Application of Cognitive Rehabilitation Theory to the Development of Smart Prompting Technologies

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***Abstract*—Older adults with cognitive impairments often have difficulty performing instrumental activities of daily living (IADLs). Prompting technologies have gained popularity over the last decade and have the potential to assist these individuals with IADLs in order to live independently. Although prompting techniques are routinely used by caregivers and health care providers to aid individuals with cognitive impairment in maintaining their independence with everyday activities, there is no clear consensus or gold standard regarding prompt content, method of instruction, timing of delivery, or interface of prompt delivery in the gerontology or technology literatures. In this paper, we demonstrate how cognitive rehabilitation principles can inform and advance the development of more effective assistive prompting technologies that could be employed in smart environments. We first describe cognitive rehabilitation theory (CRT) and show how it provides a useful theoretical foundation for guiding the development of assistive technologies for IADL completion. We then use the CRT framework to critically review existing smart prompting technologies to answer questions that will be integral to advancing development of effective smart prompting technologies. Finally, we raise questions for future exploration as well as challenges and suggestions for future directions in this area of research.**

***Index Terms*—aging, cognitive impairment, assistive technology, instrumental activities of daily living**

I. Introduction

THE world's population is aging. In the United States there will be an estimated 88.5 million individuals age 65+ in 2050 compared with 40.2 million in 2010 [1], and in the next 15 years there will be predicted shortfall of 800,000 nurses and 200,000 doctors [2]. This situation is reflected around the world and demonstrates the need for pervasive health care to scale in a way that meets or exceeds this growing demand. It is also expected that the number of individuals who will be unable to live independently in their homes and need assistance due to cognitive impairments will rise rapidly[3]. The prevalence rates for Mild Cognitive Impairment (MCI), often considered an early transition stage between normal cognitive aging and dementia [4], currently range from 3% to 20% with conversion to dementia over 2-6 years ranging from 10% to 55% [5], [6]. MCI is associated with impairments in daily functioning, particularly for complex instrumental activities of daily living (IADLs; e.g., finances and medication management) that are dependent on memory and executive functioning [7], [8]. The expected increase in the number of individuals with cognitive impairment and associated functional impairment is a growing public health concern. For example, functional impairment in the older population has been associated with increased health care utilization and placement in long-term care facilities, number of days in the hospital, falls, poorer quality of life and morbidity and mortality [9]. Therefore, along with identifying effective medications, the development and evaluation of non-pharmacological assistive interventions that are designed to help with IADL completion and improve functional independence and quality of life in persons with cognitive impairment is critical.

Higher order IADLs are affected earlier than basic activities of daily living (ADLs; e.g., bathing, grooming) in MCI [7]. Difficulties with IADL completion might include leaving a step out of an activity that is important for task completion, performing an activity step incorrectly, performing steps for an activity out of order, substituting a step that is irrelevant to the activity being performed, or failing to initiate an activity. In one study, Alzheimer's disease (AD) caregivers reported that the most common IADLs associated with decreased initiation were cooking, using the telephone (to make outgoing calls), housework, household repairs, and taking medication [10]. When IADL difficulties are encountered, individuals typically receive prompts or cues from their spouses or family members

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to help them initiate or complete the activity accurately. The amount of IADL prompting caregivers offer to individuals with MCI increases as cognitive impairment progresses, which increases the amount of caregiver responsibility and burden. In turn, individuals with MCI begin to lose independence as concerned family members insist that they be supervised. Smart environment technologies might provide novel solutions to lengthening aging in place and increasing independence for older adults with cognitive impairments while also decreasing caregiving burden.

A. *Smart Environments and Prompting Technologies*

The fields of artificial intelligence and pervasive computing have stimulated the development of smart environment technologies that aim to extend independent living in one's own home without compromising safety [11]-[15]. Technologies have been designed that can recognize and detect errors in IADL activity completion using machine learning algorithms. Researchers have also investigated challenges to providing smart environment monitoring and activity recognition in complex, real-life settings, [16], [17] which might facilitate the applicability and generalizability of smart environment technologies. Smart environment technologies have also been utilized to investigate other aspects of aging and dementia to improve patient outcomes. For example, smart technologies are being developed to unobtrusively monitor variability in the physical activity of older adults over time [18] and to assess for functional limitations [19], which may lead to the prediction and earlier detection of future cognitive and functional impairment.

In a smart home environment, Das and colleagues [20] define prompts as any form of verbal or non-verbal intervention delivered to a user on the basis of time, context or acquired intelligence that helps in successful (in terms of time and purpose) completion of an activity. Research groups have also used terms such as reminders, notifications and alerts, depending on the granularity of interventions, methods of delivery, and applications [21]. Prompting approaches can be as simple as a time-based alarm clock and as complex as a machine learning technique that learns patterns of an individual's behavior from historic data and delivers prompts when necessary through a sophisticated interface such as a smart phone. The last decade has witnessed a paradigm shift in the fundamental goal of developing prompting interventions to assist individuals in completing daily activities. While most previous prompting technologies focused on delivery of prompts at pre-selected times, the goal of current prompting technologies is to be unobtrusive, flexible, have the capability to deal with changing situations, and deliver prompts during an activity when crucial; for example, based on complex contextual information indicating the appropriate time, place, and situation in which an individual needs a prompt to initiate or carry out an unplanned complex activity.

B. *Goal of the Current Paper*

While prompting techniques are routinely used by caregivers and health care providers to aid AD patients in maintaining their independence with everyday activities, they have not been adequately explored or quantified in the gerontology and technology literatures [10]. Specifically, in the literature there is no clear consensus or gold standard regarding prompt content, method of instruction, timing of delivery, or interface of prompt delivery. Importantly, no clear theoretical model has yet been applied in the technology literature to guide and advance development of the most effective prompting technologies for individuals with cognitive impairment. These are important issues that need to be explored if our goal is to develop prompting technologies to assist older individuals with cognitive impairments in initiating and completing IADLs while also reducing caregiver burden.

We propose that the field of cognitive rehabilitation can provide a strong theoretical and empirical foundation to guide the development of effective smart environment assistive prompting technologies for cognitively impaired populations such as MCI, dementia, and traumatic brain injury (TBI). The goal of this paper is to demonstrate how cognitive rehabilitation principles can inform the development of effective assistive prompting technologies that could be employed in smart environments. In this paper, we first give a brief description of the cognitive rehabilitation framework and show how it provides a useful theoretical foundation for guiding the development of assistive technologies for IADL completion. We then use a cognitive rehabilitation theoretical framework to critically review studies completed with varying patient populations to answer several questions that will be integral to the future development of smart environment assistive prompting technologies. Finally, we provide a discussion about questions that still need to be explored as well as challenges and suggestions for future directions in this area of research.

II. Cognitive Rehabilitation Overview

Cognitive rehabilitation has been found successful in teaching individuals with dementia [22]-[24] and MCI [25] to learn or re-learn information, maintain information over time, apply information to everyday contexts, develop strategies to compensate for memory impairment, and adjust the environment to reduce memory demands [26]-[28]. Cognitive rehabilitation theory (CRT) is multi-dimensional and emphasizes the importance of an individual's personal context, environmental context, and social system [29]. According to CRT, specific techniques are not adequate for effective rehabilitation. Instead, an integrated approach that addresses cognitive, emotional and motivational aspects of functioning together in addition to techniques is necessary. CRT acknowledges the complex interactions between techniques and the social, emotional, and interpersonal context [26].

Cognitive rehabilitation often encompasses cognitive, behavioral change, and learning theories [26]. Behavioral change theory posits that behavioral change (e.g., using learned memory strategies in daily life) is most likely to occur when the cost-benefit analysis of the new behavior is positive, the person is able to form and articulate intended behavioral change, has positive experiences with the intended behavior, and is satisfied with the outcome of the behavior [30]. According to learning theory, a new behavior should be learned during an acquisition phase, applied to daily life in an application phase, and practiced so as to make it habitual and routine [31]. Overall, cognitive rehabilitation is a holistic and integrated approach that involves the individualized training of real-world tasks using a variety of techniques to significantly improve everyday memory and daily functioning [23].

Smart environment assistive interventions developed for individuals with MCI and AD could benefit from being grounded in the cognitive rehabilitation framework, which focuses on the training of real-world tasks to significantly improve an individual's everyday functioning. For example, tracking everyday functional activity accomplishment and providing reminders when individuals fail to complete daily activities are time consuming and burdensome tasks for caregivers and are often associated with adverse effects for the caregivers own health [32], yet are required for individuals who live at home. One important limitation of traditional cognitive rehabilitation interventions is that they are not automatically delivered to individuals, so the burden to remind the individual to use the compensatory aid or strategy often falls on the caregiver. Automated prompting technology informed by the cognitive rehabilitation framework and delivered in a smart environment setting has the potential to provide a better alternative in the future.

III. COMPONENTS OF COGNITIVE REHABILITATION

There are several components incorporated in CRT, including instructional techniques used to assist individuals in learning or re-learning information and external aids employed to help individuals compensate for cognitive and functional limitations [33]. The format of instruction and amount of cognitive effort exerted in the acquisition stages of learning have also been shown to impact new learning [23].

A. Instructional Techniques

Examples of specific instructional techniques include spaced retrieval, mnemonic elaboration, semantic elaboration, and prompting/cueing hierarchies with increasing or decreasing assistance. Spaced retrieval is characterized by having a person recall the information to be remembered over increasingly longer periods of time [22]. When a person correctly retrieves the information, the time interval until the next recall test in increased. If a person fails to retrieve the information, he is told the correct answer and asked to repeat it. Then, the next recall interval is set to the last one that was successful. Mnemonic elaboration is a technique in which a mnemonic, such as a verbal label that links one aspect of the item to be remembered (e.g., appearance) to another aspect (e.g., sound of first letter of its name), is created and rehearsed until established [23]. Semantic elaboration is a similar technique in which a word or image to be remembered is connected to a related idea. Prompting or cueing hierarchies involve offering individuals prompts or cues of increasing or decreasing assistance when errors are made until there is successful completion of the task. These techniques will be especially important when designing smart prompting technologies. They have been used successfully to teach or re-teach information to individuals with dementia [22]-[24], [34], [35] and TBI [36], to improve everyday memory performance (e.g., face-name associations) and to teach use of external memory aids (e.g., pager, memory board).

