Cognitive Assistive Technology

User-Controlled Prompting Method

Please mark your level of agreement regarding your perceived usefulness of this user-controlled prompting method	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Statement	1	2	3	4	5	6	7
Using this system would improve the quality of the work I do in the kitchen							
Using this system would give me greater control over kitchen tasks							
This system would enable me to accomplish kitchen tasks more quickly							
This system would improve my productivity in the kitchen							
This system would enable me to accomplish kitchen tasks with less mistakes							
This system would allow me to complete more kitchen tasks that I cannot complete independently							
Using this system would enhance my effectiveness with kitchen tasks							
Using this system would make it easier to accomplish kitchen tasks							
This system makes me feel more confident and secure with kitchen tasks							
I would like to use this system to help my daily routine in the kitchen if it is available to me							

Please mark your level of agreement regarding your perceived easy-of-use of this user-controlled prompting method	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Statement	1	2	3	4	5	6	7
The system is unnecessarily complex							
The system is easy to use							
I would still need the support from another person to be able to use the system							
Learning to use this system is easy for me							
Using the system requires a lot of mental effort							
The system helps me concentrate on the task							
I found the system is very cumbersome or burdensome to use							

Subject ID__________Date____________Investigator____________

Please respond to each question or statement by marking one box per row.

During cooking tasks with the guidance of the user-controlled prompting method…

		Never	Rarely	Sometimes	Often	Always
EDANX01 1	I felt fearful…………………………………	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
EDANX40 2	I found it hard to focus on anything other than my anxiety ………………………………	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
EDANX41 3	My worries overwhelmed me…………………	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
EDANX53 4	I felt uneasy ………………………………………	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
EDANX46 5	I felt nervous…………………………………	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
EDANX07 6	I felt like I needed help for my anxiety ……	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
EDANX05 7	I felt anxious…………………………………	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
EDANX54 8	I felt tense …………………………………………	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

1. Please rate the overall usefulness of the system in assisting you with kitchen tasks.
   - ☐ Extremely useful
   - ☐ Very useful
   - ☐ Moderately useful
   - ☐ Slightly useful
   - ☐ Not at all useful

2. Please rate the overall ease-of-use of this system in assisting you with the kitchen tasks.
   - ☐ Extremely difficult
   - ☐ Very difficult
   - ☐ Somewhat difficult
   - ☐ Neutral
   - ☐ Somewhat easy
   - ☐ Very easy
   - ☐ Extremely easy

Subject ID__________Date____________Investigator____________

3. Please rate your stress level when using the system to complete the kitchen tasks.
   - ☐ Extremely stressful
   - ☐ Very stressful
   - ☐ Moderately stressful
   - ☐ Slightly stressful
   - ☐ Not at all stressful

4. Please rate your overall satisfaction with the system.
   - ☐ Completely dissatisfied
   - ☐ Mostly dissatisfied
   - ☐ Somewhat dissatisfied
   - ☐ Neutral
   - ☐ Somewhat satisfied
   - ☐ Mostly satisfied
   - ☐ Completely satisfied

5. How do you think about your interaction with the system?
   6.1 Was it burdensome to press the button at each step to proceed?
   6.2 Was pressing the button at each step distracting to you? Did it interfere with your task performance?
   6.3 Was it cognitively demanding to use the system (e.g., remembering to press the button to proceed and knowing the current step is completed appropriately)

6. What features do you like most about the system?

7. What features do you like least about the system?

8. If this prompting system is available for you, do you desire to use it in your own kitchen? Why?

9. How much money do you think is reasonable for this prompting device?

APPENDIX G

PASS data of all participants in Chapter 5

	Highest Cue		Safety		Adequacy		Cues needed		Independent steps		Ave Independence score of the task	
	AU	UC	AU	UC	AU	UC	AU	UC	AU	UC	AU	UC
TBI01	0	3	3	2	3	2	0	1	21	20	3.00	2.95
TBI02	1	2	3	3	3	2	1	2	20	19	2.95	2.90
TBI03	3	3	2	3	3	3	1	1	20	20	2.95	2.95
TBI04	2	2	3	3	2	2	1	2	20	19	2.95	2.90
TBI05	0	2	3	2	3	2	0	1	21	20	3.00	2.95
TBI06	2	4	2	2	3	3	1	1	20	20	2.95	2.95
TBI07	8	0	3	2	3	2	3	0	19	21	2.86	3.00
TBI08	0	2	3	3	3	3	0	1	21	20	3.00	2.95
TBI09	3	4	3	3	2	3	6	9	16	16	2.76	2.76
TBI10	2	2	3	3	2	2	1	1	20	20	2.95	2.95
TBI11	0	3	3	3	3	2	0	3	21	20	3.00	2.95
TBI12	0	1	3	3	3	2	0	1	21	20	3	2.95
TBI13	2	2	3	3	2	3	1	2	20	19	2.95	2.9
TBI14	2	4	3	3	3	2	1	11	20	14	2.95	2.67
TBI15	3	2	3	3	3	3	3	4	18	18	2.86	2.86
TBI16	0	4	3	3	3	2	0	7	21	17	3	2.81
Ave	1.75	2.5	2.875	2.75	2.75	2.375	1.1875	2.9375	19.9375	18.9375	2.95	2.90
Std	2.04939	1.154701	0.341565	0.447214	0.447214	0.5	1.600781	3.234579	1.340087	1.842779	0.06679	0.086938