B. Format of Instruction and Role of Cognitive Effort

Cognitive rehabilitation techniques can be characterized as errorless or errorful learning, depending on the format of instruction. Errorless learning is a principle for guiding the implementation of specific techniques or procedures within the cognitive rehabilitation framework [23]. Errorless learning is designed to reduce errors during the acquisition phase of learning by breaking tasks down into small steps, modeling the correct behavior for the learner in advance, discouraging guessing, immediately correcting errors, and fading prompts [37]. Given that memory for personal episodes declines in the dementia process, it is difficult for individuals to learn from past errors to make corrections in the future [22]. Therefore, it is important for individuals with AD to learn during the acquisition phase without errors to avoid inaccurate learning. Studies have shown errorless learning techniques to be successful in teaching information (e.g., face-name associations and how to use external memory aids) to individuals with early AD [34] and TBI [36]. Research suggests that errorless learning might be most beneficial for simple, straightforward tasks [34] and might not be as effective as trial and error for the learning of more complex information or skills, such as routines or routes [38], [39]. In addition, research on individuals with TBI [40] suggests that errorless learning might be most beneficial to people with more severe memory impairment. Some researchers have suggested that error reduction might be less important than cognitive effort for learning new information in early AD. [24]. Cognitive effort has been conceptualized as the amount of effort a person expends during the encoding of new information during a task [24]. CRT techniques that are cognitively effortful include prompting hierarchies that offer increased assistance as necessary.

C. External Memory Aids

CRT external memory aids generally fall into two categories, including no technology and low technology aids. No technology aids include items such as planners, memory notebooks, cue cards, and white boards, and have been used to assist with cognitive limitations for many years in individuals with head injury [31], [36], MCI [41]-[43], very mild AD [44], and developmental disabilities [37]. Low technology aids are governed by time based rules and include time based alarms, pagers, voice recorders, and computers. There is evidence that people with dementia and traumatic brain injury can learn to use low tech electronic memory aids to assist them [45]-[49]. However, no technology and low technology aids are limited by a lack of generalizability and modifiability to individual needs or preferences. In addition, programming and retrieving information from these aids may be complex and difficult for people with cognitive impairment, and this burden often falls on caregivers as cognitive decline progresses. Remembering to press buttons, initiate steps, or use the aid in general might be difficult for people with cognitive impairment [49]. In addition, physically being able to press buttons or read small screens might be difficult for people with motor or sensory limitations [50]. Smart assistive technologies might be able to address the limitations of no and low tech external memory aids. For instance, researchers from multiple areas, including computer science, gerontology/dementia, and stroke rehabilitation, have recently begun developing and examining the feasibility of high technology, or "intelligent" aids. These intelligent aids will be described in more detail in the next section.

D. *Summary*

Individuals with MCI and dementia experience impairments in daily functioning, particularly with IADLs, which limit independent living. Prompts to initiate or complete IADLs are commonly given by caregivers to assist with IADL completion, which contribute to caregiver burden. The cognitive rehabilitation framework can provide a theoretical foundation to guide the development of assistive technologies for individuals with MCI in smart environments. Following this framework, assistive interventions should be individualized and targeted to real world tasks to improve everyday functioning. Furthermore, this model provides a framework of instructional techniques and approaches that have been used successfully with individuals with early AD to teach new information and methods to compensate for memory impairment. For instance, spaced retrieval, mnemonic elaboration, and cueing hierarchies have been successfully used to teach individuals new information, such as name-face associations, that can improve everyday memory. In addition, external memory aids have been used successfully to help these individuals compensate for memory impairment. Some cognitive rehabilitation studies suggest that prompting techniques that incorporate increasing assistance, which involves cognitively effortful and errorful learning, are more effective than other techniques for assisting individuals with AD in everyday memory problems [24]. This evidence can be interpreted to suggest that there is potential for the development of assistive prompting technologies grounded in cognitive rehabilitation principles to assist this population in IADL initiation and completion.

IV. Assistive Prompting Technologies

There are many questions in the literature that still need to be answered to advance research in the development of assistive prompting technologies, including what are the most effective timing and method of prompt delivery, content, language of prompts, and interface used for delivery of prompts. To begin answering these questions and stimulate theory driven research in smart prompting technology design and instrumentation, we will critically review characteristics of smart prompting systems within CRT. Specifically, we will discuss the goals and available outcome data from each prompting system in the context of CRT. Additionally, we will address how current methods might incorporate cognitive rehabilitation techniques to improve effective outcomes. We will critically review prompt delivery (timing and method), content (modality and level), language, and interface in the context of CRT format of instruction, role of cognitive effort, instructional techniques, and external memory aids.

A. *Prompt Delivery*

Prompt delivery can encompass the timing and the method (e.g., time, location, machine learning) of which information is delivered. In everyday life, many older adults need to complete IADLs and commonly receive prompts from caregivers to initiate or complete them. For example, older adults with cognitive limitations use medical devices on a daily basis that are often complex and involve many steps [57], and these devices might become confusing and difficult to operate independently as cognitive deficits progress. CRT provides a framework to help determine when and how prompts can be delivered most effectively to increase accurate task initiation and completion.

B. *Timing of Prompt Delivery*

Cognitive rehabilitation studies have shown that both errorless and errorful approaches are effective in teaching new information to individuals with AD [23], [24], although errorful learning might be more useful for more complex, everyday tasks and for individuals with less severe memory impairment. Anecdotally, caregivers report giving prompts after their care partner has made an error and is not correcting it on his or her own, and the caregiver repeats the prompt until the activity is completed successfully. This is an example of an errorful prompting approach for IADL completion and is supported by the cognitive rehabilitation literature [34]. Smart prompting technologies for IADLs will likely be most effective if they employ an errorful learning approach (i.e., prompting after error) because CRT research suggests that trial and error learning is most beneficial for the learning of more complex information or skills. This is particularly true for individuals with milder forms of cognitive impairment who can learn from mistakes to correct them in the future. In contrast, smart IADL prompting technologies designed for moderate to severely impaired individuals will likely be more effective if they employ errorless learning techniques (i.e., prompting prior to error), especially in the training phase, to enhance learning and uptake of the technology.

C. *Method of Prompt Delivery*

Prompts can be delivered or initiated based on time, location, context, artificial intelligence planning, and machine learning assessment of user needs (in order of increasing complexity and consistency with the goals of CRT; see Table 1).

Time-Based

The simplest example of a time-based prompt or reminder is an alarm clock, which produces a general audible or vibration alert to acquire the user's attention when the appointed time arrives. Most electronic devices such as phones and organizers include this feature. In addition, Google Calendar [58] is currently being widely used on the internet to set reminders for certain events. In the context of CRT, time-based prompts generally fall within the category of low technology compensatory aids and include time-based alarms, pagers, voice recorders, and computer alarms. Despite the simplicity, reliability, availability, and precision of time-based prompts, they have inherent limitations according to CRT. Most notably, they have to be delivered at a specific time and do not take into account important aspects of an individual’s environment. These characteristics can lead to time-based prompts being ineffective in everyday situations, such as when an individual is sleeping, in a different room, or in the middle of a complex and time-sensitive activity. Consistent with this, one group [56], [59] found that time-based prompts resulted in significantly lower medication adherence than context-based prompts in a study of medication prompting with healthy older adults. Similarly, Kaushik et al [22] found that older adults perceived context- aware prompts as more helpful than time-based prompts. Based on CRT, to be more effective, time-based prompts housed in low-technology compensatory aids could benefit from incorporating adaptability and integrating information about activity and environmental context.

In addition, while time-based prompts can assist with task initiation at predetermined times, they cannot detect errors once a task has begun and subsequently assist with task completion. CRT posits that prompts are most effective when delivered using a trial and error approach (e.g., after an error has been made). Therefore, time based prompts/aids could benefit from incorporating more sophisticated technology to be able to detect errors during IADL completion and deliver prompts after errors are made. Furthermore, even if time-based prompts could be adapted according to the user’s demands, the burden to set the prompt remains on the user, which poses a challenge for older adults with cognitive impairment. High technology external aids, consistent with CRT, address this challenge by incorporating sophisticated machine learning techniques into prompting systems that do not require user initiation or feedback to receive prompts.

Location-Based

Location-based prompts are more complex than time-based prompts. In general, they are incorporated into mid-level technology based external aids such as mobile phones or GPS receivers. These prompts are often used in association with time-based or context-aware prompts to provide more precise location-related reminders to a user. By taking into account an individuals’ environment and delivering prompts targeted to a specific location, location-based prompts are more closely aligned with CRT than simple time-based prompts. For example, Marmasse and colleagues [60] used GPS to determine location and pioneered work on delivering proactive location-based reminders and messages, such as sending a grocery list through a mobile device when in close physical proximity to a grocery store. The Place-Its application [61], designed around the post-it usage metaphor, used mobile phones as the ubiquitous platform to detect an individual's location and deliver reminders at remote locations. While location-based reminder systems have the advantage of being relatively simple and effective to remind a person to perform an activity at the appropriate location, limitations of these systems are that they generally provide one type of prompt content (e.g., verbal or text instruction), do not integrate other types of context (e.g., temporal, activity aware) to enhance the system’s applicability, and do not have the capability of detecting errors and delivering prompts during a complex activity. CRT posits that it would be more useful for a prompting device to send a prompt based on time and location, as well as the detection of errors or inconsistencies in activities and behavior. Incorporating aspects of CRT such as instructional techniques (e.g., graded hierarchy) to guide the development of the most appropriate prompt content could make these approaches more effective.

Context-Aware

Although context-aware prompting systems have been used for a number of years, several groups have made important developments in this area recently. Context-aware prompting systems could be considered high technology external aids, consistent with CRT, and have the significant advantage of delivering assistance to individuals when needed as compared to low or no technology aids. Another significant advantage is that these systems remove the burden from the caregiver of delivering prompts when needed. The Forget-me-not project [62], one of the pioneering works in this area, used a small electronic device similar to a PDA to gather contextual information from a user’s environment. It associated items of interest with icons to help users to remember various tasks that needed to be completed, such as email and telephone calls. Using contextual information to assist in determining the most appropriate timing and situation for delivering prompts is consistent with CRT, which emphasizes an individual’s personal context and social system in the rehabilitation of cognitive deficits. Nevertheless, limitations of this early system include small device and display icons, which could be difficult for older adults to see or manipulate. In addition, it might be difficult for older adults with memory impairment to remember where to find or how to use the device. This system was not formally tested with human participants for feasibility or efficacy.

Context-based prompting systems harnessed in mobile high technology external aids (e.g., PDAs, smart phones) have inherent benefits as well as limitations for a memory impaired population. While individuals can carry the prompting device outside of the home for mobile prompt delivery, developers should design products that are unobtrusive and can secure to a person comfortably so that they will not get misplaced or removed for aesthetic or comfort reasons. Also, if user feedback is required, devices should be designed with large screens and buttons on a simple interface. CRT suggests that incorporating these environmental aspects into the design of context based prompting devices will result in higher efficacy and acceptance.

Another milestone was set by Dey and colleagues when they developed CyberMinder [63], a context-aware reminder application based on the Context Toolkit [64] that focused on using complex contextual information beyond either time or location to determine a prompt situation (see Table 1). Integrating multiple types of contextual information to provide more flexible and adaptive assistance to individuals is supported by CRT. Hristova and colleagues [65] later used the Context Toolkit to build a prompting application for ambient assisted living to support heart rate monitoring, medication prompting, generation of agenda reminders, weather alerts, emergency notification, etc. The system was, however, limited by a lack of data privacy, security, and robust conflict reasoning mechanisms.

Context-aware computing to assist people with dementia to complete ADLs that require privacy, such as toileting, was proposed by Mihailidis and Fernie [66]. The authors highlighted the importance of gaining and using information about this population’s unique needs to inform the design of prompting technologies that act like human caregivers and have the capability to continually learn and grow with the user. Later, Kautz and colleagues developed an artificial intelligence planning based approach, called the Assistive Cognition Project [67], [68], which included novel representation and reasoning techniques for context-aware cognitive assistance that can help individuals with AD carry out multi-step everyday tasks like cooking.

Prompting applications for smart phone based cognitive assistance have also been developed [69], [70] (see Figure 1). Helal and colleagues [69] developed smart phone applications that interact with a smart house sensor network to assist individuals with activities of daily living by means of reminders, orientation, context-sensitive teaching and monitoring. In one application, prompts are delivered through flat screen monitors in the house in a hierarchy from least to most direct. In CRT, using a graded hierarchy of prompts (an errorful and cognitively effortful type of learning) has shown to be effective in assisting cognitively impaired populations complete tasks. One significant benefit of a context-based prompting system that employs a graded hierarchy of prompts for IADLs is that the burden to deliver prompts that increase in level of assistance is removed from the caregiver. In order to enhance the ability to capture the attention of individuals with AD, the authors suggested using prompts with voices from family members, familiar sounds and smells. Tailoring prompt voices to be familiar to the individual will increase context based prompt effectiveness according to CRT.

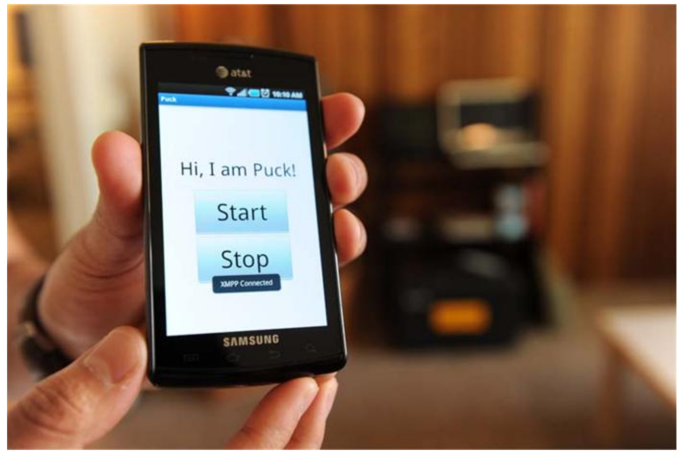

Fig 1. Smart phone-based prompting system

HYCARE [71], or hybrid context-aware reminding framework, uses a novel scheduling mechanism to handle synchronous time-based and asynchronous event-based reminding services. The scheduling mechanism is designed to organize, coordinate, and resolve conflicts between the different types of reminders, categorized by time and event and further into fixed/urgent or relevant. In order to deal with possible conflict between the prompts or asynchronous events happening (e.g., phone call) while a prompt is being delivered, the processing system prioritizes the types of prompts into a hierarchy and the more urgent prompts take precedence over the less urgent prompts. Overall, these unique aspects of this prompting system allow it to be more flexible and generalizable to what happens in older adults’ daily lives, allowing for and handling things such as interruptions and deviations from strict time and event based schedules when appropriate. Flexibility that adds to the generalizability of the prompting system to everyday life, along with delivering prompts in a hierarchical fashion depending on need, is aligned with CRT.

Within CRT, context-based prompting systems could be considered high technology external aids. These systems have been shown to have significant advantages over time-based and location-based prompting systems that are harnessed in low technology external aids, including improved patient outcomes [72], and greater flexibility and specificity to individual user’s cognitive, social, emotional, and environmental needs and preferences. These characteristics align context-based prompting with CRT more than simple time and location based approaches. In addition, according to behavioral change theory, prompting technology is likely to be better accepted and used if the individual has positive experiences and is satisfied with the outcome of the prompt. Incorporating cognitive rehabilitation based instructional techniques (e.g. graded prompt hierarchy) and format of instruction (e.g., trial and error approach) into these approaches will produce prompting approaches that are more effective. Limitations of many context-based systems are a lack of robust reasoning and conflict resolution mechanisms, which are important for assisting with complex activities of daily living.

AI Planning

Assistance in a smart environment to increase the independence of individuals with cognitive impairment involves not only reminders of events at certain times or places, but also guidance when errors are made during task completion for multiple step IADLs, such as cooking, taking medication, or carrying out household chores. Approaches will benefit from utilization of artificial intelligence that enables detection of critical errors as they occur in real time and provision of graduated levels of prompting assistance after errors are made to be effective according to CRT. However, the applications of AI- based planning approaches in smart environments have been very limited and AI planning approaches grounded within CRT need to be further developed. For example, Marquardt and colleagues used a planning approach for service composition [73] to facilitate the cooperation of multiple devices in smart environments to enable real-time service support. Other groups have used plan recognition and temporal reasoning techniques to describe goals and plans of users at various levels of abstraction in order to allow for greater flexibility and spontaneity of prompt delivery in various changing situations [68]. Levinson [74] used a planning based handheld prompting system to help individuals with traumatic brain injury maintain their independence in carrying out daily activities. This prompting system used classical deterministic planning algorithms to compute a best plan for completion of an activity and provided step-by-step guidance through tasks in the form of visual and audio cues. The above prompting approaches represent initial steps towards CRT's goals of providing prompting assistance that is generalizable to everyday tasks such as complex IADLs.

A planning system that uses Markov decision processes (MDPs) to determine when and how to provide prompts to users with dementia to guide them through the activity of handwashing was proposed by Boger et al. [52]. This framework named "COACH" [86] uses markerless flocking to track the activity, partially observable Markov decision process (POMDP) to model the handwashing guidance problem, and refined audio prompts and video demonstrations. Although this framework was proposed to be generalizable to other ADLs, no further work has been published.

Planning based prompting systems such as COACH are more consistent with CRT than less sophisticated approaches because they provide individualized step-by-step assistance for everyday tasks important to independent living. AI planning approaches will benefit from incorporating instructional techniques (e.g., graded prompting hierarchies) into the content of cues and tailoring type and modality of cues to individual needs and preferences. These issues will be addressed in more detail later in the prompt content section of the paper.

Machine Learning

Inhabitants in a smart environment will require assistance for initiation or completion of IADLs that are highly complex, which necessitates the development of effective AI prompting approaches that are aligned with CRT goals. There are certain conditions when planning approaches might be inefficient and classic machine learning techniques could be used effectively to predict a prompt situation based on historic data. For example, in the Assistive Cognition Project [68], dynamic Bayesian networks were used to create predictive models of user behavior from observations. Rudary and colleagues [55] integrated temporal constraint reasoning with reinforcement learning to build an adaptive reminder system, which can personalize to a user and adapt to both short and long term changes. Although this approach is useful when there is no direct or indirect user feedback, it relies on a complete pre-programmed schedule of user activities. Machine learning based prompting techniques will benefit from sophisticated techniques that allow them to adapt to a user's changing environment spontaneously.

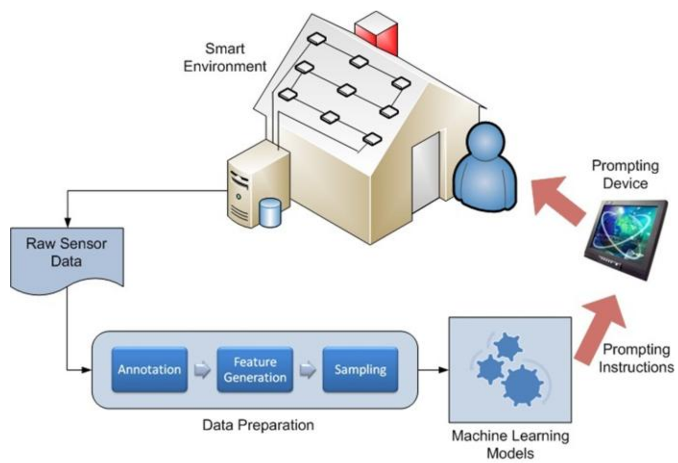

Fig 2. Machine Learning based prompting system developed by Das et al. [70]

Das and colleagues [20], [75] were the first to use machine learning techniques to learn the contexts to determine when to deliver prompts for eight different IADLs in a smart environment, such as cooking, washing hands, using the telephone, and cleaning. This work is an important first step in breaking down the complex sequence of steps involved in carrying out IADLs that are critical for independent living. Furthermore, this work is applying machine learning techniques to the data to develop a system that will provide automated prompts for IADLs when appropriate (e.g., errors are made that prohibit the successful completion of the activity; See Figure 2).