APPENDIX H

Neuropsychologogical/behavioral data of all participants in Chapter 5

ID	MoCA screen	1 Digit span	2 Digit symbol	3 VRII Reg	4 CVLT Irecall	5 CVLT Srecall	6 CVLT Lrecall	7 Trail making	8 Six elements
TBI01	25	63	43	63	44	40	40	53	1
TBI02	20	40	43	43	37	40	40	33	4
TBI03	23	30	57	50	57	60	50	50	4
TBI04	24	40	40	50	45	40	40	37	1
TBI05	17	53	43	70	34	35	35	37	2
TBI06	25	77	53	63	72	70	65	57	4
TBI07	23	47	40	53	49	45	40	50	3
TBI08	25	50	40	43	38	30	35	43	4
TBI09	21	43	33	40	28	20	20	20	2
TBI10	22	30	43	50	50	45	50	50	4
TBI11	25	50	50	50	25	20	20	37	4
TBI12	24	50	47	47	76	60	50	53	4
TBI13	23	57	43	70	55	60	60	57	4
TBI14	21	40	30	43	26	40	35	20	3
TBI15	25	47	47	47	67	55	50	57	4
TBI16	25	50	57	53	71	50	45	63	4

APPENDIX I

Comparison between machine inferences and human observer decisions

			Door Sensor				Power Sensor				Kinect Sensor			
Subject ID	Overall decisions	Overall adequate decisions	Decisions	Avg of Time Diff	Std. of Time Diff	Adequate Decisions	Decisions	Avg of Time Diff	Std. of Time Diff	Adequate Decisions	Decisions	Avg of Time Diff	Std. of Time Diff	Adequate Decisions
P02	0.64	0.30	1.00	0.4	2.0	1.00	0.44	-28.3	25.8	0.11	0.52	-21.0	13.6	0.00
P03	0.71	0.41	0.88	0.2	0.9	0.88	0.56	-33.4	31.6	0.11	0.68	-10.8	13.3	0.26
P04	0.68	0.41	1.00	1.3	3.8	0.94	0.56	-17.0	17.8	0.11	0.56	-10.8	10.5	0.23
P05	0.77	0.28	0.88	2.8	2.5	0.81	0.44	-50.2	18.8	0.00	0.81	-19.5	18.9	0.09
P06	0.77	0.45	0.94	0.5	0.5	0.94	0.89	-23.0	48.5	0.33	0.65	-13.6	27.0	0.23
P07	0.57	0.18	x	x	x	x	0.78	-13.1	45.2	0.11	0.77	-13.3	12.6	0.26
P08	0.65	0.35	0.94	-1.1	0.9	0.94	0.67	-28.0	37.8	0.11	0.50	-9.3	33.0	0.13
P09	0.63	0.30	0.94	-1.7	2.3	0.81	0.33	-30.8	10.3	0.00	0.56	-25.5	38.5	0.13
P10	0.63	0.36	1.00	-0.6	0.3	1.00	0.67	-18.5	16.3	0.22	0.42	-22.1	34.5	0.06
P11	0.73	0.36	1.00	0.0	3.2	0.94	0.78	-23.5	31.1	0.22	0.58	-17.4	26.6	0.10
P12	0.70	0.30	1.00	-2.6	3.1	0.88	x	x	x	x	0.72	-22.0	18.6	0.09
P13	0.75	0.35	1.00	-1.2	1.6	0.94	0.44	-43.9	22.1	0.00	0.72	-19.1	15.9	0.16
P14	0.68	0.34	0.94	-1.2	0.9	1.00	0.78	-27.3	42.2	0.33	0.52	-9.7	46.4	0.00
P15	0.73	0.38	0.94	-1.0	1.2	0.94	0.78	-28.2	39.9	0.33	0.61	-22.9	27.1	0.10
P16	0.46	0.36	1.00	-1.9	1.2	1.00	x	x	x	x	0.29	-10.2	8.6	0.10
Average	0.67	0.34	0.96	-0.8	1.4	0.93	0.62	-28.0	31.1	0.15	0.59	-17.4	18.9	0.13
Std	0.08	0.06	0.05	n/a	n/a	0.06	0.17	n/a	n/a	0.12	0.13	n/a	n/a	0.08

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