TABLE I
DESCRIPTION OF PROMPTING APPROACHES: METHOD OF PROMPT DELIVERY
*LISTED IN CHRONOLOGICAL ORDER BY PUBLICATION DATE

Article	Population and Sample Size	Description of Prompting Approach	Study Findings
Lamming & Flynn (1994); Dey &Abowd (2000)	N/A	Google Location determines the user's network location and allows location information to be utilized.	N/A
Levinson (1997)	N/A	Handheld prompting system uses classical deterministic planning algorithms to compute a best plan for completion of an activity and provides step-by-step guidance through tasks in the form of visual and audio cues.	N/A
Marmesse et al. (2000)	N/A	Prompting system delivers proactive location-based reminders and messages through a mobile device that uses GPS to determine location. For example, when a user is in close physical proximity to a grocery store, he is sent a reminder of his grocery list.	N/A
Dey et al. (2001)	N/A	Cyberminder focuses on using complex contextual information beyond either time or location to determine a prompt situation. For example, multiple pieces of context or “sub-situations”, including location, time, and activity status are analyzed, and if multiple conditions are met, a prompt is delivered.	N/A
Mihaildis & Fernie (2002); Kautz et al. (2002)	N/A	Assistive Cognition Project prompting system senses aspects of an individual's location and environment (both outdoors and at home) by relying on a wide range of sensors such as GPS, active badges, motion detectors and other ubiquitous computing infrastructure. ADL prompter is designed to recognize whether a user is meeting his goal or activity plan and sense his emotional reactions during an activity through voice intonation and skin conductance to assist in discriminating appropriate situations to offer prompts. Uses plan recognition and temporal reasoning techniques to describe goals and plans of users at various levels of abstraction in order to allow for greater flexibility and spontaneity of prompt delivery in various changing situations. Uses Dynamic Bayesian networks to create predictive models of user behavior from observations. Relational Markov models allow states belonging to different types.	N/A
Haigh et al. (2003)	N/A	Independent Life Style Assistant prompting system uses machine learning techniques to capture interactions among devices, environment and humans to meet the goal of helping older adults live independently in their homes longer. Patterned behavior profiles build models of which sensor firings correspond to which activities (e.g., medication management, mobility), in which order. Schedule information for regular activities is learned.	N/A
Helal et al. (2003)	N/A	Prompting system notifies user when certain events happen. Prompts are delivered through flat screen monitors in the house in a hierarchy from least to most direct. Prompts begin with a verbal instruction to capture a user’s attention and progress to visual displays, enriched audio, and vibrations if necessary.	N/A
Kautz et al. (2003)	N/A	Forget-me-not employs a small electronic device similar to a PDA that gathers contextual information from a user’s environment. It associates items of interest with icons to help users to remember various tasks that need to be completed, such as email and telephone calls.	N/A
Pineau et. al. (2003)	N/A	Prompting system combines AI planning technology with an assistive robot. Uses a variant of partially observable Markov decision processes (POMDPs) to design the high level control system for “Nursebot”, an artificially intelligent robot designed to assist elderly people with daily activities. The robot primarily provides intelligent reminders regarding specific activities but also engages in a certain degree of social interaction.	N/A
Pollack et al. (2003) Rudary et al. (2004)	N/A	Prompting system called “Autominder” is designed to assist individuals with cognitive impairment in ADL and IADL completion. Autominder consists of a plan manager, a client modeler, and a personal cognitive orthotic. Autominder uses dynamic Bayesian networks as an underlying domain model. The plan manager stores information related to the individual’s daily plan of activities. The client modeler observes and tracks how the individual executes the plan. The personal cognitive orthotic determines if there are discrepancies between planned and observed activity. Automatically generates reminders through a robot.	N/A
Sohn et al. (2005)	10 healthy young adults	Prompting system uses mobile phones as the ubiquitous platform to detect an individual's location and deliver reminder messages at a physically remote location.	Location-based reminders were fairly accurate and perceived as helpful.

TABLE I (CONTINUED)

Article	Population and Sample Size	Description of Prompting Approach	Study Findings
Boger et al. (2006)	30 professional caregivers of persons with dementia	Prompting system called "COACH" is designed to monitor hand washing activity progress through a video camera and use AI planning techniques to provide a hierarchy of pre-recorded audiovisual prompts when there is user regression or departure from the appropriate sequence of steps. In this study, a researcher simulated cognitive impairment during a handwashing activity. In a second scenario, caregivers read scripted prompts to the person completing the activity. Participants rated both scenarios for effectiveness of prompting.	Caregivers reported that the automated prompt system was not as effective as human prompting, although results indicated that both systems were effective. Caregivers offered suggestions for future prompting systems.
Sjogreen (2006)	N/A	Google calendar application is widely used on the internet to give reminders for certain events through general audible or vibration alerts to acquire the user's attention when the appointed time arrives.	N/A
Lundell et al. (2007)	11 healthy older adults	The efficacy of time-and context-based prompts were compared in a study of medication prompting. Time-based prompts were delivered at pre-determined times selected by the participant. Context-based prompts were delivered only when the system inferred that participants were likely to miss taking their vitamin based on individual patterns of activity.	Time based prompts resulted in significantly lower medication adherence than context aware prompts.
Vurgun et al. (2007)	6 healthy older adults	Prompting system delivers context-based or simple rule-based prompts for a medication task.	Medication adherence improvement was higher with context-aware than with rule-based prompts
Du et al. (2008)	N/A	HYCARE prompting system classifies reminders into four categories (e.g., remembering, maintaining social contacts, performing daily life activities, and enhanced feeling of safety). Context-aware reminder rules are based on contextual information such as time, location, and user activity.	N/A
Hristova et al.(2008)	N/A	Prompting system performs services for ambient assisted living that can support heart rate monitoring, medication prompting, and generation of agenda reminders, weather alerts, and emergency notification.	N/A
Kaushik et al. (2008)	1 Healthy older adult	Evaluated efficacy of a context based system based on ambient sensors that delivered prompts via a mobile device to complete various medical tasks in the home.	Context based reminders led to faster reaction times than non-context based and were perceived by the participant as being more useful
Marquardt et al. (2008, 2009)	N/A	Uses planning approach for service composition to facilitate the cooperation of multiple devices in smart environments to enable more advanced technologies. AI planning based service composition models a smart environment as a planning problem.	N/A
Chang et al. (2009)	8 adults with cognitive impairment (TBI, PDD, dementia, epilepsy, Schizophrenia)	Prompting system provides unique-to-the-user prompts (e.g., verbal or pictorial) that are triggered by context. The authors conducted a small pilot study with eight individuals with cognitive impairment, in which they compared task performance accuracy with the help of either a human job coach or the PDA prompter device.	Results indicated that PDA prompting was more reliable than human prompting. Participants reported liking the PDA's and finding the verbal and pictorial prompts helpful.
Das et al. (2010, 2011)	300 healthy older adults, MCI, and dementia	IADLs subdivided into activity steps and errors committed by participants while performing the IADLs later labeled as prompt situations. Supervised machine learning models were trained on this data and prompting situations were tested.	N/A

This type of prompting technology will be most effective if machine learning models are developed that can identify subtle activity steps in which errors are committed by residents.

Overall, a primary goal of CRT is to provide assistance that is generalizable, adaptive, and responsive to changing contexts. As such, machine learning prompting systems attempt to integrate data from multiple sources, learn highly complex and nuanced contexts, personalize to a user, and adapt to both short and long term changes. Machine learning approaches also attempt to deliver prompts when assistance is needed, such as when an error in activity completion is made. Future machine learning prompting systems could be further improved by incorporating CRT instructional techniques (e.g., graded prompt hierarchies) into prompt delivery.

Summary

Overall, there have been tremendous advances in the methods of prompt delivery over the past 20 years, from time based to AI planning and machine learning approaches. Available prompting approaches vary to the degree they incorporate CRT goals and methods, such as format of instruction, level of cognitive effort required, and instructional techniques into their methods of prompt delivery. According to CRT, time and location based prompts are effective in relatively simple situations and for predetermined tasks. Completely integrated context-aware prompting systems have the capability to deliver prompts at appropriate times, places, and according to other aspects of environmental context (e.g.., temporal, activity aware) to effectively address errors and inconsistencies in complex activities and behavior. This integrative prompting approach will be more versatile and effective than solely time- and location-based prompts. For example, high technology prompting systems could utilize machine learning algorithms to plan and model an individual's complex activities, identify subtle activity steps, detect errors, and deliver graded hierarchies of prompts (e.g., CRT technique) when errors are made. Technologies built on CRT principles also have the potential to help individuals with cognitive impairments learn or re-learn everyday tasks.

High technology prompting approaches could be improved further by tailoring prompt content (e.g., modality, level of information, language) to individual needs and preferences given that behavioral change is most likely to occur when the cost-benefit analysis of using support is positive and the user is satisfied with the outcome. Challenges that remain to be overcome in this area of research include further elucidating the complex contexts that are involved in many IADLs, making advances in reasoning and conflict resolution mechanisms, and handling privacy and data security concerns. Individualized prompts that are adaptive and flexible to an individual's changing context and needs are consistent with CRT and would significantly reduce caregiver burden. However, automatically recognizing and adapting to these dynamics needs is a tremendous challenge for researchers. We have also found that most papers in the area of automated prompting do not report results from human studies demonstrating the feasibility or efficacy of the prompting system prototypes, and further research is needed to extend the generalizability of these technologies with older adults in real-world settings.

Prompt Content

In addition to the timing and method of prompt delivery, it is also important to consider how the content of prompts can be designed to be most effective according to CRT (See Table 2). Within the context of CRT, prompt content can encompass the modality (e.g. verbal, visual, physical, or multi-modal) of information presentation or the level of information (e.g., indirect guidance back to a task or direct instruction of what to do; minimal or specific detail) presented. Other important aspects of content include type of language (e.g., wording, tone, gender) used in prompts. The most appropriate and effective type of smart prompt, including level, modality, and language, has yet to be established with older adults, persons with MCI, and persons with AD, although CRT provides data regarding which types of prompt content are likely to be the most effective.

Modality of Prompts

In cognitive rehabilitation studies with AD and TBI populations, researchers typically use verbal and physical prompts to assist with memory and everyday functioning [22], [23] (See Table 2). Cook, Fay, and Rockwood [10] surveyed AD caregivers and found that the most common type of prompts included verbal prompts to begin an activity, taking the lead in activities to get a patient started, and arranging activities for a patient. Studies in the area of pervasive developmental disorders (PDD) have shown that modalities of cues given are usually verbal, visual, or physical [76]. Recent studies have investigated the use of the combination of verbal and visual prompts delivered through electronic devices in smart environments for individuals with AD [51], [52], and findings highlighted the usefulness of having visual prompts to accompany verbal prompts. In general, prompt modalities used in most CRT studies in the literature tend to be verbal, physical, or visual [10], [76]. AD caregivers report giving verbal prompts most commonly [10] and individuals with cognitive and functional impairment report them being more helpful than other types of prompts [77]. Verbal prompting has the advantage of not requiring an individual to stop an activity to look at a screen or monitor when in the middle of performing an activity.

Level of Information

Another important aspect of prompt content is the level of information (e.g., indirect or direct; minimal or specific detail) presented in a prompt. Studies in the areas of PDD and gerontechnology have highlighted the importance of using CRT based instructional techniques such as graded cue hierarchies with increasing levels of directive assistance because not all individuals respond to the same level of prompt (See Table 2). In other words, the level of information delivered in a prompt could vary to match an individual's level of cognitive or functional impairment. According to CRT, graded prompt hierarchies are a cognitively effortful approach, and thus more effective for individuals with less severe cognitive impairment. Greber et al. [78] developed a hierarchical model of facilitated learning for children with disabilities. Levels of cues used were either direct or indirect (e.g., "Do this, do it this way" vs. "Uh oh, I think there is a problem") and either adult or child initiated. The authors first used the 'least informative prompt' (the most indirect strategy necessary to facilitate performance), and only moved to a more direct level of prompting if the student failed to engage successfully with the task. They found that this approach facilitated skill attainment and activity completion in children with disabilities. Similarly, in a recent PDD study [79] to improve independent functioning, researchers evaluated a work system individualized to the specific needs (e.g., structure or predictability) of each autistic child, highlighting the importance of developing cues that match individual needs and level of impairment. Overall, in PDD studies, individuals with less severe impairments have been found to respond to less directive cues, while individuals with more severe impairments respond better to more directive cues [78]. Consistent with this observation, in a recent study, participants with moderate AD were able to respond to machine based prompting with limited human assistance, while individuals with severe AD were largely unable to respond to the prompting without complete human assistance [80].

TABLE II
DESCRIPTION OF PROMPTING APPROACHES: PROMPT CONTENT
*LISTED IN CHRONOLOGICAL ORDER BY PUBLICATION DATE

Article	Population and Sample Size	Description of Prompting Approach	Study Findings
Milhaildis et al. (2001)	Healthy adults simulating cognitive impairment in dementia	"COACH" System delivers combined audio/visual prompts from minimal detail (e.g., "turn the cold water on") to most specific detail (e.g., "[Name], turn the water on using the blue tap in front of you")	The system delivered cues in a timely and appropriate manner.
Vincent et al. (2002)	5 individuals with significant cognitive or functional impairment and their caregivers	Researchers evaluated different forms of in-home technology to improve ADL completion and decrease caregiver burden. Remote control door locks, intercom, and verbal reminders were evaluated.	Users seemed to have a positive perception of the impact of the technologies on many of their ADLs. Remote control was difficult for participants and verbal reminders were very helpful.
Greber et al. (2007)	4 children with autism	Researchers developed a 4-quadrant model of facilitated learning for children with disabilities. 2 continuums that divide the 4 quadrants are *Direct/Indirect* (e.g., "Do this, do it this way" vs. "Uh oh, I think there is a problem") and *Adult vs. Child Initiated*. Adult initiated, direct strategies include: direct instruction, demonstration, physical facilitation, and task specification. Adult initiated, indirect strategies include: tactile prompts, non-verbal prompts, indirect questioning, and think-aloud modeling.	Their approach facilitated skill attainment and activity completion in children with disabilities, and posttest results showed between 58% and 76% improvement in independence over the pretest results on the target tasks for all participants.
Hume & Odom (2007)	3 children with autism	Researchers evaluated a work system individualized to the *specific needs* of each autistic child. Teacher prompting: a physical, verbal, visual, or proximal cue used to redirect student's attention to task.	After learning the individual work system, autistic children showed increases in on-task behavior, increases in the number of tasks completed or play materials utilized, and reduction of teacher prompts, highlighting the importance of developing cues that match individual needs and level of impairment.
Mataric et al. (2007)	6 individuals recovering from stroke	Researchers used a Socially Assistive Robot to monitor patients' use of stroke affected limb, and provided encouragement, guidance, and reminders. Three human robot interaction modes include feedback only through sound effects, feedback through a synthesized voice/ not persistent, and feedback through a pre-recorded human voice/ persistent.	Participants enjoyed presence of and interaction with robot, the pre-recorded voice was preferred over the synthesized voice, and male participants preferred a male voice and vice versa. Patient compliance with rehabilitation exercises was higher with a robot than without a robot and with more animated interaction modes.
Si et al. (2007)	N/A	Prompting system called "CoReDa" is designed to assist persons with AD in ADL completion. Prompts are emitted in 3 modalities, including blinking LED lights, picture of object, and text message. Two levels of prompt are delivered, including minimal message with less blinks and specific message with more blinks.	N/A
Kurt & Tekin-Itar (2008)	4 preschool aged children with autism	Researchers compared constant time delay (CTD) and simultaneous (SP) prompting techniques in an embedded instruction format to teach leisure skills to preschool children with autism. CTD includes giving and fading verbal and physical prompts in a systematic and time lagged manner after immediate and delayed interval trials. SP includes offering prompts immediately after task instruction.	Both prompting methods were effective at skill acquisition and maintenance. Using an embedded instruction format, in which skills are taught and practiced in natural settings, was important for the generalizability of the learned skills to natural settings
Witte (2009)	5 individuals with moderate and severe AD	A machine based electronic memory aid (EMA) is designed to assist individuals who have moderate and severe AD with ADLs. The participants' responses to prompts were recorded under two conditions: (1) in-person prompting and (2) machine-based prompting utilizing the EMA.	Participants with moderate AD were able to respond to the machine based prompting. Participants with severe AD were either completely unable to respond to the machine based prompting or needed a large amount of in person assistance.
Das et al. (in press)	2 healthy young adults	A context-aware prompting system, augmented by a smart phone, is designed to determine prompt situations in a smart home environment. While context-aware systems use temporal and environmental information to determine context, this system also uses ambulatory information from accelerometer data of a phone which also acts as a mobile prompting device.	Feedback from participants focused on improving the timing of prompts and shortening the task instructions. Both participants commented on the volume of the prompts for one of the tasks and indicated that environment noise (i.e., running water) interfered with understanding the prompt.

In a recent study, Seelye and colleagues [94] also showed that less directive verbal cues were effective with a less memory impaired MCI population.

In a gerontechnology study, Milhaildis and colleagues [51] demonstrated that individuals simulating cognitive impairment in dementia could benefit from graded hierarchy of audiovisual prompts to complete a hand washing activity. This system delivered prompts from minimal detail, which gently cued the person (e.g., “turn the cold water on”), to most specific detail (e.g., “[Name], turn the water on using the blue tap in front of you”) designed to get the person’s attention as well as provide more specific information on how to complete a step in the activity. Using time delayed procedures [81], [82], prompts were delivered if an individual did not start or complete an activity step after a certain amount of time had elapsed. Following CRT, this approach could be made more effective by not relying on videotaping individuals performing the task and by not requiring individuals to wear a large tracking bracelet on their wrists during the activity, which might not be practical or desirable for individuals with dementia. In addition, this approach could be improved by being broadened to apply to a broader range of ADL and IADL activities.

Overall, available research suggests that individuals might benefit from graded or hierarchical levels of information presented in prompts, with assistance increasing as necessary. These findings are consistent with the CRT instructional technique of using prompting hierarchies with increasing assistance, which are errorful and cognitively effortful approaches. Some studies have focused on progressive levels of information directiveness given in the prompts, while others have focused on progressive levels of detail given in the prompts. Research from the social psychology literature on over helping provides additional support for the idea of offering progressive levels of assistance to individuals having difficulty completing tasks, starting with the lowest level. For example, autonomy help, which is characterized by a helper giving some clues to a recipient while still leaving it up to a recipient to figure out the task, is more likely to result in independence than dependency help, which is characterized by a helper offering complete assistance and doing the task for the recipient [83]. In addition, research has shown that an individual who offers help when assistance is not solicited is considered less competent and less effective in satisfying the recipient [84].

Language

Important aspects of prompts that might influence their use by older adults are their wording, tone, and gender of voice. Mataric and colleagues [54] conducted a pilot study using a socially assistive robot to aid post-stroke patients with rehabilitation therapy. The researchers studied how different robot behaviors influenced participant’s compliance with rehabilitation therapy. Results indicated that the participants enjoyed the presence of and interaction with the robot, the pre-recorded voice was preferred over the synthesized voice, and male participants preferred a male voice and vice versa. In addition, patient compliance with rehabilitation exercises was higher with more animated interaction modes. In a study by Boger and colleagues [52], caregivers offered suggestions for development of future prompting systems, including using positive feedback, a friendly voice, and polite tone, and using prompts that are tailored to each person’s abilities. In general, it is clear that language of prompts is an important aspect to an older adult’s openness to receiving the prompts. This literature is consistent with CRT’s goals and suggests that smart prompting approaches can benefit from using human voices, friendly wording and tone, and instructions that are tailored to the individual.

Summary

Overall, verbal and visual physical prompts are most commonly given by caregivers and researcher implemented prompting systems to assist individuals with a variety of tasks. Studies from multiple disciplines suggest that CRT based instructional techniques such as graded prompting hierarchies with increasing assistance, have the potential to assist individuals with ADL and IADL completion. A few smart prompting system prototypes have incorporated prompt hierarchies designed according to level of detail of information given, starting with minimal detail and progressing to specific detail. This approach has the potential to improve the effectiveness and acceptability of smart prompting systems based on CRT. CRT research suggests that prompt effectiveness might differ according to a person’s level of cognitive impairment. Specifically, aspects of prompt content, such as modality and level of information, could vary based on individual characteristics, such as level of cognitive or functional impairment. For example, in PDD studies, individuals with less severe impairments have been found to respond to less directive cues, while individuals with more severe impairments respond better to more directive cues [78]. Flexibility in prompt content being delivered is important and will likely be essential when working with individuals with progressive cognitive disorders.

Traditional cognitive rehabilitation studies have shown that prompting techniques can be effective with individuals with severe memory impairment [22]. However, in these studies, prompts are given to individuals by human researchers, who might mimic caregivers in natural settings and offer more in person reassurance and subtle cues than machines can offer. Overall, these results suggest that individuals with more severe cognitive impairment might be less likely to benefit from machine based prompting systems for IADL completion than individuals with mild to moderate cognitive impairment. However, if prompting technology was introduced earlier when cognitive impairment was less severe, it might become more familiar and routine, enabling the individual to use and benefit from it longer. Furthermore, individuals with moderate to severe impairment might also benefit from errorless methods of instruction to facilitate successful learning and use of technology based prompting systems.

V. Interface to prompt Delivery

Gerontechnology researchers have used a variety of prompt delivery interfaces, including blinking lights [53], pagers, computer screens [51], smart phones [70] (see Figure 2), and robots [54], [55] (See Table 2). Within CRT, these interfaces can be considered low or high technology external aids. High technology aids (e.g., smart phones, computer screens, robots) have been designed to deliver context and artificial intelligence (AI) based reminders or prompts to assist cognitively impaired older adults with activities of daily living [51]-[54]. High technology aids are more effective than low technology aids according to CRT and have the potential to relieve some burden from human caregivers who typically deliver prompts. Given the importance of usability and ease of use for uptake of electronic devices by older adults, effective interfaces for prompting systems should be designed that accommodate older adults' unique physical and sensory needs, such as sight, hearing, and fine motor impairments [50] . Computer screen interfaces for delivery of prompts can be large enough to see clearly and stationary so that they remain in one area of the residence so as to not get lost or misplaced. Limitations are that computer or television screens cannot be carried around, and are unable to leave a residence like a mobile phone. On the other hand, portable devices carry the risk of being lost or misplaced more easily than stationary objects. Smart prompting technologies have also been harnessed within assistive robotic interfaces. The Autominder System developed by Pollack and colleagues [85] uses dynamic Bayesian networks and delivers prompts through a robot named "Pearl". Pineau et. al [86] used a variant of partially observable Markov decision processes (POMDPs) to design the high level control system for "Nursebot", an artificially intelligent robot designed to assist elderly people with daily activities (See Figure 3). The robot primarily provides intelligent reminders regarding specific activities but also engages in a certain degree of social interaction. Incorporating social contexts into the development of assistive interventions is an important part of CRT.

VI. Older Adults' Attitude Toward Technology

Within the context of CRT, behavioral change theory posits that adopting new strategies requires that individuals have positive experiences and be satisfied with the outcome. In addition, an integrated approach that addresses cognitive, emotional and motivational aspects of functioning together in addition to techniques is necessary for effective rehabilitation. Therefore, perceived utility of assistive technology [87] and how the technology might positively or negatively impact social network, emotional functioning, and lifestyle [88], [89] are important to older adults' acceptance of assistive technologies. In one study, older adults reported that the most

Fig 3. Nursebot: Robot designed to assist elderly people with daily activities

useful assistive technologies are those that support their values of personal identity, dignity, independence, and maintenance of social ties [88]. Similarly, technologies must be designed to meet older adults' needs, such as safety and security, love and belonging, and esteem [89]. Technologies that are designed to improve one aspect of an individual's life (e.g., safety) might not be adopted because they compromise another aspect of life deemed important (e.g., esteem) [89].

Overall, studies show that acceptance will be decreased if devices are physically obtrusive, interfere with current lifestyle, are difficult to use and interact with, do not ensure privacy, and function poorly [90]-[92]. CRT suggests that for successful adoption of assistive technologies, they must fit into the older adult's lifestyle and environment, be functionally adaptive, and support one's changing values [88]. For instance, allowing the user to initiate interactions and giving options for device aesthetic appearance and graduated levels of assistance received respects individual autonomy, adult dignity, and decision making.

VII. Discussion

Growing evidence suggests that individuals with mild cognitive impairments have difficulty completing IADLs. The recent multidisciplinary work of researchers in artificial intelligence, pervasive computing, and gerontology suggests that smart environments might be able to play a role in assisting these individuals. Specifically, smart environment technologies that provide automated prompts for accurate IADL initiation and completion might help keep individuals with MCI functioning independently in their homes longer, allowing them to age in place. In addition, automated prompting technologies might help reduce caregiver burden. Importantly, to our knowledge, no clear theoretical model has been applied to guide the development of assistive prompting technologies. The goal of this review was to bridge this gap in the literature by critically reviewing existing smart prompting technologies in the context of CRT's goals, techniques, and instructional formats to advance the future development of smart prompting technology design and instrumentation.

Cognitive rehabilitation is a holistic and integrative approach that aims to train individuals on real-world tasks using a variety of techniques to significantly improve everyday memory and daily functioning [27], [93]. It has been used successfully with many populations, including those with AD, TBI, and developmental disabilities. One important limitation of traditional cognitive rehabilitation interventions is that they are not automatically delivered to individuals, so the burden to remind the individual to use the compensatory aid or strategy often falls on the caregiver. Therefore, smart prompting technologies harnessed in high technology external aids that incorporate CRT methods could provide a more promising alternative in the future.

Smart prompting technologies should incorporate time- and location- context information as well as more complex aspects of environmental and behavioral context, especially for providing assistance with complex everyday tasks to individuals with mild cognitive impairments. For example, high technology prompting systems could utilize machine learning algorithms to plan and model an individual's complex activities, identify subtle activity steps, detect errors, and deliver graded hierarchies of prompts (e.g., CRT technique) when errors are made. These methods are also consistent with how caregivers typically give prompts in their natural environments and are supported by the social psychology literature on maintaining a sense of patient autonomy and satisfaction.

Individuals with MCI have the potential to benefit from prompting technologies to assist with IADL completion [94]. If a prompting system was provided early enough in the MCI process, it might help keep a person functioning more independent in daily activities and less reliant on a caregiver for a longer period of time than without one. Using technology to extend aging in place, thereby delaying placement of individuals in assisted living care, and reducing caregiver burden could provide significant benefits to individuals, families, and society.

According to CRT's goals and methods, the most ideal prompting technology for complex IADL's will be capable of assisting with variety of IADLs in complex situations and be designed to adjust to fluctuations or progression in the individual's cognitive functioning and environment. For instance, individuals with mild cognitive impairments will benefit from a prompting system that employs increased levels of assistance as needed when errors are made during complex task completion. Individuals with severe cognitive impairments might require more directive, multi-modal prompting that anticipates and reduces errors, especially during the learning process. Future prompting technologies should be incorporated into high technology external aids designed with machine learning techniques that allow it to handle unpredictable contexts, resolve conflicts between planned and unplanned situations fluidly and quickly, and break down highly complex IADLs into their subtle and nuanced component steps and sequences. Finally, in order for prompting technologies to be most effective, they should be transmitted through an interface that is acceptable, pleasing, and convenient for the user and easily generalizable to a variety of different environments. Designers must keep the user involved when developing new prompting technologies. This will maximize the applicability of the prompting technology to assist individuals with MCI and other cognitive disorders in completing everyday activities in their homes.

VIII. Challenges for Future Work

There are several potential challenges and issues researchers and designers should keep in mind when considering the development and implementation of automated smart prompting interventions for cognitively impaired populations. First, privacy and confidentiality are important to older adults and they might not be open to technology that seems invasive, such as video cameras, wired sensors, wearable equipment, and robots in their homes for monitoring and intervention purposes. However, studies have shown that perception of user need for assistive technology often outweighs privacy concerns [91]. Regardless, technologies will need to be designed that are as noninvasive and natural as possible. In addition, smart home environments collect and aggregate large volumes of inhabitants' personally sensitive data and residents typically have limited control over this data[95]. Improperly protected personal information could lead to security problems such as spyware, phishing, and identity theft [96]. Left unsolved, these problems could cause potentially beneficial smart home technologies to be rejected. To meet these challenges, prompting approaches need to be developed that can flexibly modify access to a user's data depending on the user's desired level of privacy in a given situation [95].

According to CRT, individuals are more likely to accept and adopt new strategies (e.g., technologies) if the experience learning and interacting with it is positive, the outcome of the strategy is satisfactory, and the strategy supports one's lifestyle, autonomy, and changing values, In fact, one study showed that older adults with MCI might be open to learning and using technology if it is designed with their unique needs in mind [50]. Therefore, researchers and designers will need to create smart prompting devices and user interfaces that are designed specifically for the unique sensory, motor, emotional, and lifestyle needs and values of older adults. For example, large print and buttons, non-glare surfaces, simple steps, and verbal prompts that are in the appropriate vocal range, tone, wording, and preferred gender would be most effective. Prompting systems should be designed that allow the user to initiate interactions, give options for device aesthetic appearance, and provide graduated levels of assistance as needed or desired.

An additional challenge might be individuals' ability to learn how to use technology depending on their level of cognitive impairment. Individuals with MCI have less severe memory and functional impairment than individuals with AD and have far greater potential to benefit from prompting technology. Designers should create smart prompting systems that are capable of providing a flexible range of prompting assistance to individuals with mild to severe cognitive impairments, given that individuals with MCI might progress to dementia. Many smart prompting system prototypes reviewed in this paper have not been tested in clinical studies for feasibility or efficacy. To move this field forward and produce more effective smart prompting technologies for cognitively impaired populations, engineers and designers must collaborate with clinical scientists to develop and employ scientifically sound clinical studies to test the prototypes with populations of interest.

Financial limitations of individuals who could benefit most from the technology are also important to consider. Many older adults have financial constraints and might not be able to afford technology in their homes if it is very expensive. Therefore, it will be critical to design and produce technologies that are accessible to the mass public. Similarly, assistive prompting technology should be a cost effective alternative to natural caregiver prompting. For example, one goal of prompting technology is to help keep individuals in their homes longer while simultaneously reducing caregiver burden, which in turn might prevent caregiver burnout and decrease their stress so that they are healthier.

Another significant challenge is determining how to design computer algorithms and activity recognition to automate prompting technologies in real time that adapt to changing contexts. One significant problem to solve is that the number and order of steps to activity completion varies across individuals, which highlights the importance of CRT's emphasis on flexibility and individualization of assistive strategies. One possible solution to this problem is to design prompting systems that provide adjustable levels of prompting that can be individualized to users, consistent with CRT's graded hierarchy of prompts technique.

Determining how to expand smart environment prompting technology so that it could be used outside of a person's home may be even greater challenge; for example, when he or she goes to the grocery store or to a doctor's appointment. One potential solution to this problem is the use of portable devices such as smart phones, which have grown in popularity in recent years. Smart phones have advanced processing capabilities and can run computer algorithms similar to computers. Also, they can be carried in a purse or in a pocket, making them portable and discreet. These are just a few of the challenges that await more in-depth examination by researchers. Importantly, the literature reviewed in the current paper highlights the need for researchers and clinicians in health care and technology disciplines to work together to address the remaining challenges in order to advance the development of CRT based smart environment prompting technologies.

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References

[1] G. Vincent and V. Velkoff, "The next four decades – the older population in the United States: 2010 to 2050," US Census Bureau2010.
[2] A. Salzhauer, "Is there a patient in the house? ," Harvard Business ReviewNovember 1, 2005 2005.
[3] R. L. Ernst and J. W. Hay, "The US economic and social costs of Alzheimer's disease revisited," American Journal of Public Health, vol. 84, pp. 1261-1264, 1994.
[4] B. Winblad, K. Palmer, M. Kivipelto, V. Jelic, L. Fratiglioni, L. O. Wahlund, A. Nordberg, L. Backman, M. Albert, O. Almkvist, H. Arai, H. Basun, K. Blennow, M. D. Leon, C. Decarli, T. Erkinjuntti, E. Giacobini, C. Graff, J. Hardy, C. Jack, A. Jorm, K. Ritchie, C. V. Duijn, P. Visser, and R. C. Petersen, "Mild cognitive impairment—beyond controversies, towards a consensus: report of the International Working Group on Mild Cognitive Impairment," Journal of Internal Medicine, vol. 256, pp. 240-246, 2004.
[5] A. Busse, J. Bischkopf, S. Riedel-Heller, and M. Anger-Meyer, "Mild cognitive impairment: prevalence and incidence according to different diagnostic criteria," British Journal of Psychiatry, vol. 182, pp. 449-454, 2003.
[6] D. B. Howieson, R. Camicoli, J. Quinn, L. C. Silbert, B. Care, M. M. Moore, and J. Kaye, "Natural history of cognitive decline in the oldest old," Neurology, vol. 60, pp. 1484-1494, 2003.
[7] S. T. Farias, D. Mungas, B. R. Reed, D. H. Harvey, D. Cahn-Weiner, and C. Decarli, "MCI is associated with deficits in everyday living," Alzheimer's disease and Associated Disorders, vol. 20, pp. 217-223, 2006.
[8] M. Schmitter-Edgecombe, E. Woo, and D. Greeley, "Characterizing multiple memory deficits and their relation to everyday functioning in individuals with mild cognitive impairment. ," Neuropsychology, vol. 23, pp. 168-177, 2009.
[9] P. D. St. John and P. R. Montgomery, "Cognitive impairment and life satisfaction in older adults.," International journal of geriatric psychiatry, vol. 25, pp. 814-821, 2010.
[10] C. Cook, S. Fay, and K. Rockwood, "Decreased initiation of usual activities in people with mild-to-moderate Alzheimer's disease: a descriptive analysis from the VISTA clinical trial," International Psychogeriatrics, vol. 20, pp. 952-963, 2008.
[11] D. Cook and M. Schmitter-Edgecombe, " Assessing the quality of activities in a smart environment," Methods of Information in Medicine, vol. 48, pp. 480-485, 2009.
[12] F. Doctor, H. Hagras, and V. Callaghan, "A fuzzy embedded agent-based approach for realizing ambient intelligence in intelligent inhabited environments," IEEE Transactions on Systems, Man, and Cybernetics, Part A, vol. 35, pp. 55-65, 2005.
[13] S. Intille and K. Larson, "Designing and evaluating supportive technology for homes," in IEEE/ASME International Conference on Advanced Intelligent Mechatronics, 2003.
[14] M. Z. Mozer, "Lessons from an adaptive home," in Smart Environments: Technology, Protocols, and Applications, D. Cook and S. K. Das, Eds., ed: Wiley, 2004, pp. 273-298.
[15] G. M. Youngblood and D. J. Cook, "Data mining for hierarchical model creation," in IEEE Transactions on Systems, Man, and Cybernetics, Part C., 2007, pp. 561-572.
[16] G. Singla, C. Cook, and M. Schmitter-Edgecombe, "Recognizing independent and joint activities among multiple residents in smart environments," Ambient Intelligence and Humanized Computing Journal, vol. 1, pp. 57-63, 2010.
[17] D. Cook, "Learning setting-generalized activity models for smart spaces," IEEE Intelligent Systems, 2011.
[18] T. L. Hayes, M. Pavel, and J. A. Kaye, "An unobtrusive in-home monitoring system for detection of key motor changes preceding cognitive decline," Conf Proc IEEE Eng Med Biol Soc, vol. 4, pp. 2480-3, 2004.
[19] C. Parsey, P. Sawadi, M. Schmitter-Edgecombe, and D. Cook, "Measures of Everyday Functioning in a Smart Environment," presented

at the Festival of International Conferences on Caregiving, Disability, Aging and Technology, Toronto, Canada, 2011.
[20] B. Das, C. Chen, A. Seelye, and D. Cook, "An automated prompting system for smart environments," in 9th International Conference on Smart Homes and Health Telematics, 2011.
[21] P. Kaushik, S. Intille, and K. Larson, "User-adaptive reminders for home-based medical tasks. A case study," Methods of Information in Medicine, vol. 47, pp. 203-207, 2008.
[22] M. S. Bourgeois, C. Camp, M. Rose, B. White, M. Malone, J. Carr, and M. Rovine, "A comparison of training strategies to enhance use of external aids by persons with dementia," Journal of Communication Disorders, vol. 36, 2003.
[23] L. Clare and B. A. WIlson, "Memory rehabilitation techniques for people with early-stage dementia," Zeitschrift fur Gerontopsychologie & Psychiatrie, vol. 17, pp. 109-117, 2004.
[24] J. Dunn and L. Clare, "Learning face-name associations in early-stage dementia: Comparing the effects of errorless learning and effortful processing," Neuropsychological Rehabilitation, vol. 17, pp. 735-754, 2007.
[25] B. M. Hampstead, K. Sathian, A. B. Moore, C. Nalisnick, and A. Y. Stringer, "Explicit memory training leads to improved memory for face–name pairs in patients with mild cognitive impairment: Results of a pilot investigation," Journal of the International Neuropsychological Society, vol. 14, pp. 883-889, 2008.
[26] L. Clare, B. A. WIlson, G. Carter, and J. R. Hodges, "Cognitive rehabilitation as a component of early intervention in Alzheimer’s disease: a single case study," Aging & Mental Health, vol. 7, pp. 15-21, 2003.
[27] L. Clare and R. T. Woods, "Cognitive training and cognitive rehabilitation for people with early-stage Alzheimer’s disease: A review," Neuropsychological Rehabilitation, vol. 14, pp. 385-401, 2004.
[28] S. Josephsson, L. Backman, L. Borrel, B. Bernspang, L. Nygard, and L. Ronnberg, "Supporting everyday activities in dementia: an intervention study.," International journal of geriatric psychiatry, vol. 8, pp. 395-400, 1993.
[29] G. Cipriani, A. Bianchetti, and M. Trabucchi, "Outcomes of a computer-based cognitive rehabilitation program on Alzheimer's disease patients compared with those affected by mild cognitive impairment," Archives of Gerontology and Geriatrics, vol. 43, pp. 327-335, 2006.
[30] A. J. Rothman, A. S. Baldwin, and A. W. Hertel, "Self-regulation and behavior change: Disentangling behavioral initiation and behavioral maintenance," in Handbook of self-regulation: Research, theory, and applications. vol. 574, R. F. Baumeister and K. D. Vohs, Eds., ed New York, NY, US: Guilford Press, 2004.
[31] M. M. Sohlberg and C. A. Mateer, "Training use of compensatory memory books: A three-stage behavioral approach," Journal of Clinical and Experimental Neuropsychology, vol. 11, pp. 871-891, 1989.
[32] P. P. Vitaliano, D. Echeverria, J. Yi, P. E. M. Phillips, H. Young, and I. C. Siegler, "Psychophysiological Mediators of Caregiver Stress and Differential Cognitive Decline.," Psychology and Aging, vol. 20, pp. 402-411, 2005.
[33] L. Clare, "Cognitive training and cognitive rehabilitation for people with early-stage dementia," Reviews in Clinical Gerontology, vol. 13, pp. 75-83, 2003.
[34] [L. Clare, B. A. WIlson, G. Carter, K. Breen, A. Gosses, and J. R. Hodges, "Intervening with Everyday Memory Problems in Dementia of Alzheimer Type: An Errorless Learning Approach," Journal of Clinical and Experimental Neuropsychology, vol. 22, pp. 132-146, 2000.
[35] L. Clare, B. A. Wilson, G. Carter, I. Roth, and J. R. Hodges, "Relearning Face–Name Associations in Early Alzheimer’s Disease," Neuropsychology, vol. 16, pp. 538-547, 2002.
[36] [36] L. A. EHLHARDT, M. M. SOHLBERG, A. GLANG, and R. ALBIN, "TEACH-M: A pilot study evaluating an instructional sequence for persons with impaired memory and executive functions," Brain Injury, vol. 19, pp. 569-583, 2005.
[37] M. M. SOHLBERG, L. A. EHLHARDT, and M. Kennedy, "Instructional techniques in cognitive rehabilitation: A preliminary report," Seminars in Speech and Language, vol. 26, pp. 268-279, 2005.
[38] J. J. Evans, B. A. WIlson, U. Schuri, J. Andrade, A. Baddeley, and O. Bruna, "A comparison of 'errorless' and 'trial and error' learning methods for teaching individuals with acquired memory deficits," Neuropsychological Rehabilitation, vol. 10, 2000.
[39] R. S. P. Jones and C. B. Eayrs, "The use of errorless learning procedures in teaching people with a learning disability: A critical review," Mental Handicap Research, vol. 5, pp. 204-212, 1992.
[40] M. Page, B. A. WIlson, A. Shiel, G. Carter, and D. Norris, "What is the locus of the errorless-learning advantage?," Neuropsychologia, vol. 44, pp. 90-100, 2006.
[41] M. C. Greenaway, S. M. Hanna, S. W. Lepore, and G. E. Smith, "A Behavioral Rehabilitation Intervention for Amnestic Mild Cognitive Impairment," American Journal of Alzheimer’s Disease & Other Dementias, vol. 23, 2008.
[42] A. K. Troyer, K. J. Murphy, N. D. Anderson, M. Moscovitch, and F. I. M. Craik, "Changing everyday memory behaviour in amnestic mild cognitive impairment: A randomised controlled trial," Neuropsychological Rehabilitation, vol. 18, pp. 65-88, 2008.
[43] L. Clare, J. V. Paasschen, S. J. Evans, C. Parkinson, R. T. Woods, and D. E. J. Linden, "Goal-oriented cognitive rehabilitation for an individual with Mild Cognitive Impairment: Behavioural and neuroimaging outcomes," Neurocase 15, vol. 4, 2009.
[44] M. Schmitter-Edgecombe, J. T. Howard, S. P. Pavawalla, L. Howell, and A. Rueda, "Multidyad Memory Notebook Intervention for Very Mild Dementia: A Pilot Study," American Journal of Alzheimer’s Disease & Other Dementias, vol. 23, pp. 477-487, 2008.
[45] T. Hart, R. Buchhofer, and M. Vaccaro, "Portable electronic devices as memory and organizational aids after traumatic brain injury: a consumer survey study," Journal of Head Trauma Rehabilitation, vol. 19, pp. 351-365, 2004.
[46] O'Neil-Pirozzi, H. Kendrick, R. Goldsteing, and M. Glenn, "Clinician influences on use of portable electronic memory devices in traumatic brain injury rehabilitation," Brain Injury, vol. 18, pp. 179-189, 2004.
[47] V. d. Broek, J. Downes, Z. Johnson, B. Dayus, and N. Hilton, "Evaluation of an electronic memory aid in the neuropsychological rehabilitation of prospective memory deficits," Brain Injury, vol. 14, pp. 455-462, 2000.
[48] M. Oriani, E. Moniz-Cook, G. Binetti, G. Zanieri, G. B. Frisoni, C. Geroldi, and L. P. DeVreese, "An electronic memory aid to support prospective memory in patients in the early stages of Alzheimer’s disease: A pilot study. ," Aging & Mental Health, vol. 7, pp. 22-27, 2003.
[49] N. Kapur, E. L. Glisky, and B. A. WIlson, "Technological memory aids for people with memory deficits," Neuropsychological Rehabilitation, vol. 14, pp. 41-60, 2004.
[50] A. M. Seelye, D. B. Howieson, K. Wild, L. R. Sauceda, and J. A. Kaye, "Living well with MCI: Behavioral interventions for older adults with mild cognitive impairment," in New Directions in Aging Research: Health and Cognition, R. Brougham, Ed., ed New York: Nova Science Publishers, Inc., 2009, pp. 57-74.
[51] A. Mihaildis, G. R. Fernie, and J. C. Barbenel, "The use of artificial intelligence in the design of an intelligent cognitive orthosis for people with dementia," Assistive Technology, vol. 13, pp. 23-39, 2001.
[52] J. Boger, J. Hoey, P. Poupart, C. Boutilier, G. Fernie, and A. Mihaildis, "A planning system based on markov decision processes to guide people with dementia through activities of daily living," IEEE Transactions on Information Technology in Biomedicine, vol. 10, pp. 323-333, 2006.
[53] H. Si, S. J. Kim, N. Kawanishi, and H. Morikawa, "A context-aware reminding system for daily activities of dementia patients," in Proceedings from the 27th International Conference on Distributed Computing Systems, 2007.
[54] M. J. Mataric, J. Eriksson, D. J. Feil-Seifer, and C. J. Winstein, "Socially assistive robotics for post-stroke rehabilitation," Journal of NeuroEngineering and Rehabilitation, vol. 4, 2007.
[55] M. Rudary, S. Singh, and M. Pollack, "Adaptive cognitive orthotics: combining reinforcement learning and constraint-based temporal reasoning," in The twenty-first international conference on Machine learning, 2004, p. 91.
[56] J. Lundell, T. L. Hayes, S. Vurgun, U. Ozertem, J. Kimel, J. Kaye, F. Guilak, and M. Pavel, "Continuous activity monitoring and intelligent contextual prompting to improve medication adherence," Conf Proc IEEE Eng Med Biol Soc, vol. 2007, pp. 6287-90, 2007.
[57] J. M. Hickman, W. A. Rogers, and A. D. Fisk, "Training older adults to use new technology," J Gerontol B Psychol Sci Soc Sci, vol. 62 Spec No 1, pp. 77-84, Jun 2007.

[58] C. Sjogreen, "How we built google calendar," in Carson Workshop, 2006.

[59] T. L. Hayes, K. Cobbinah, T. Dishongh, J. Kaye, J. Kimel, M. Labhard, T. Leen, J. Lundell, U. Ozertem, and M. Pavel, "A Study of Medication-Taking and Unobtrusive, Intelligent Reminding," Journal of Telemedicine and e-Health, vol. 15, pp. 770-776, 2009.

[60] N. Marmasse and C. Schmandt, Location-aware information delivery with commotion," in Handheld and Ubiquitous Computing: Springer, 2000.

[61] T. Sohn, K. Li, G. Lee, I. Smith, J. Scott, and W. Griswold, "Place-its: A study of location-based reminders on mobile phones," in UbiComp 2005: Ubiquitous Computing, 2005, pp. 232-250.

[62] M. Lamming and M. Flynn, "Forget-me-not: Intimate computing in support of human memory," in FRIEND21, 1994, pp. 2-4.

[63] A. Dey and G. Abowd, "A context-aware system for supporting reminders," in Handheld and Ubiquitous Computing, ed: Springer, 2000, pp. 201-207.

[64] A. Dey, G. Abowd, and D. Salber, "A conceptual framework and a toolkit for supporting the rapid prototyping of context-aware applications," Human-Computer Interaction, vol. 16, pp. 97-166, 2001.

[65] A. Hristova, A. Bernardos, and J. Casar, "Context-aware services for ambient assisted living: A case-study," in First International Symposium on Applied Sciences on Biomedical and Communication Technologies, 2008, pp. 1-5.

[66] A. Mihaildis and G. Fernie, "Context-aware assistive devices for older adults with dementia," Gerontechnology, vol. 2, pp. 173-189, 2002.

[67] H. Kautz, L. Arnstein, G. Borriello, O. Etzioni, and D. Fox, "An overview of the assisted cognition project," in AAAI-2002 Workshop on Automation as Caregiver: The Role of Intelligent Technology in Elder Care, 2002, pp. 60-65.

[68] H. Kautz, O. Etzioni, D. Fox, D. Weld, and L. Shastri, "Foundations of assisted cognition systems," 2003.

[69] S. Helal, C. Giraldo, Y. Kaddoura, C. Lee, H. El Zabadani, and W. Mann, "Smart phone based cognitive assistant," in UbiHealth 2003: The 2nd International Workshop on Ubiquitous Computing for Pervasive Healthcare Applications, 2003.

[70] B. Das, A. M. Seelye, B. L. Thomas, D. J. Cook, L. B. Holder, and M. Schmitter-Edgecombe, "Using Smart Phones for Context-Aware Prompting in Smart Environments," in IEEE International Workshop on Consumer eHealth Platforms, Services and Applications (CeHPSA), Las Vegas, Nevada, 2012.

[71] K. Du, D. Zhang, X. Zhou, M. Mokhtari, M. Hariz, and W. Qin, "Hycare: A hybrid context-aware reminding framework for elders with mild dementia," Smart Homes and Health Telematics, pp. 9-17, 2008.

[72] S. Vurgun, M. Philprose, and M. Pavel, "A statistical reasoning system for medication prompting," in UbiComp 2007: Ubiquitous Computing, 2007, pp. 1-18.

[73] F. Marquardt and A. Uhrmacher, "Evaluating ai planning for service composition in smart environments," in Proceedings of the 7th International Conference on Mobile and Ubiquitous Multimedia, 2008, pp. 48-55.

[74] R. Levinson, "The planning and execution assistant and training system," Journal of Head Trauma Rehabilitation, vol. 12, pp. 769-775, 1997.

[75] B. Das, C. Chen, N. Dasgupta, D. Cook, and A. Seelye, "Automated prompting in a smart home environment," in IEEE International Conference on Data Mining Workshops, 2010, pp. 1045-1052.

[76] C. J. Cress and A. Hoffman, "Parent directiveness in free play with young children with physical impairments," Communication Disorders Quarterly, vol. 29, pp. 99-108, 2008.

[77] C. Vincent, G. Drouin, and F. Routhier, "Examination of new environmental control applications," Examination of new environmental control applications, vol. 14, pp. 98-111, 2002.

[78] C. Greber, J. Ziviani, and S. Rodger, "The four quadrant model of facilitated learning: A clinically based action research project," Australian Occupational Therapy Journal, vol. 54, pp. 149-152, 2007.

[79] K. Hume and S. Odom, "Effects of an individual work system on the independent functioning of students with autism," Journal of Autism and Developmental Disorders, vol. 37, pp. 1166-1180, 2007.

[80] M. R. Witte, "Feasibility of machine-based prompting for people with alzheimer's disease," University of Florida, Dissertation Abstracts International: Section B: The Sciences and Engineering 2009.

[81] M. G. Giles, J. E. Ridle, A. Dill, and S. Frye, "A consecutive series of adults with brain injury treated with a washing and dressing retraining program," The American Journal of Occupational Therapy, vol. 51, pp. 256-266, 1997.

[82] O. Kurt and E. Tekin-Iftar, "A Comparison of Constant Time Delay and Simultaneous Prompting Within Embedded Instruction on Teaching Leisure Skills to Children With Autism," Topics in Early Childhood Special Education, vol. 28, pp. 53-64, 2008.

[83] A. Nadler, "Personality and help seeking: Autonomous versus dependent seeking of help," in Sourcebook of social support and personality. , G. R. Pierce, B. Lakey, I. G. Sarason, and B. R. Sarason, Eds., ed New York, NY, US Plenum Press, 1997, pp. 379-407.

[84] E. B. Ryan, A. P. Anas, and A. J. S. Gruneir, "Evaluations of Overhelping and Underhelping Communication : Do Old Age and Physical Disability Matter?," Journal of Language and Social Psychology, vol. 25, pp. 97-107, 2006.

[85] M. Pollack, L. Brown, D. Colbry, C. McCarthy, C. Orosz, B. Peintner, S. Ramakrishnan, and I. Tsamardinos, "Autominder: An intelligent cognitive orthotic system for people with memory impairment," Robotics and Autonomous Systems, vol. 44, pp. 273-282, 2003.

[86] J. Pineau, M. Montemerlo, M. Pollack, N. Roy, and S. Thrun, "Towards robotic assistants in nursing homes: Challenges and results," IEEE Transactions on Information Technology in Biomedicine, vol. 42, pp. 271-281, 2003.

[87] K. Wild, L. Boise, J. Lundell, and A. Foucek, "Unobtrusive In-Home Monitoring of Cognitive and Physical Health: Reactions and Perceptions of Older Adults," J Appl Gerontol, vol. 27, pp. 181-200, 2008.

[88] J. Forlizzi, C. DiSalvo, and F. Gemperle, "Assistive robotics and an ecology of elders living independently in their homes," Human-Computer Interaction, vol. 19, pp. 25-59, 2004.

[89] S. Thielke, M. Harniss, H. Thompson, S. Patel, G. Demiris, and K. Johnson, "Maslow’s Hierarchy of Human Needs and the Adoption of Health-Related Technologies for Older Adults," Ageing International, In Press.

[90] R. Beringer, A. Sixsmith, M. Campo, J. Brown, and R. McCloskey, "The “Acceptance” of Ambient Assisted Living: Developing an Alternate Methodology to This Limited Research Lens," presented at the 9th International Conference on Smart Homes and Health Telematics, 2011.

[91] K. L. Courtney, "Privacy and senior willingness to adopt smart home information technology in residential care facilities," Methods Inf Med, vol. 47, pp. 76-81, 2008.

[92] E. D. Mynatt, J. Rowan, S. Craighill, and A. Jacobs, "Digital family portraits: supporting peace of mind for extended family members.," in SIGCHI Conference on Human Factors in Computing Systems, New York, NY, 2001, pp. 333-340.

[93] D. A. Loewenstein, A. Acevedo, S. J. Czaja, and R. Dura, "Cognitive rehabilitation of mildly impaired Alzheimer disease patients on cholinesterase inhibitors," American Journal of Geriatric Psychiatry, vol. 12, pp. 395-402, 2004.

[94] A. Seelye, A. Smith, M. Schmitter-Edgecombe, and D. Cook, "Cueing technologies for assisting persons with mild cognitive impairment in instrumental activity of daily living completion in an experimenter-assisted smart apartment environment.," presented at the Thirtieth annual meeting of the National Academy of Neuropsychology, Vancouver, Canada, 2010.

[95] S. Moncrieff, S. Venkatesh, and G. West, "Dynamic privacy assessment in a smart house environment using multimodal sensing," ACM Transactions on Multimedia Computing, Communications, and Applications, vol. 5, 2008.

[96] R. Babbitt, "Information Privacy Management in Smart Home Environments: Modeling, Verification, and Implementation.," in Computer Software and Applications Conference, 2006, pp. 344-346.

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